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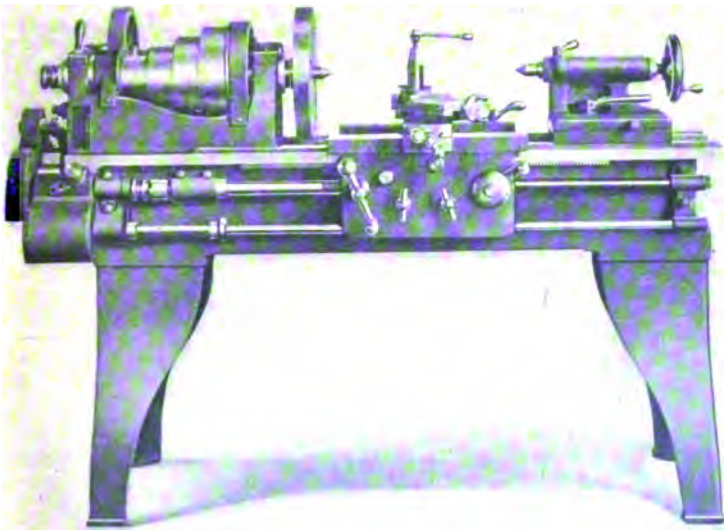
OPERATION OF MACHINE TOOLS

BY FRANKLIN D. JONES

THE LATHE—PART I

SECOND EDITION



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NUMBER 91

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THE LATHE

PART I

CONTENTS

INTRODUCTION

MACHINERY'S Reference Book, No. 91, is the first of a series containing, in condensed form, information on the operation of various types of machine tools. The first two books (Nos. 91 and 92) are descriptive of lathe work, and the succeeding numbers deal with machines of other types, such as the planer, shaper, drill-press, horizontal and vertical boring machines, milling machine, and grinder. In each case, a tool of typical design has been selected, and the important points connected with its operation and use have been considered. The method of setting up a Brown & Sharpe automatic screw machine, with a detailed description of its operation, is also given in this series. In the operation or manipulation of machine tools, as well as in other branches of machine construction, there are many things which are learned more easily by experience than in any other way; in fact, it would be impossible by a written explanation to convey more than a crude idea regarding many methods connected with shop practice. Therefore, in this series, no attempt has been made to cover every phase of machine work, but we have endeavored to explain the more important features connected with the use of standard machine tools. The various methods referred to are not, in every case, given as the best from a standpoint of accuracy, nor has the time element always been considered, but an effort has been made, instead, to select simple methods and examples which would clearly illustrate the principles involved. As the variety of machine tools now in use is extensive, and as different types can often be employed for the same kind of work, it might be well, in the beginning, to call attention to the fact that the best type of tool to use for machining a given class of work frequently depends on circumstances. To illustrate, a certain part might be turned in a lathe, which could be finished in some form of automatic or semi-automatic turning machine much more quickly. It does not necessarily follow, however, that the automatic is the best machine to use; because the lathe is designed for general work and the part referred to could doubtless be turned with the regular lathe equipment, whereas the automatic machine would require special tools and it would also need to be carefully adjusted. Therefore, if only a few parts were needed, the lathe would be the best tool to use, but if a large number were required, the automatic or semi-automatic machine would probably be preferable, because the saving in time effected by the latter type would more than offset the expense for tool equipment and setting the machine. It is also necessary, in connection with some work, to consider the degree of accuracy required, as well as the rate of production, and it is because of these varying conditions that work of the same general class is often done in machines of different types, in order to secure the most efficient results. This matter has been referred to at the outset to indicate, in a general way, the principle of tool selection.

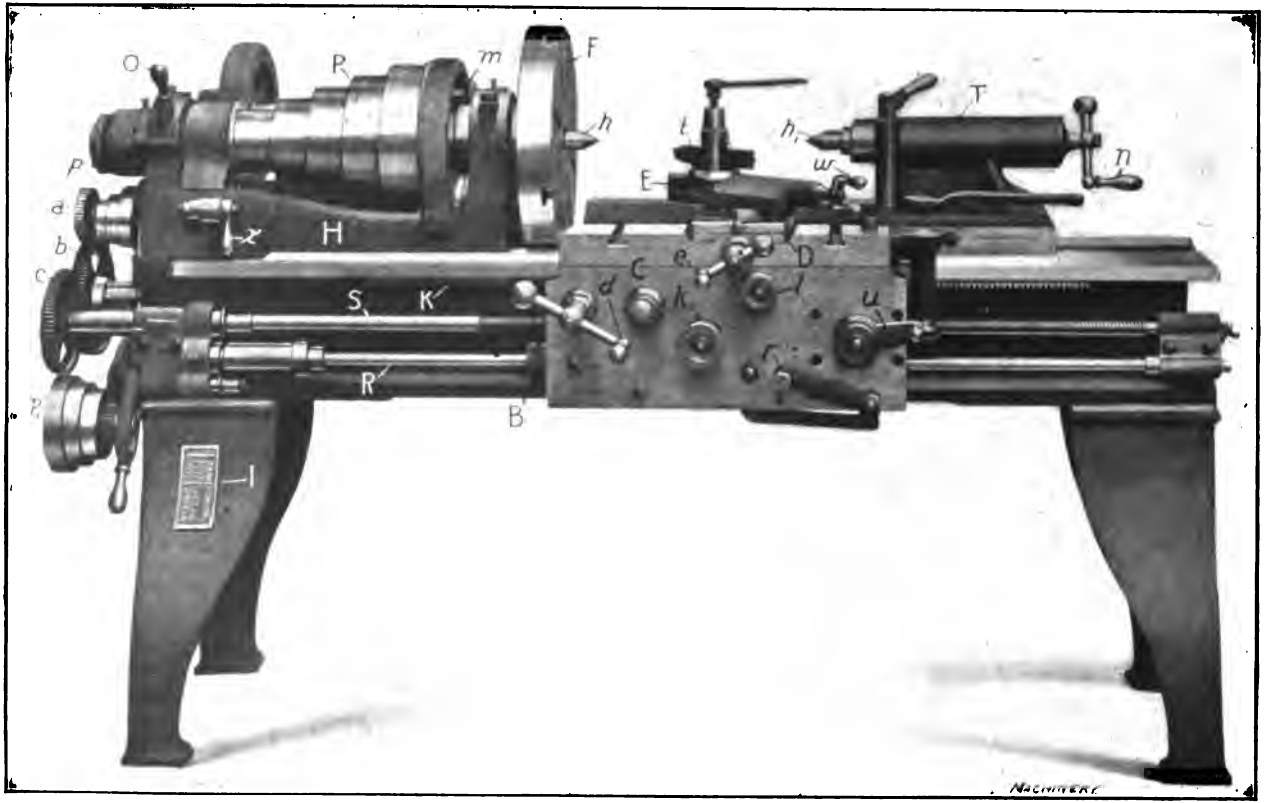


Fig. 1. Bradford Standard Lathe—View of Front or Operating Side

CHAPTER I

GENERAL DESCRIPTION OF AN ENGINE LATHE

The standard "engine" lathe, which is the type commonly used by machinists for doing general work, is one of the most important tools in a machine shop, because it is adapted to a great variety of work, such as turning all sorts of cylindrically shaped parts, boring holes, cutting threads, etc. The illustration Fig. 1 shows a lathe which, in many respects, represents a typical design, and while some of the parts are arranged differently on other makes, the general construction is practically the same as on the machine illustrated.

The principal parts are the bed *B*, the headstock *H*, the tailstock *T*, and the carriage *C*. The headstock contains a spindle which is rotated by a belt that passes over the cone-pulley *P*, and this spindle rotates the work, which is usually held between pointed or conical centers *h* and h_1 in the headstock and tailstock, or in a chuck screwed onto the spindle instead of the faceplate *F*. The carriage *C* can be moved lengthwise along the bed by turning handle *d*, and it can also be moved by power, the movement being transmitted from the headstock spindle either through gears *a*, *b*, *c*, and screw *S*, or by a belt operating on pulleys *p* and p_1, which drive the feed-rod *R*. The screw *S* is used when cutting threads, and the feed-rod *R* for ordinary turning operations; in this way the screw is worn as little as possible, and its accuracy is preserved. On the carriage, there is a cross-slide *D* which can be moved at right angles to the lathe bed by handle *e*, and on *D* there is an upper or compound slide *E* which can be swiveled to different positions. The tool *t*, that does the turning, is clamped to the upper slide, as shown, and it can be moved with relation to the work by the lengthwise movement of the carriage *C* on the bed, by moving slide *D* crosswise, and by slide *E*, which can be set to any required angle. The first two movements can be effected by power, the lengthwise feed being engaged by tightening knob *k*, and the cross-feed by tightening knob *l*. The direction of either of these movements can also be reversed by shifting lever *r*. Ordinarily the carriage and slide are adjusted by hand to bring the tool into the proper position for turning to the required diameter, and then the power feed (operating in the desired direction) is engaged. The tailstock *T* can be clamped in different positions along the bed, to suit the length of the work, and its center h_1 can be moved in or out for a short distance, when adjusting it to the work, by turning handle *n*.

As some metals are much harder than others, and as the diameter of the part that is to be turned also varies, speed changes are necessary, and these are obtained by placing the driving belt on different steps of cone-pulley *P*, and also by the use of back-gears. The cone-pulley can be connected directly with the spindle or be disengaged from it by means of bolt *m*. When the pulley and spindle are connected, five speeds (with this particular lathe) are obtained by simply shifting the driving belt to different steps of the cone. When a slower speed is required than can be obtained with the belt on the largest step of the cone, the latter is disconnected from the spindle, and the back-gears *G* and G_1, (shown in the plan view Fig. 2) are moved forward into mesh by turning handle *O;* the drive is then from cone-pulley *P* and gear *L* to gear *G*, and from gear G_1 to the large gear *J* on the spindle. When driving through the back-gears, five more speed changes are obtained by shifting the position of the driving belt, as before. Changes of feed for the tool are also required, and these are obtained by shifting the belt operating on pulleys *p* and p_1 to different-sized steps.

Front and rear views of the carriage apron, which contains the

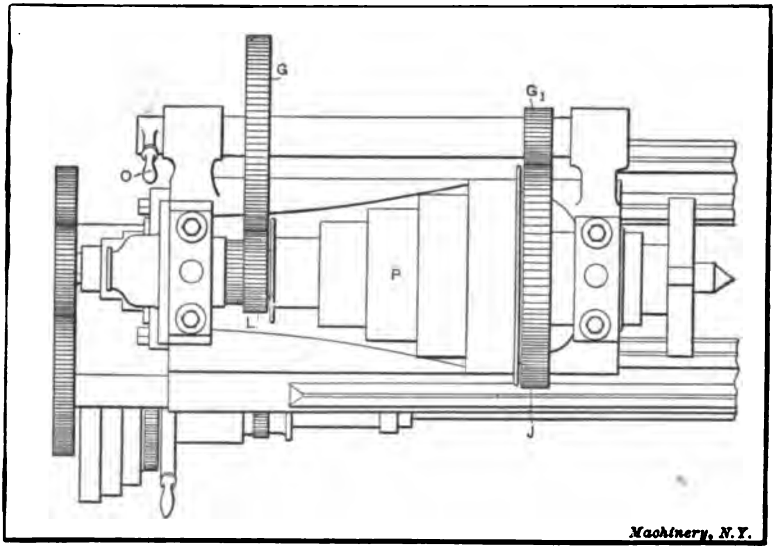


Fig. 2. Plan View of Headstock showing Back-gears

feeding mechanism, are shown in Figs. 3 and 4, to indicate how the feeds are engaged and reversed. The feed-rod *R* (Fig. 1) drives the small bevel gears *A* and A_1 (Figs. 3 and 4) which are mounted on a slide *S* that can be moved by lever *r* to bring either bevel gear into mesh with gear *B*. Gear *B* is attached to pinion *b* (see Fig. 3) meshing with gear *C*, which, when knob *k* is tightened, is locked by a friction clutch to pinion *c*. The latter pinion drives gear *D* which rotates shaft *E*. A pinion cut on the end of shaft *E* engages rack *K* (Fig. 1) attached to the bed, so that the rotation of *E* (which is controlled by knob *k*) moves the carriage along the bed. To reverse the direction of the movement, it is only necessary to throw gear *A* into mesh and gear A_1 out, or *vice versa*, by operating lever *r*. When the carriage is traversed by hand, shaft *E* and gear *D* are rotated by pinion d_1 connected with handle *d*.

The drive for the cross-feed is from gear *C* to gear *F* which can be engaged through a friction clutch (operated by knob *l*) with gear *G* meshing with a pinion *H*. The latter rotates the cross-feed screw, which passes through a nut attached to slide *D* (Fig. 1), thus moving

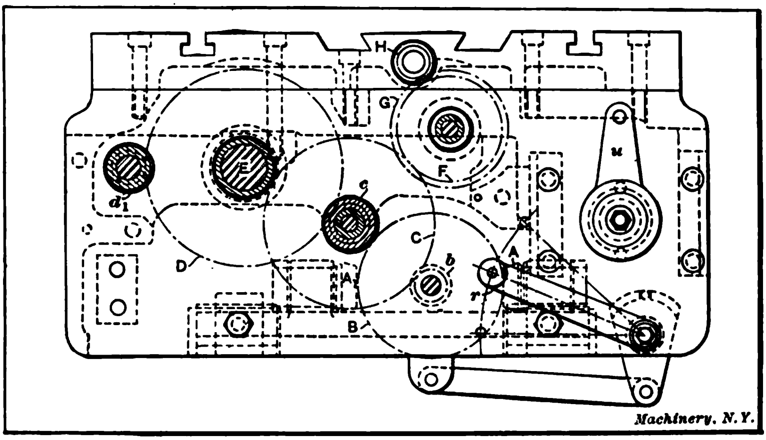


Fig. 3. Lathe Apron

the latter at right angles to the ways of the bed. The cross-feed is also reversed by means of lever *r*. As previously explained, lead-screw *S* is only used for feeding the carriage when cutting threads. The carriage is engaged with this screw by means of two half-nuts *N*

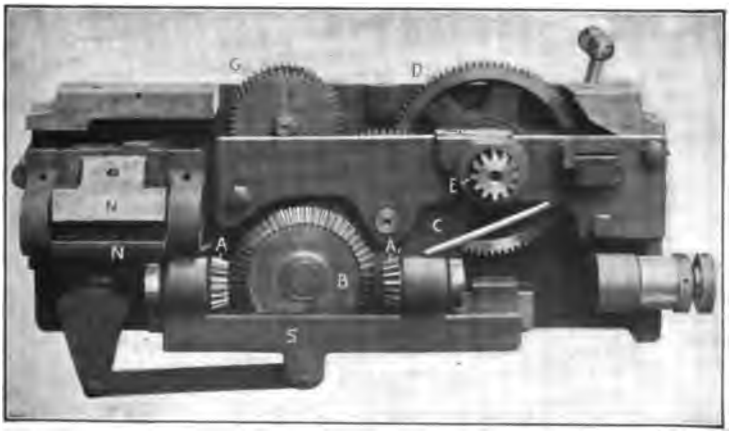


Fig. 4. Rear View of Lathe Apron

that are free to slide vertically and are closed around the screw by operating lever *u*. These half-nuts can only be closed when lever *r* is in a central or neutral position, so that the screw feed and the regular turning feed cannot be engaged at the same time.

CHAPTER II

EXAMPLE OF CYLINDRICAL TURNING

Having now considered the principal features of what might be called a standard lathe, the method of using it in the production of machine parts will be explained. The first example of work that will be referred to is shown in Fig. 6, which represents a drawing of the part. It is a steel shaft, the diameter of which must be 2¼ inches and the length 14½ inches, these being the finished dimensions. We will assume that the rough stock is cut off to a length of 14⅝ inches and has a diameter of 2⅝ inches. The first step in this operation is to form conically shaped center-holes in each end of the piece as indicated at *c* in Fig. 5. As all work of this kind is held, while being turned, between the centers *h* and h_1, holes corresponding in shape to these centers are necessary to keep the work in place. There are several methods of forming these center-holes, as explained in Chapter III.

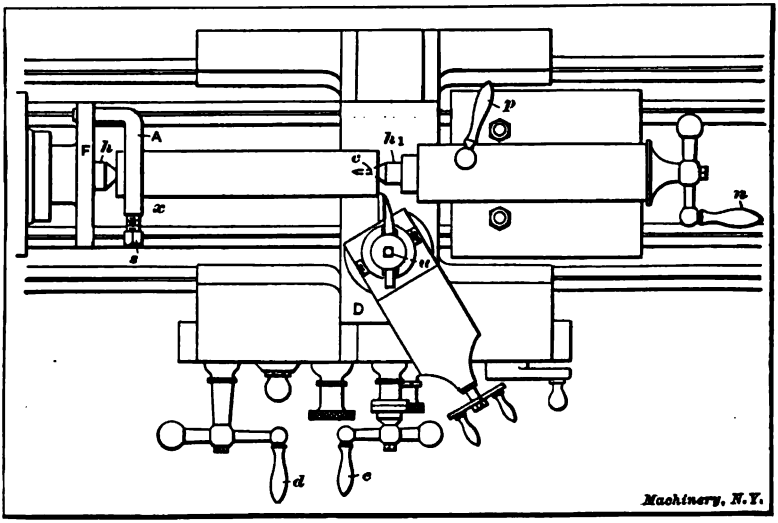


Fig. 5. Plan View showing Work Mounted Between Centers

After the work is centered, a dog *A* is clamped to one end by tightening screw *s*, and is then placed between the centers. The dog has a projecting end or tail, as it is commonly called, which enters a slot in the faceplate *F* and thereby drives or rotates the work, when power is applied to the lathe spindle onto which the faceplate is screwed. The tailstock center h_1, after being oiled, should be set up just tight enough to eliminate all play, without interfering with a free rotary movement of the work. This is done by turning handle *n*, and when the center is properly adjusted, the tailstock spindle containing the center is locked by tightening handle *p*.

Facing the Ends Square with a Side Tool

Everything is now ready for the turning operation. The ends of the piece should be faced square before turning the body to size, and the tool for this squaring operation is shown in Fig. 7; this is known

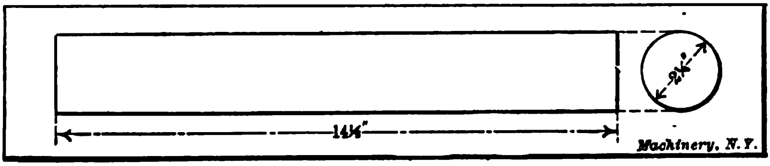


Fig. 6. Example of Plain Cylindrical Work

as a side tool. It has a cutting edge *e* which shaves off the metal as indicated in the end view by the dotted lines. The side *f* is ground to an angle so that when the tool is moved in the direction shown by the arrow, the cutting edge will come in contact with the part to be turned; in other words, side *f* is ground so as to provide clearance for the cutting edge. In addition, the top surface against which the chip bears, is beveled to give the tool keenness so that it will cut easily. As the principles of tool grinding are treated separately in Chapter V of MACHINERY'S Reference Book, No. 92, we shall for the present consider the tool's use rather than its form. For facing the end, the side tool is clamped in the toolpost by tightening the screw *u*,

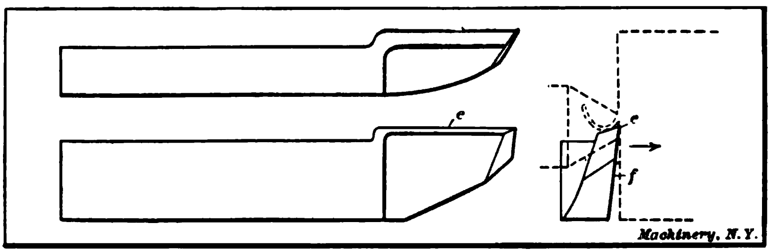


Fig. 7. Right-side Tool

Fig. 5, and it should be set with the cutting edge slightly inclined from a right-angled position as shown. The cutting edge should also be about the same height as the center of the work. When the tool is set, the lathe (if belt-driven) is started by shifting an overhead belt and the tool is then moved in until the point is in the position shown at *A*, Fig. 8. The tool-point is then fed against the end by handle *d*, Fig. 5, until a light chip is being turned off, and then it is moved outward by handle *e* (as indicated by the arrow at *B*, Fig. 8), the carriage remaining stationary. As the movement of the tool-point is guided by the cross-slide *D*, which is at right angles with the axis of the work, the end will be faced square. For short turning operations of this kind, the power feeds are not used as they are intended for comparatively long cuts. If it were necessary to remove much metal from the end, a number of cuts would be taken across the end; in this case, however, the rough stock is only 1/8 inch too long so that this end need only be made true. After taking a cut as described, the surface, if left rough by the tool-point, should be made smooth by a second or finishing cut. If the tool is ground slightly round at the point and the cutting edge is set almost square, as at *C*, Fig. 8, a smooth finish can be obtained; the cut, however, should be light and the outward feed uniform. The work is next reversed in the centers and the driving dog is placed on the end just finished; the other end is then faced, enough metal being removed to make the piece 14½ inches long, as called for on the drawing. This completes the facing operation.

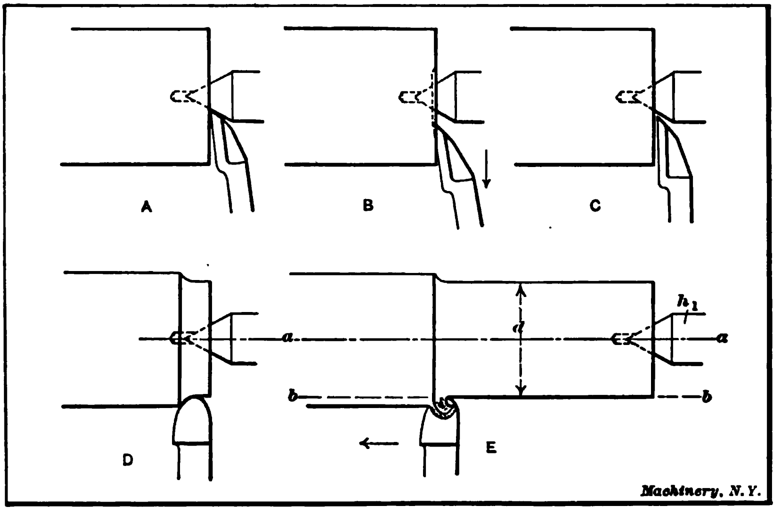


Fig. 8. Facing End with Side Tool and Turning Work Cylindrical

If the end of the work does not need to be perfectly square, the facing operation can be performed by setting the tool in a right-angled position and then feeding it sidewise, thus removing a chip equal to the width of one side. Evidently this method is confined to comparatively small diameters and the squareness of the turned end will be determined by the position of the tool's cutting edge.

Lathe Turning Tool—Turning Work Cylindrical

The tool used to turn the body to the required diameter is shaped differently from the side tool, the cutting edge *E* being curved as shown in Fig. 9. A tool of this shape can be used for a variety of cylindrical turning operations. As most of the work is done by that part of the edge marked by arrow *a*, the top of the tool is ground to slope back from this part to give it keenness. The end *F*, or the flank, is also ground to an angle to provide clearance for the cutting edge; for without such clearance, the flank would rub against the work and the cutting edge would be ineffective. This type of tool is placed about square with the work, for turning, and with the cutting end a little above the center.

Before beginning to turn, a pair of outside calipers should be set

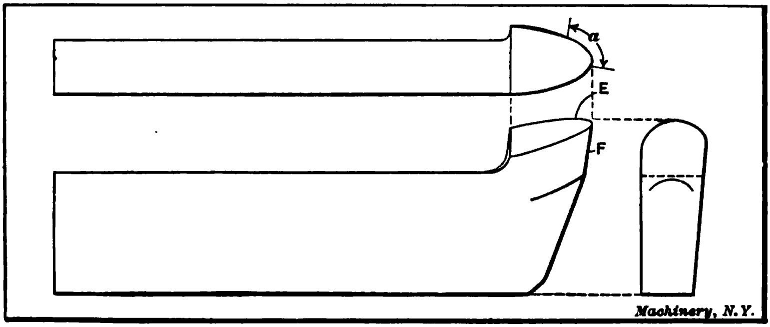


Fig. 9. Tool used for Cylindrical Turning

to 2¼ inches, which, in this case, is the finished diameter of the work. Calipers are sometimes set by using a graduated scale as at *A*, Fig. 10, or they can be adjusted to fit a standard cylindrical gage of the required size as at *B*. Very often fixed caliper gages *C* are used instead of the adjustable spring calipers. These fixed gages, sometimes called "snap" gages, are accurately made to different sizes, and they

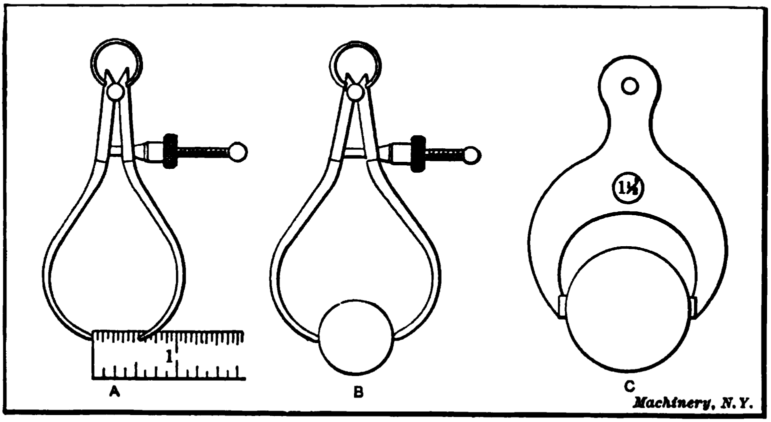


Fig. 10. Setting Calipers by Scale—Setting by Gage—Fixed Gage

are particularly useful when a number of pieces have to be turned to exactly the same size.

The turning tool is started at the right end of the work and the carriage should be moved with the left hand when beginning a cut. as shown in Fig. 11, in order to have the right hand free for calipering. A short space is first turned by hand feeding, as at *D*, Fig. 8, and when the calipers show that the diameter is slightly greater than the finished size (to allow for a light finishing cut), the power feed for the carriage is engaged; the tool then moves along the work reducing it as at *E*. Evidently, if the movement is along a line *b—b*, parallel with the axis *a—a*, the diameter *d* will be the same at all points, and a true cylindrical piece will be turned. On the other hand, if the axis *a—a* is inclined one way or the other, the work will be made tapering; in fact, the tailstock center h_1 can be adjusted laterally for turning tapers, but for straight turning, both centers must be in alignment with the carriage travel. Most lathes have lines on the stationary and movable parts of the tailstock base which show when the centers are set for straight turning. These lines, however, may not be absolutely correct, and it is good practice to test the alignment of the centers before beginning to turn. This can be done by taking

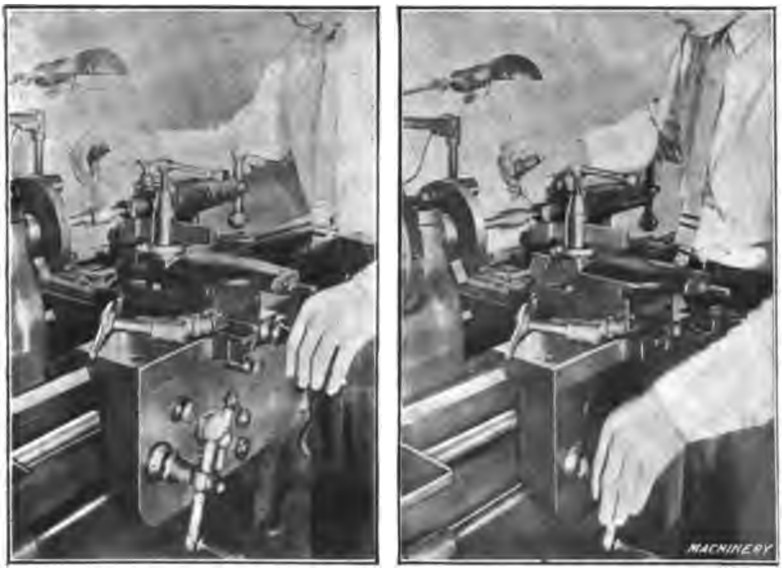


Fig. 11. Views showing how the Cross-slide and Carriage are Manipulated by Hand when Starting a Cut

trial cuts, at each end of the work (without disturbing the tool's crosswise position), and then comparing the diameters, or by testing the carriage travel with a true cylindrical piece held between the centers.

If the relative positions of the lathe centers is not known, the work should be calipered as the cut progresses to see if the diameter *d* is the same at all points. In case the diameter gradually increases, the tailstock center should be shifted slightly to the rear before taking the next cut, but if the diameter gradually diminishes, the adjustment would, of course, be made in the opposite direction. The diameter is tested by attempting to pass the calipers over the work. When the measuring points just touch the work as they are gently passed across it, the diameter being turned is evidently the same as the size to which the calipers are set.

As the driving dog is on one end, the cut cannot be taken over the entire length, and when the tool has arrived at say position *x*, Fig. 5, it is returned to the starting point and the work is reversed in the centers. The large end is then turned, and if the cross-slide has not been moved, the tool will meet the first cut. The two cuts will not be joined or blended together perfectly, however, and for this reason a cut should be continuous when this is possible.

Roughing and Finishing Cuts

Ordinarily in lathe work, as well as in other machine work, there are two classes of cuts, known as roughing and finishing cuts. Roughing cuts are for reducing the work as quickly as possible almost to

Fig. 12. Filing Work after Finishing Cut is taken

the required size, whereas finishing cuts, as the name implies, are intended to leave the part smooth and of the proper size. When the rough stock is only a little larger than the finished diameter, a single cut is sufficient, but if there is considerable metal to turn away, one or more deep roughing cuts would have to be taken, and, finally, a light cut for finishing. In this particular case, one roughing and one finishing cut would doubtless be taken, as the diameter has to be reduced 3/8 inch. Ordinarily the roughing cut would be deep enough to leave the work about 1/32 or perhaps 1/16 inch above the finished size. When there is considerable metal to remove and a number of roughing cuts have to be taken, the depth of each cut and the feed of the tool are governed largely by the pulling power of the lathe and the strength of the work to withstand the strain of a heavy cut.

Of course, just as few cuts as possible should be taken in order to save time. The speed of the work should also be as fast as the conditions will allow for the same reason, but as there are many things which govern the speed, the feed of the tool, and the depth of the cut, these important points are referred to separately in Chapter III of MACHINERY's Reference Book No. 92.

Filing and Finishing

In many cases the last or finishing cut does not leave as smooth a surface as is required and it is necessary to resort to other means. The method commonly employed for finishing in the lathe is by the use of a file and emery cloth. The work is rotated considerably faster for filing than for turning, and the entire surface is filed by a flat, single-cut file, held as shown in Fig. 12. The file is passed across the work and advanced sidewise for each forward stroke until the entire surface is finished. The file should be kept in contact with the work continually, but on the return stroke, the pressure should be relieved.

The movement of the file during the forward or cutting stroke should be much slower than when filing in a vise. By moving the file slowly, the work can make a number of revolutions for each stroke, which tends to keep it round, as practically the same amount of metal is removed from the entire circumference. On the other hand, short rapid strokes tend to produce flat spots, or at least an irregular surface, especially if the work can only make part of a revolution for each cutting stroke. The pressure on the file during the forward stroke, should also be kept as nearly uniform as possible. It is very difficult to file a part smooth and at the same time to keep it round and cylindrical, and the more filing that has to be done, the greater the chance of error. For this reason, the amount left for filing should be very small; in fact, the metal removed by filing should be just enough to take out the tool marks and give a smooth finish. Very often a satisfactory finish can be obtained with a turning tool, and filing is not necessary at all.

Sometimes particles of metal collect between the teeth of a file and make deep scratches as the file is passed across the work. When this, occurs, the teeth should be cleaned by using a wire brush or a file card, which is drawn across the file in the direction of the teeth. This forming of tiny particles between the teeth is known as "pinning" and it can sometimes be avoided by rubbing chalk on the file. Filing is not only done to obtain a smooth finish, but also to reduce the work to an exact diameter, as a very slight reduction can be made in this way. If a polish is desired, this can be obtained by holding a piece of emery cloth tightly around the work as it revolves. Most cylindrical parts can be finished more quickly and accurately in the grinder than in the lathe, and many classes of work are, at the present time, simply rough-turned in the lathe and then ground to size in a cylindrical grinding machine.

CHAPTER III

CENTERING

As mentioned in the preceding chapter, there are a number of different methods of forming center-holes in the ends of parts that have to be turned while held between lathe centers. A method of centering light work, which requires few special tools, is first to locate a central point on the end and then drill and ream the center-hole by using the lathe itself.

Locating the Center—Drilling in the Lathe

Hermaphrodite dividers are useful for finding the center, as illustrated at *A*, Fig. 13, but if the work is fairly round, a center-square *B* is preferable. A line is scribed across the end and then another line at right angles to the first by changing the position of the square; the

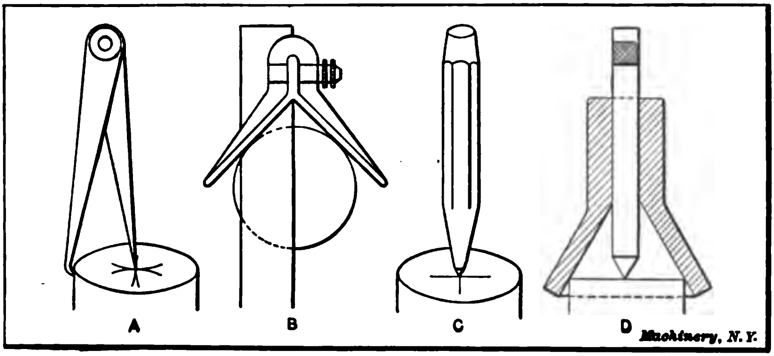


Fig. 13. Centering End with Punch preparatory to Drilling

intersection of these two lines will be the center, which should be marked by striking a pointed punch *C* with a hammer. If a cup or bell center-punch *D* is available, it will not be necessary to first make center lines, as the conical part shown locates the punch in a central position. This style of punch should only be used on work which is fairly round.

After small centers have been located in both ends, their position can be tested by placing the work between the lathe centers and rotating it rapidly by drawing the hand quickly across it. By holding a piece of chalk close to the work as it spins around, a mark will be made on the "high" side if the centers are not accurate; the centers are then shifted toward these marks. If the work is close to the finished diameter, the centers should, of course, be located quite accurately in order that the entire surface of the work will be turned true when it is reduced to the finished size.

One method of finishing these center-holes is indicated in Fig. 14. A chuck *C* is screwed onto the spindle in place of the faceplate, and a combination center drill and reamer *R* is gripped by the chuck jaws and set to run true. The center is then drilled and reamed at one end by pressing the work against the revolving drill with the tailstock spindle, which is fed out by turning handle *n*. The piece is then reversed for drilling the opposite end. The work may be kept from revolving while the centers are being drilled and reamed, by attaching

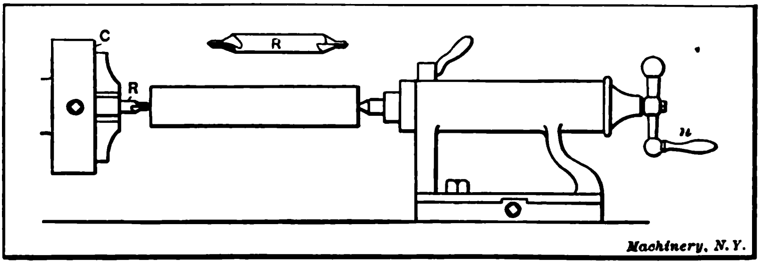
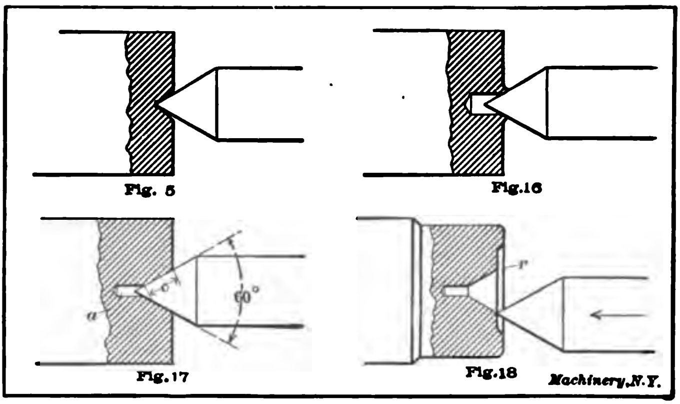


Fig. 14. Drilling Centers in the Lathe

a dog to it close to the tailstock end and then adjusting the cross-slide until the dog is in contact with it. From the foregoing it will be seen that the small centers made by punch *C*, Fig. 13, serve as a starting point for the drill and also as a support for the outer end of the work while the first hole is being drilled.

The form of center-hole produced by a combination drill and reamer is shown in Fig. 17. A small straight hole *a* in the bottom prevents



Figs. 15 to 18. Centers of Incorrect and Correct Form

the point of the lathe center from coming in contact with the work and insures a good bearing on the conical surface *c*. The standard angle for lathe centers is sixty degrees, as the illustration shows, and the tapering part of all center-holes should be made to this angle.

Centering Machine

Many shops have a special machine for forming centers which enables the operation to be performed quickly. One type of centering machine is shown in Fig. 19. The work is gripped in a chuck *C* that automatically locates it in a central position so that it is not necessary to lay out the end before drilling. There are two spindles *s* and s_1 one of which holds the drill and the other the countersink, and these are rotated by a belt passing over pulley *P*. Each of these spindles is advanced by lever *L* and either of them can be moved to a position central with the work, as they are mounted in a swiveling frame. In operating this machine, a small straight hole is first made by a twist drill held in one of the spindles; the other spindle is then moved over to the center and the hole is reamed tapering. The

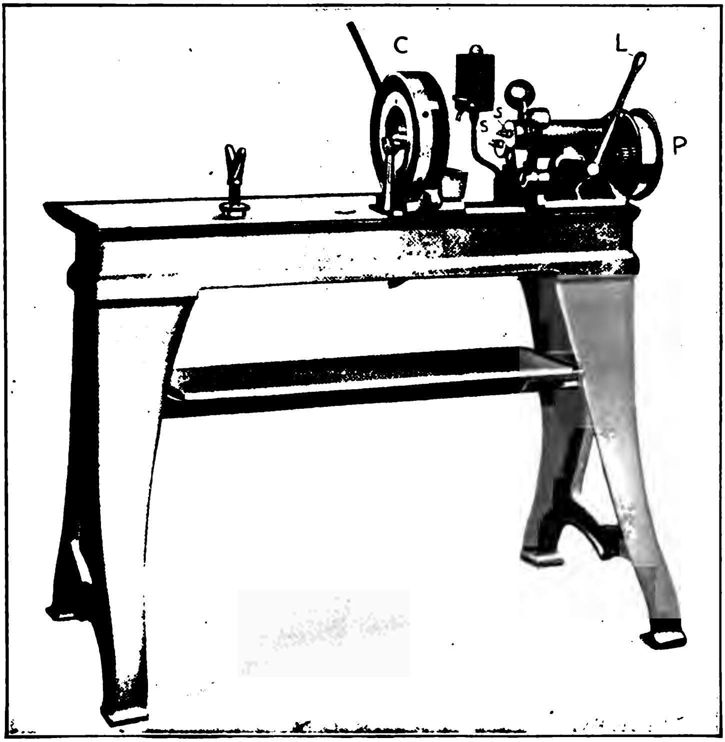


Fig. 19. Special Machine for Centering

arrangement is such that neither spindle can be advanced by the feeding lever except when in a central position. The amount that each spindle can be advanced is limited by a fixed collar inside the head, and there is also a swinging adjustable stop against which the end of the work should be placed before tightening the chuck. These two features make it possible to ream center holes of the same size or depth in any number of pieces.

Different Forms of Centers

In some poorly equipped shops it is necessary to form centers by the use of a center-punch only, as there is no better tool. If the end of the punch has a sixty-degree taper, a fair center can be formed in this way, but it is not a method to be recommended, especially when accurate work is required. Sometimes centers are made with punches that are too blunt, producing a shallow center, such as the one shown in Fig. 15. In this case all the bearing is on the point of the lathe center, which is the worst possible place for it. Another way is to simply drill a straight hole as in Fig. 16; this is also bad practice

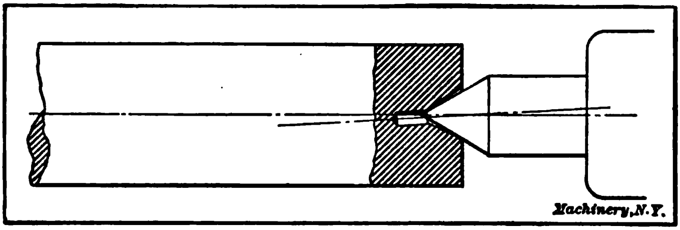


Fig. 20. The Imperfect Center Bearing is the Result of Centering before Straightening

in more than one respect. Fig. 18 shows a form of center which is often found in the ends of lathe arbors, the mouth of the center being rounded, at *r*, and the arbor end recessed as shown. The rounded corner prevents the point of the lathe center from catching when it is moved rapidly towards work which is not being held quite centrally, and the end is recessed to protect the center against bruises. Stock that is bent should always be straightened before the centers are drilled and reamed. If the work is centered first and then straightened,

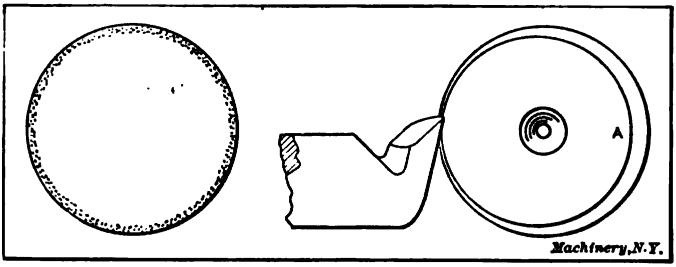


Fig. 21. Tool Steel should be centered Concentric, in order to remove the Decarbonized Outer Surface

the bearing on the lathe center would be as shown in Fig. 20. The center will then wear unevenly with the result that the surfaces last turned will not be concentric with those which were finished first.

Precaution When Centering Tool Steel

Ordinarily centers are so located that the stock runs approximately true before being turned, but when centering material to be used in making tools, such as reamers, mills, etc., which need to be hardened, particular care should be taken to have the rough surface run fairly true. This is not merely to insure that the piece will "true-up," as there is a more important consideration the disregard of which often affects the quality of the finished tool. As is well known, the degree of hardness of a piece of tool steel that has been heated and then suddenly cooled, depends upon the amount of carbon that it contains, steel that is high in carbon becoming much harder than that which contains less carbon. Furthermore the amount of carbon found at the surface, and to some little depth below the surface of a bar of steel, is less than the carbon contained in the rest of the bar. This is illustrated diagrammatically in Fig. 21 by the shaded area in the view to the left. (This decarbonization is probably due to the action of the oxygen of the air on the bar during the process of manufacture.) If stock for a reamer is so centered that the tool removes the decarbonized surface only on one side, as illustrated to the right, evidently when the reamer is finished and hardened, the teeth on the side *A* will be harder than those on the opposite side, which would not have been the case if the rough bar had been centered true. To

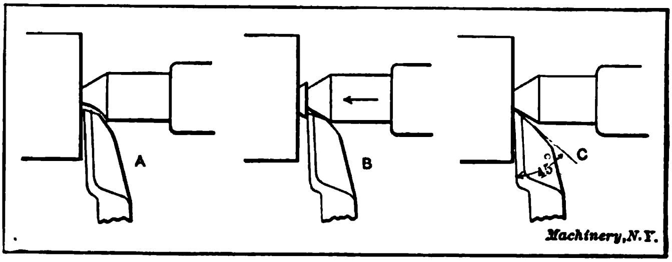


Fig. 22. Three Methods of Facing the End Square

avoid any trouble of this kind, stock that is to be used for hardened tools, should be enough larger than the finished diameter and so centered that this decarbonized surface will be entirely removed in turning.

Facing the Ends of Centered Stock

As a piece of work is not properly centered until the ends are faced square, we will consider this operation in connection with centering. Some machinists prefer lathe centers that are cut away as shown at *A*, Fig. 22, so that the point of the side tool can be fed in far enough to face the end right up to the center hole. Others, instead of using a special center, simply loosen the regular one slightly and then, with the tool in a position as at *B*, face the projecting teat by feeding both tool and center inward as shown by the arrow. Whenever this method is employed, care should be taken to remove any chips from the center hole which may have entered. A method which makes it unnecessary to loosen the regular center, or to use a special one, is to provide clearance for the tool-point by grinding it to an angle of approximately forty-five degrees, as shown at *C*. If the tool is not set too high, it can then be fed right up to the lathe center and the end squared without difficulty. As for the special center *A*, the use of special tools and appliances should always be avoided unless they effect a saving in time or their use makes it possible to accomplish the same end with less work.

CHAPTER IV

THE USE OF LATHE MANDRELS

When it is necessary to turn the outside of a part having a hole through it, centers cannot, of course, be drilled in the ends and other means must be resorted to. We shall assume that the bushing *B*, Fig. 24, has a finished hole through the center, and it is desired to turn the outside cylindrical and concentric with the hole. This could be done by forcing a tightly-fitted mandrel *M*, having accurately-centered ends, into the bushing, and inserting the mandrel and work between the lathe centers h and h_1 as shown. Evidently, if the mandrel runs true on its centers, the hole in the bushing will also run true and the outside can be turned the same as though the mandrel and

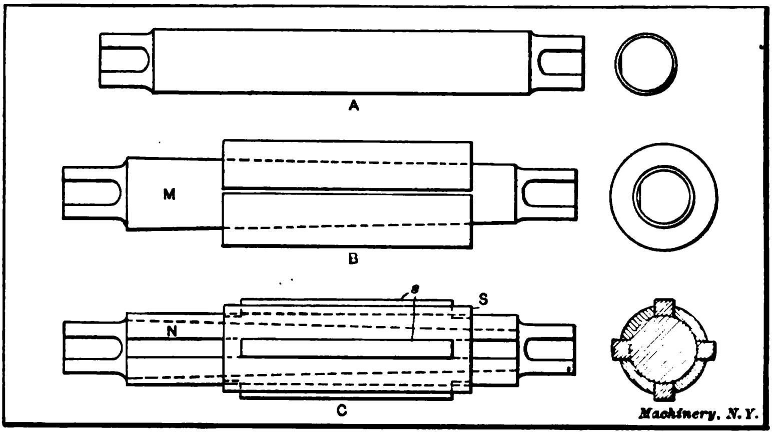


Fig. 23. Different Types of Mandrels

bushing were a solid piece. From this it will be seen that a mandrel simply forms a temporary support for work that is bored and therefore cannot be centered.

Another example of work that would be turned on an arbor is shown in Fig. 25. This is a small cast-iron wheel having a finished hole through the hub, and the outer surface and sides of the rim are to be turned true with this hole. In this case, the work would also be held by pressing a mandrel through the hub as shown. This method, however, would only apply to comparatively small wheels because it would be difficult, if not impossible, to prevent a large wheel from turning on the arbor when taking a cut, and even if it could be driven, large work could be done to better advantage on another type of machine. (The vertical boring mill is used extensively for turning arge wheels). When turning the outside of the rim, a tool similar that shown at *t* should be used, but for facing or turning the sides, might be better, if not necessary, to use tools having bent ends shown by the dotted lincs; in fact, turning tools of various kinds are made with the ends bent to the right or left, as this enables

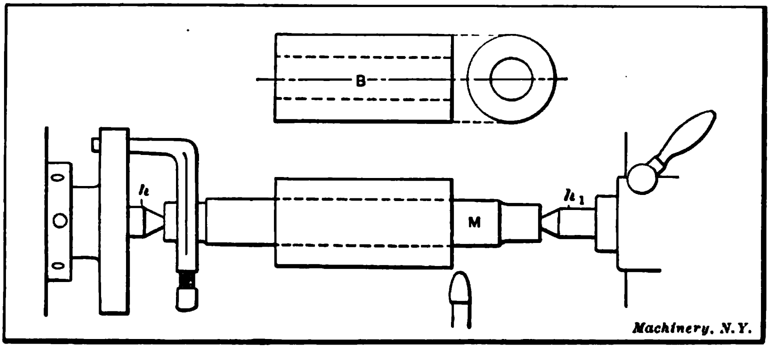


Fig. 24. Bushing mounted on Mandrel for Turning

them to be used on surfaces that could not be reached very well with a straight tool.

If a comparatively large pulley is mounted near the end of the mandrel, it can be driven directly by pins attached to the faceplate and

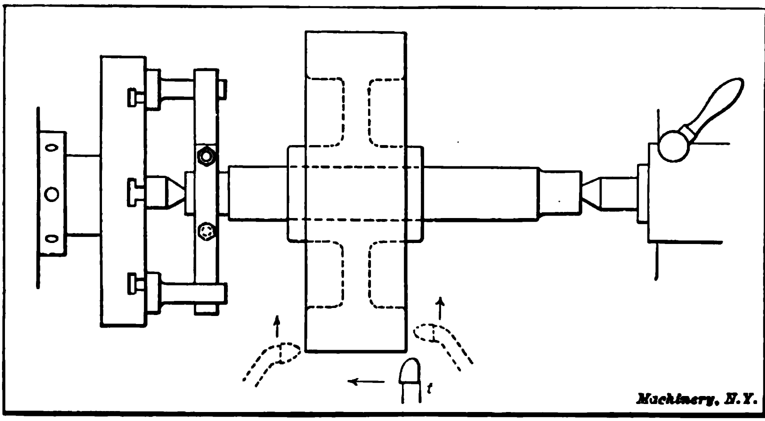


Fig. 25. Turning Pulley Held on Mandrel

engaging the pulley arms. When this method is employed, a dog is, of course, unnecessary.

Different Types of Lathe Mandrels

Three different types of lathe mandrels are shown in Fig. 23. The kind shown at *A* is usually made of tool steel and the body is finished to a standard size. The ends are somewhat reduced and flat spots are milled, as shown, to give the clamping screw of the dog a good grip. This type is used very extensively, but in shops where a great variety of work is being done and there are many odd-sized holes, the expanding mandrel *B* can be used to advantage. This type, instead of being solid, consists of a tapering inner mandrel *M* on which is placed a split bushing that can be expanded, within certain limits, by driving in the tapering member. The advantage of this type is that a compartively small stock of mandrels is required, as different sized bushings can be used. This type can also be fitted to holes of odd sizes, whereas a solid mandrel must be provided for each different size of hole. The latter are, however, more accurate than the expanding type. Another form of expanding mandrel is shown at *C*. This type has a straight body *N* in which four tapering grooves are cut lengthwise, as shown, and there is a sleeve *S*, containing four slots that are located to correspond with the tapering grooves. Strips *s* are fitted in these slots, and as the part *N* is driven in, the strips are moved outward as they ascend the tapering grooves. By having different sets of these strips of various heights, one mandrel of this type can be made to cover quite a range of sizes. It is not suited, however, to thin work, as the pressure, being concentrated in four places, would spring it out of shape.

Fig. 26. Press for Forcing Mandrels into Work

Particular care should be taken to preserve the accuracy of the centers of lathe mandrels by keeping them clean and well-oiled while in use.

Mandrel or Arbor Press

The best method of inserting a mandrel in a hole is by using a press, Fig. 26, designed for that purpose, but if such a press is not available and it is necessary to drive the mandrel in, a "soft" hammer, made of copper, lead or other soft material, should be used to protect the end of the mandrel. In either case, the mandrel should not be forced in too tightly, for if it fits properly, this will not be necessary in order to hold the work securely. On the other hand, the work might easily be broken by attempting to force the mandrel in as far and as tightly as possible. In using the arbor press, the work is placed on the base *B* with the hole in a vertical position, and the arbor (which should be oiled slightly) is forced down into it by ram *R*, operated by lever *L*. Slots are provided in the base, as shown, so that the end of the arbor can come through at the bottom of the hole. The lever of this particular press is counterweighted so that it rises to a vertical position when released. The ram can then be adjusted quickly to any required height by the handwheel seen at the left.

Some shops are equipped with power-driven mandrel or arbor presses. This type is particularly desirable for large work, owing to the greater pressure required for inserting mandrels that are comparatively large in diameter. One well-known type of power press is driven by a belt, and the downward pressure of the ram is controlled by a handwheel. The ram is raised or lowered by turning this handwheel in one direction or the other, and a gage shows how much pressure is being applied. This type of press can also be used for other purposes, such as forcing bushings or pins into or out of holes, bending or straightening parts, or for similar work.

CHAPTER V

CHUCK AND FACEPLATE WORK

Many parts that are turned in the lathe are so shaped that they cannot be held between the lathe centers like shafts and other similar pieces and it is often necessary to hold them in a chuck *A*, Fig. 27, which is screwed on the lathe spindle instead of the faceplate. The work is gripped by the jaws *J* which can be moved in or out to accommodate various diameters. There are three classes of chucks ordinarily used on the lathe, known as the independent, universal, and combination types. The independent chuck is so named because each jaw can be adjusted in or out independently of the others by turning the jaw screws *S* with a wrench. The jaws of the universal chuck all move together and keep the same distance from the center, and

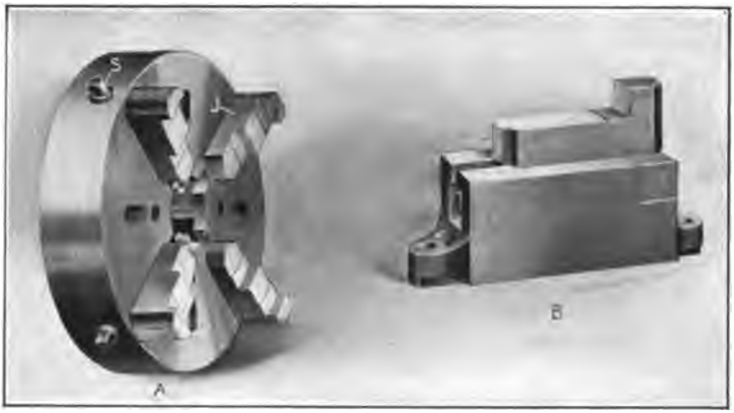


Fig. 27. Chuck and Faceplate Jaw

they can be adjusted by turning any one of the screws *S*, whereas with the independent type the chuck wrench must be applied to each jaw screw. The combination chuck, as the name implies, may be changed to operate either as an independent or universal type. The advantage of the universal chuck is that round and other parts of a uniform shape are located in a central position for turning without any adjustment. The independent type is, however, preferable in some respects as it is usually stronger and adapted for holding odd-shaped pieces because each jaw can be set to any required position.

Radial Facing or Turning

As an example of chuck work, we shall assume that the sides of disk *D*, Fig. 28, are to be turned flat and parallel with each other and that an independent chuck is to be used. First the chuck is screwed on the lathe spindle (after removing the faceplate) by holding it with the right hand and turning the lathe spindle with the left by pulling down on the belt. The chuck jaws are then moved out or in, as the case may be, far enough to receive the disk and each jaw is set about the same distance from the center by the aid of concentric circles on the face of the chuck. The jaws are then tightened while the disk is held back against them to bring the rough inner surface in a vertical plane. If the work is quite heavy, it can be held against the chuck, before the jaws are tightened, by inserting a piece of wood between it and the tailstock center; the latter is then run out far enough to force the work back. The outside or periphery of the disk should run nearly true and it may be necessary to move

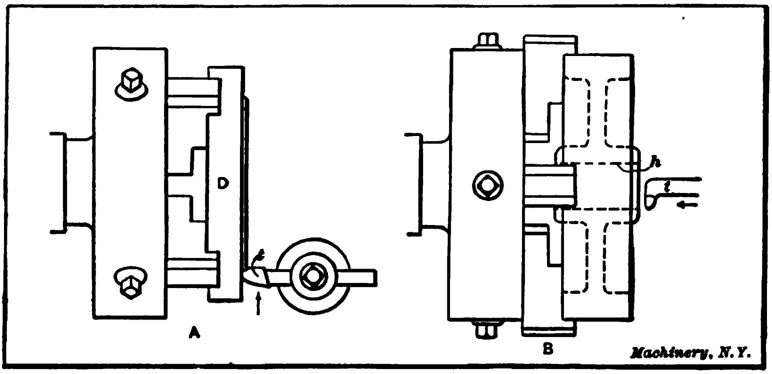


Fig. 28. Radial Facing—Boring Pulley Held in Chuck

the jaws in on one side and out on the other to bring the disk to a central position. To test its location, the lathe is run at a moderate speed and a piece of chalk is held near the outer surface. If the latter runs out, the "high" side will be marked by the chalk, and this mark can be used as a guide in adjusting the jaws. It should be remembered that the jaws are moved only one-half the amount that the work runs out.

A round-nosed tool *t* of the shape shown is used for radial facing or turning operations of the kind illustrated. This tool is similar to the kind used when turning between centers, the principal difference being in the direction of the top slope. The radial facing tool should be ground to slope downward toward *a* (see Fig. 29) whereas the regular turning tool slopes toward *b*, the inclination in each case being away from that part of the cutting edge which does the work. The cutting edge should be the same height as the lathe centers, and the cut is taken by feeding the tool from the outside in to the center. The cut is started by hand and then the power feed is engaged, except for small surfaces. The first cut should, if possible, be deep enough to get beneath the scale, especially if turning cast iron, as a tool which just grazes the hard outer surface in spots will be dulled in a comparatively short time. If it were simply necessary to turn a true flat surface and the thickness of the disk were immaterial, two cuts would be sufficient, unless the surface were very uneven, the first or roughing cut being followed by a light finishing cut. For a finishing cut, the same tool could be used but if there were a number of disks to be faced, a square-nosed tool *F*, Fig. 29, could probably be used to better advantage. This type has a broad flat cutting edge that is set parallel with the rough-turned surface and this broad edge

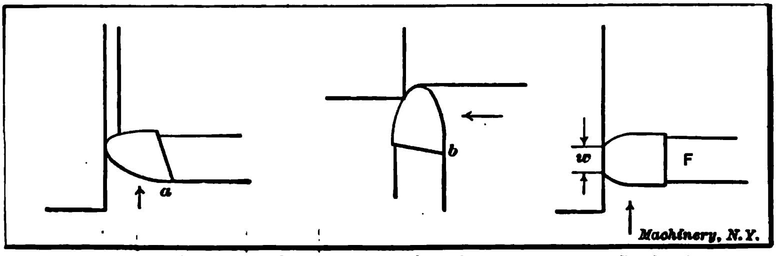


Fig. 29. Top of Tool should Slope away from Working Part of Cutting Edge

enables a coarse feed to be taken, thus reducing the time required for the finishing cut. If a coarse feed were taken with the round tool, the turned surface would have spiral grooves in it, whereas with the broad cutting edge, a smooth surface is obtained even though the feed is coarse. The amount of feed per revolution of the work, however, should always be less than the width *w* of the cutting edge. Very often broad tools cannot be used for finishing cuts, especially when turning steel, because their greater contact causes chattering and results in a rough surface. An old and worn lathe is more liable to chatter than one that is heavy and well-built, and as the diameter of the work also makes a difference, a broad tool cannot always be used for finishing, even though, theoretically, it would be preferable. After

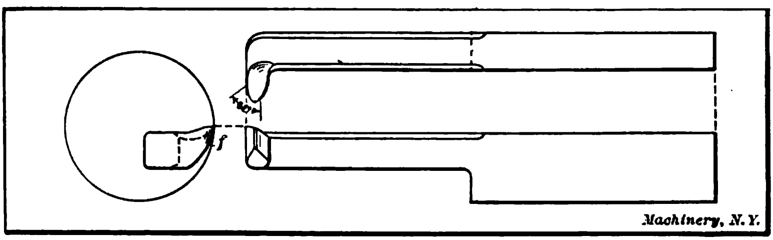


Fig. 30. Boring Tool

one side of the disk is finished, it is reversed in the chuck, the finished surface being placed against the jaws. The remaining rough side is then turned, care being taken when starting the first cut to caliper the width of the disk at several points to make sure that the two sides are parallel.

Example of Boring-Tool Used

Another example of chuck work is shown at *B*, Fig. 28. In this case a cast-iron pulley is to have a true hole *h* bored through the hub. (The finishing of internal cylindrical surfaces in a lathe is referred to as boring rather than turning). The casting should be set true by the rim instead of by the rough-cored hole in the hub; this can be done by the use of chalk as previously explained. Even though a universal type of chuck were used, the jaws of which, as will be recalled, are self-centering, it might be necessary to turn the pulley relative to the chuck as a casting sometimos runs out because of

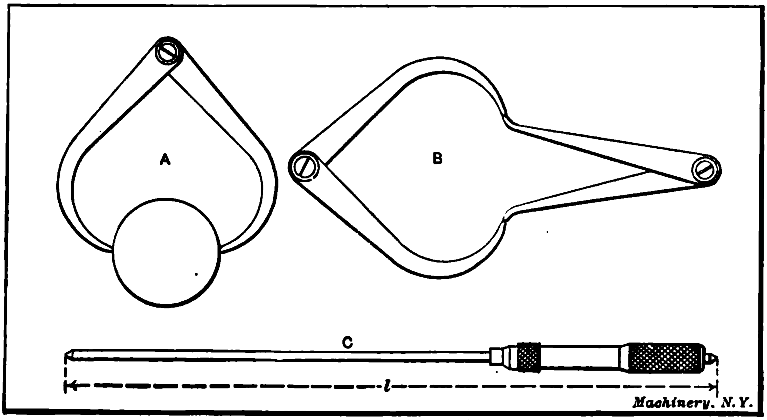


Fig. 31. Setting Outside Calipers—Transferring Measurement to Inside Calipers—Micrometer Gage

rough spots or lumps which happen to come beneath one or more of the jaws. The shape of tool *t* for boring is quite different from one used for outside turning, as shown by Fig. 30., The cutting end is forged approximately at right angles to the body or shank, and the

Fig. 32. Standard Plug Gage

top surface is ground to slope away from the working part *w* of the cutting edge, as with practically all turning tools. The front part or flank *f* is also ground away to give the edge clearance. This type of tool is clamped in the toolpost with the body about parallel with the lathe spindle, and ordinarily the cutting edge would be about as high as the center of the hole, or a little below if anything. When starting a cut, the tool is brought up to the work by moving the carriage and it is then adjusted radially to get the right depth of cut.

The power feed for the carriage is then used, the tool feeding back through the hole as indicated by the arrow, Fig. 28. In this case, as with all turning operations, the first cut should be deep enough to cut beneath the hard outer scale at every part of the hole. Usually a rough-cored hole is so much smaller than the finished size that several cuts are necessary; in any case the last or finishing cut should be

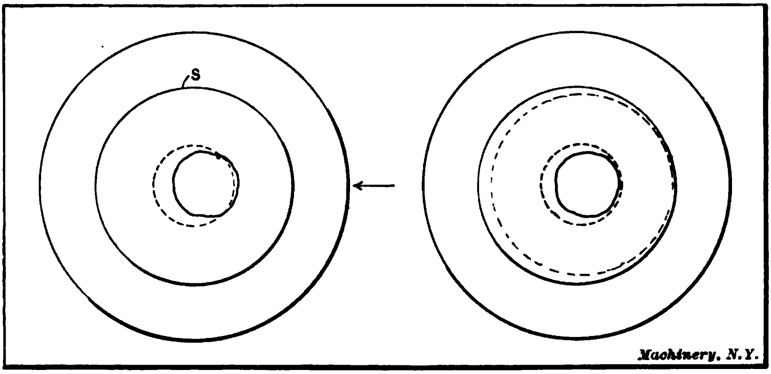


Fig. 33. Setting Work with reference to Surfaces to be Turned

very light to prevent the tool from springing away from the work, so that the hole will be as true as possible. Boring tools, particularly for small holes, are not as rigid as those used for outside turning, as the tool has to be small enough to enter the hole and for this reason comparatively light cuts have to be taken. When boring a

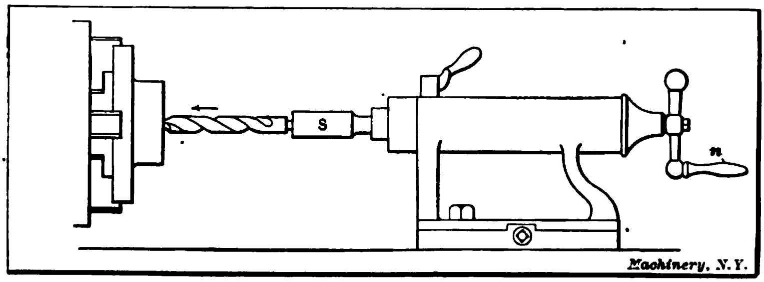


Fig. 34. Drilling in the Lathe

small hole, the largest tool that will enter it without interference should be used to get the greatest rigidity possible.

Measuring Bored Holes

The diameters of small holes that are being bored are usually measured with inside calipers or standard gages. If the pulley were being bored to fit over some shaft, the diameter of the shaft would first be measured by using outside calipers as shown at *A*, Fig. 31, the measuring points of the calipers being adjusted until they just made contact with the shaft when passed over it. The inside calipers are then set as at *B* to correspond with the size of the shaft, and the hole is bored just large enough to admit the inside calipers easily. Very accurate measurements can be made with calipers, but to become expert in their use requires experience. Some mechanics never become proficient in the art of calipering because their hands are "heavy" and they lack the sensitiveness and delicacy of touch that is necessary. For large holes, a gage C is often used, the length l being adjusted to the diameter desired. Small holes are often bored to fit hardened steel plug gages (Fig. 32), the cylindrical measuring ends of which are made with great accuracy to standard sizes. This type of gage is particularly useful when a number of holes have to be bored to the same size, all holes being made just large enough to fit the gage without any perceptible play.

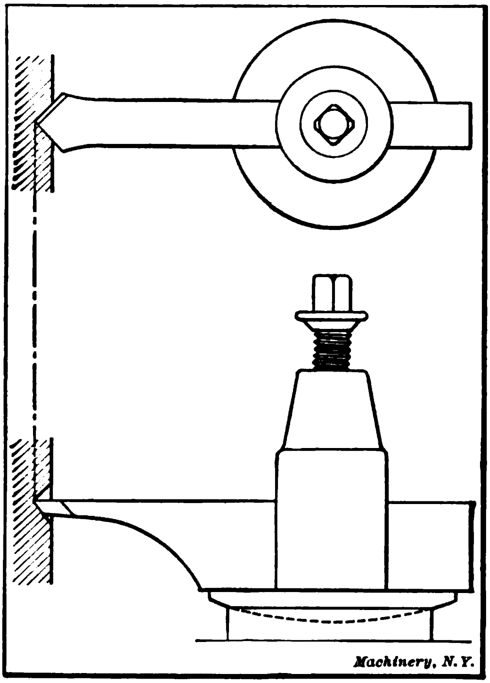


Fig. 35. Special Tool which Forms a Center for Starting the Drill

Setting Work in the Chuck

When setting a part in a chuck, care should be taken to so locate it that every surface to be turned will be true when machined to the finished size. As a simple illustration, let us assume that the hole through the cast-iron disk, Fig. 33, has been cored considerably out of center as shown. If the work is set by the outside surface S, as it would be ordinarily, the hole is so much out of center that it will not be true when bored to the finished size, as indicated by the dotted lines. On the other hand, if the rough hole is set true, the outside cannot be finished all over, without making the diameter too small, when it is finally turned. In such a case, the casting should be shifted, as shown by the arrow, to divide the error between the two surfaces, both of which can then be turned as shown by the dotted lines in the view to the right. This principle of dividing the error when setting work can often be applied in connection with turning and boring. Hence, after a casting or other part has been set true by the most important surface, all other surfaces which require machining should then be tested to make sure that they all can be finished to the proper size.

Drilling and Reaming

When a hole is to be bored from the solid, it is necessary to drill a hole before a boring tool can be used. One method of drilling in the lathe is to insert an ordinary twist drill in a holder or socket *S*, Fig. 34, fitted in the tailstock spindle in place of the center. The drill is then fed through the work by turning the handle *n* and feeding the spindle outward as shown by the arrow. Before beginning to drill, it is well to turn a conical spot or center for the drill point by using a special tool, Fig. 35, having a point like a flat drill. This tool is clamped in the toolpost with the point at the same height as the lathe centers. It is then moved to the center of the work and a conical center is turned as shown by the sectional view. If the drill were not given this true starting point, it probably would enter the work more or less off center. Drills can also be started without

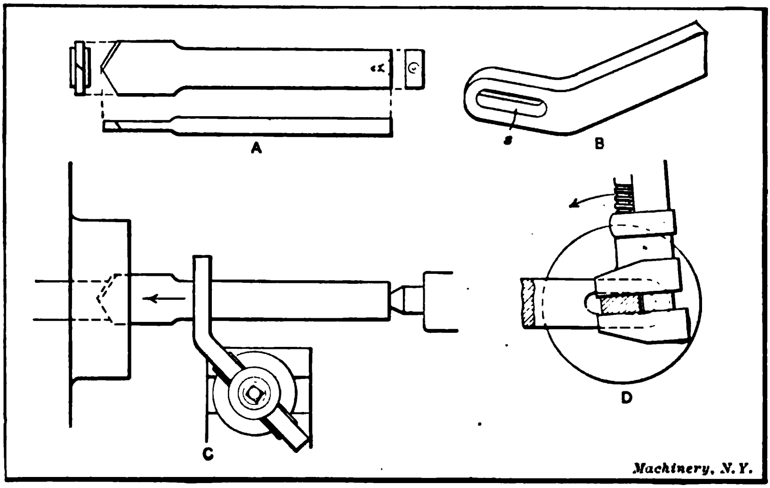


Fig. 36. Flat Drill and Holder

turning a center by bringing the square end or butt of a tool-shank held in the toolpost, in contact with the drill near the cutting end. If the point starts off center, thus causing the drill to wobble, the stationary tool-shank will gradually force or bump it over to the center.

Small holes are often finished in the lathe by drilling and reaming without the use of a boring tool. The form of drill that is used quite extensively for drilling cored holes in castings is shown in Fig. 36 at *A*. This drill is flat and the right end has a large center hole for receiving the center of the tailstock. To prevent the drill from turning, a holder *B*, having a slot *s* in its end through which the drill passes, is clamped in the toolpost, as at *C*. This slot should be set central with the lathe centers, and the drill, when being started, should be held tightly in the slot by turning or twisting it with a wrench as indicated in the end view at *D;* this steadies the drill and causes it to start fairly true even though the cored hole runs out considerably.

Another style of tool for enlarging cored holes is shown in Fig. 37, at *A*. This is a rose chucking reamer, having beveled cutting edges on the end and a cylindrical body, which fits closely in the reamed hole, thus supporting and guiding the cutting end. The reamer shown at *B* is a fluted type with cutting edges that extend from *a* to *b*; it is used for finishing holes and the drill or rose reamer preceding it should leave the hole very close to the required size. These reamers are held while in use in a socket inserted in the tailstock spindle, as when using a twist drill.

Holding Work on Faceplate

Some castings or forgings are so shaped that they cannot be held in a chuck very well, or perhaps not at all, and work of this kind is often held by clamping it to the faceplate. An example of faceplate work is shown in Fig. 38. This is a rectangular cast-iron plate having a round boss or projection, the end *e* of which is to be turned parallel with the back face of the plate which was previously finished on a planer. A rough cored hole through the center of the boss also

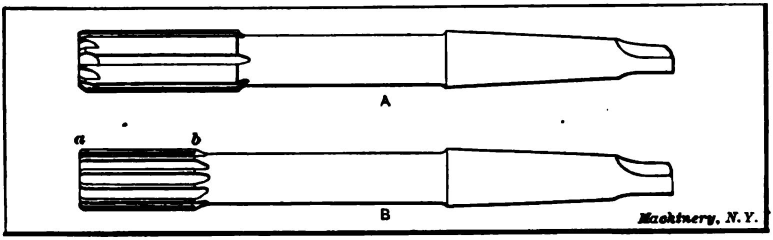


Fig. 37. Rose and Fluted Reamers

needs to be bored true. The best way to perform this operation in the lathe would be to clamp the finished surface of the casting directly against the faceplate by bolts and clamps *a*, *b*, *c*, and *d*, as shown; the work would then be turned just as though it were held in a chuck. By holding the casting in this way, face *e* will be finished parallel with the back surface because the latter is clamped directly against the true-running surface of the faceplate. If a casting of this shape were small enough it could also be held in the jaws of an independent chuck, but if the surface *e* needs to be exactly parallel with the back face, it is better to clamp the work to the faceplate. Most lathes have two faceplates: One of small diameter used principally for driving work turned between centers, and a large one for holding heavy or irregularly shaped pieces; either of these can be screwed on the spindle and the large faceplate has a number of slots through which clamping bolts can be inserted.

The proper way to clamp a piece to the faceplate depends, of course, largely on its shape and the location of the surface to be machined, but in any case it is necessary to hold it securely to prevent any shifting after a cut is started. Sometimes castings can be held by inserting bolts through previously drilled holes, but when clamps are used in connection with the bolts, their outer ends are supported by hard wood or metal blocks which should be just high enough to make the clamp bear evenly on the work. When deep roughing cuts have to be taken, especially on large diameters, it is well to bolt a piece to the faceplate and against one side of the casting, as at *D*, to act as a driver and prevent the work from shifting; but a driver would not be needed in this particular case. Of course a faceplate driver is always placed to the rear, as determined by the direction of rotation, because the work tends to shift backward when a cut is being taken. If the surface which is clamped against the faceplate is finished as in this case, the work will be less likely to shift if a piece of paper is placed between it and the faceplate. Work mounted on the faceplate is generally set true by some surface before turning. As the hole in this casting should be true with the round boss, the casting is shifted on the faceplate until the rough outer surface of the boss runs true;

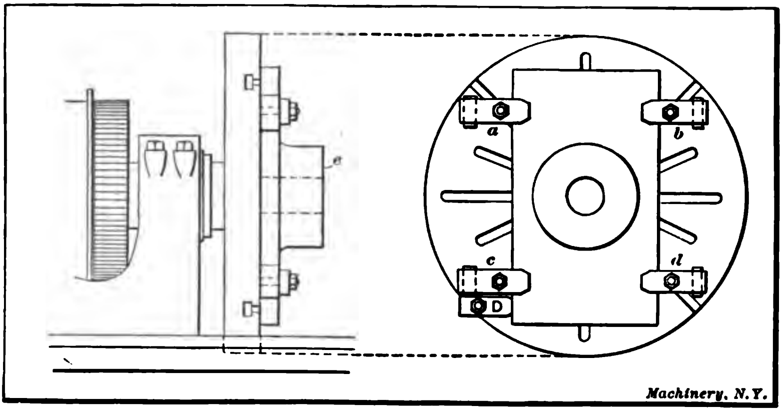


Fig. 38. Casting Clamped to Faceplate for Turning

the clamps which were previously set up lightly are then tightened. The face *e* is first turned by using a round-nosed tool. This tool is then replaced by a boring tool and the hole is finished to the required diameter. If the hole being bored is larger than the central hole in the faceplate, the casting should be clamped against parallel pieces, and not directly against the faceplate, to provide clearance for the tool when it reaches the inner end of the hole and prevent cutting the faceplate. The parallel pieces should be of the same thickness and be located near the clamps to prevent springing the casting.

Application of Angle-plate to Faceplate

Another example of faceplate work is shown in Fig. 39. This is a cast-iron elbow *E*, the two flanges of which are to be faced true and square with each other. The shape of this casting is such that it would be very difficult to clamp it directly to the faceplate, but it is easily held on an angle-plate *P*, which is bolted to the faceplate. The two surfaces of this angle-plate are square with each other so that when one flange of the elbow is finished and bolted against the angle-plate, the other will be faced square. When setting up an angle-plate for work of this kind, the distance from its work-holding side to the center of the faceplate is made equal to the distance *d* between the center of one flange and the face of the other, so that the flange to be faced will run about true when bolted in place. As the angle-plate and work are almost entirely on one side of the faceplate, a weight *W* is attached to the opposite side for counterbalancing. Very often weights are also needed to counterbalance offset parts that are

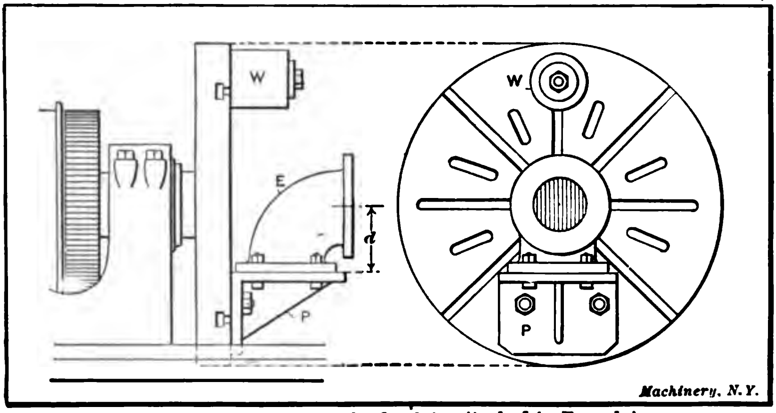


Fig. 39. Work Held on Angle-plate attached to Faceplate

bolted directly to the faceplate. Sometimes it is rather difficult to hold heavy pieces against the vertical surface of the faceplate while applying the clamps, and occasionally the faceplate is removed and placed in a horizontal position on the bench; the work can then be located about right, and after it is clamped, the faceplate is placed on the lathe spindle by the assistance of a crane.

Special faceplate jaws such as the one shown to the right in Fig. 27, can often be used to advantage for holding work on large faceplates. Three or four of these jaws are bolted to the faceplate which is converted into a kind of independent chuck. These faceplate jaws are especially useful for holding irregularly shaped parts as the different jaws can be located in any position.

CHAPTER VI

LATHE TURNING TOOLS

Notwithstanding the fact that a great variety of work can be done in the lathe, the number of turning tools required is comparatively small. Fig. 41 shows the forms of tools that are used principally, and typical examples of the application of these various tools are indicated in Fig. 42. The reference letters used in these two illustrations correspond for tools of the same type, and both views should be referred to in connection with the following description.

The tool shown at *A* is the form generally used for rough turning, that is for taking deep cuts when considerable metal has to be removed. At *B* a tool of the same type is shown, having a bent end which enables it to be used close up to a shoulder or surface *s* that might come in contact with the tool-rest if the straight form were employed. Tool *C*, which has a straight cutting end, is used on certain classes of work for taking light finishing cuts, with a coarse feed. As explained in Chapter V, this type of tool will leave a smooth finish even though

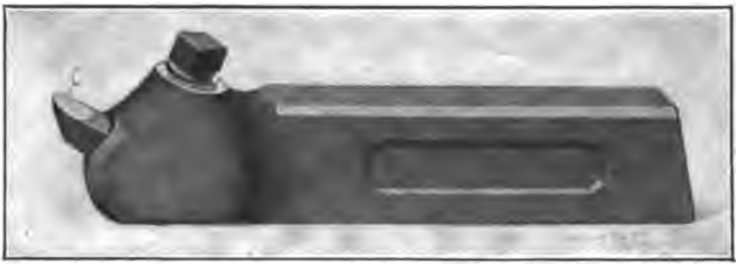


Fig. 40. Turning Tool with Inserted Cutter

the feed is coarse, provided the flat cutting edge is set parallel with the tool's travel so as to avoid ridges. Broad-nosed tools and wide feeds are better adapted for finishing cast iron than steel. When turning steel, if the work is at all flexible, a broad tool tends to gouge into it and for this reason round-nosed tools and finer feeds are generally necessary. A little experience in turning will teach more on this point than a whole chapter on the subject.

The side tools shown at *D* and *E* are for facing the ends of shafts, collars, etc. The first tool is known as a right-side tool because it operates on the right end or side of a shaft or collar, whereas the left-side tool *E* is used on the opposite side, as shown in Fig. 42. Side tools are also bent to the right or left because the cutting edge of a straight tool cannot always be located properly for facing certain surfaces. A bent right-side tool is shown at *F*. A form of tool that is frequently used is shown at *G;* this is known as a parting tool and is used for severing pieces and for cutting grooves, squaring corners, etc. The same type of tool having a bent end is shown at *H* (Fig.

42) severing a piece held in the chuck. Work that is held between centers should not be entirely severed with a parting tool unless a steady-rest is placed between the tool and faceplate, as otherwise the tool may be broken by the springing of the work just before the piece is cut in two. It should be noted that the sides of this tool slope inward

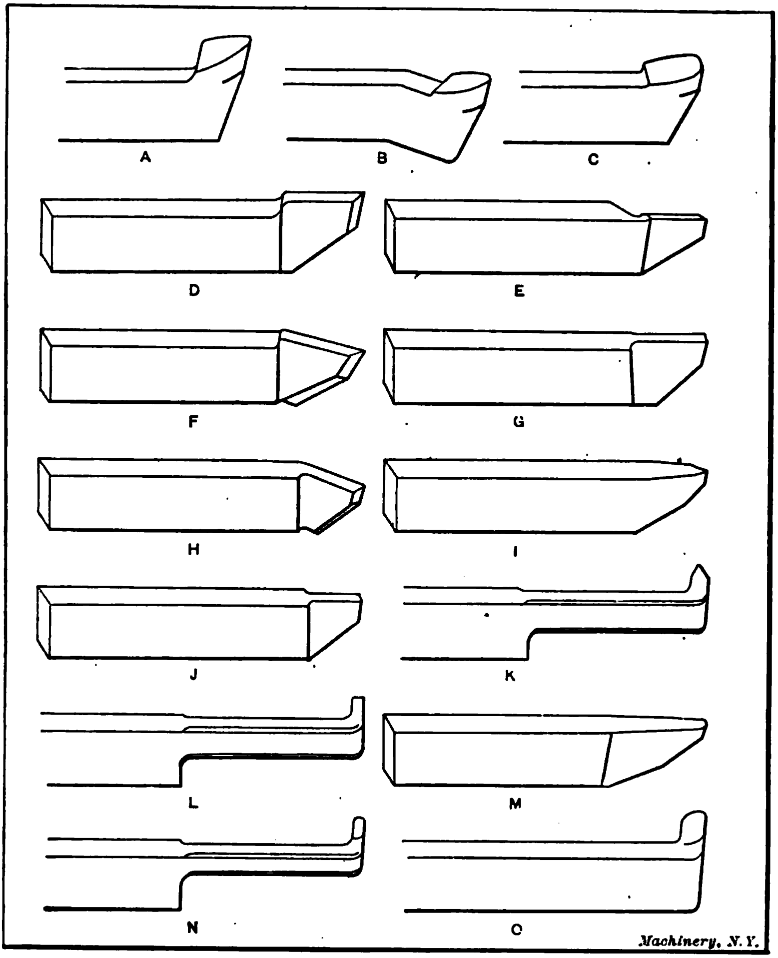


Fig. 41. Set of Lathe Turning Tools for General Work

back of the cutting edge to provide clearance when cutting in a narrow groove.

At *I* a thread tool is shown for cutting a U. S. standard thread. This thread is the form most commonly used in this country at the present time. A tool for cutting a square thread is shown at *J*. This is shaped very much like a parting tool except that the cutting

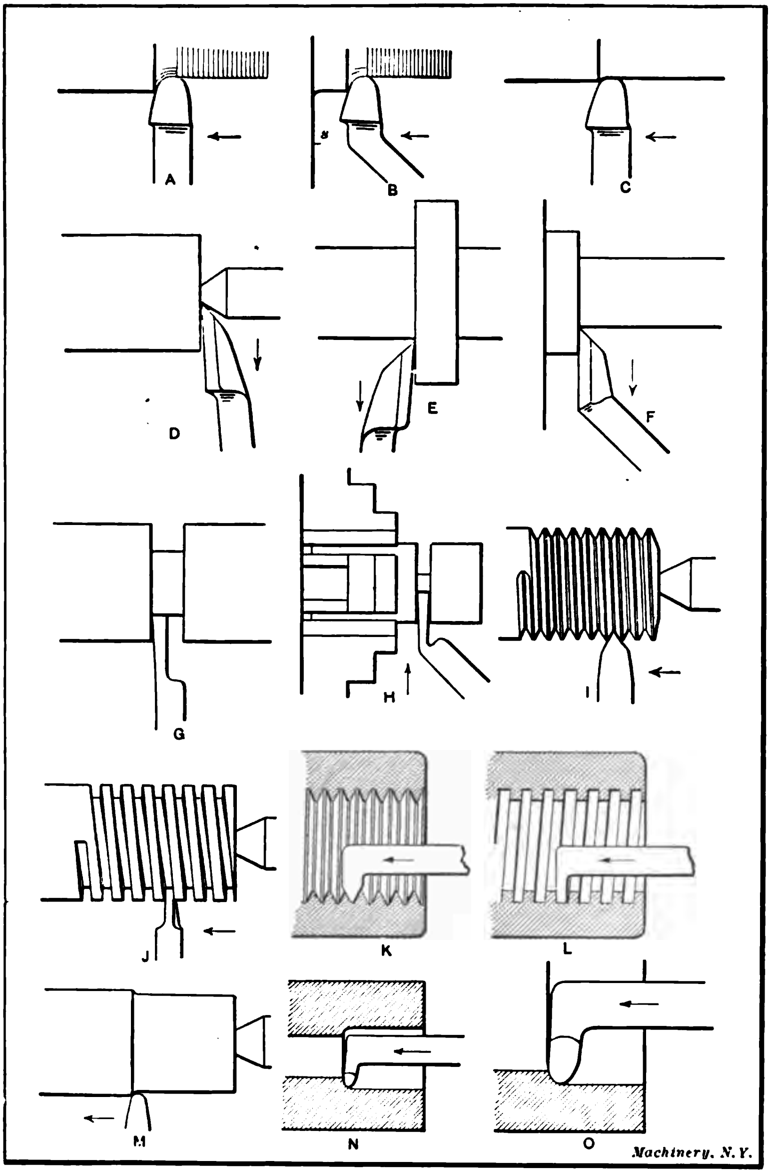


Fig. 42. Views illustrating Use of Various Types of Lathe Tools

end is inclined slightly to correspond with the helix angle of the thread, as explained in Chapter IV, of MACHINERY'S Reference Book, No. 92, which contains descriptions of different thread forms and methods of cutting them. Internal thread tools are shown at *K* and *L* for cutting U. S. standard and square threads in holes. It will be seen that these tools are somewhat like boring tools excepting the ends which are shaped to correspond with the thread which they are intended to cut.

A tool for turning brass is shown at *M*. Brass tools intended for general work are drawn out quite thin and they are given a narrow rounded point. The top of the brass tool is usually ground flat or without slope as otherwise it tends to gouge into the work, especially

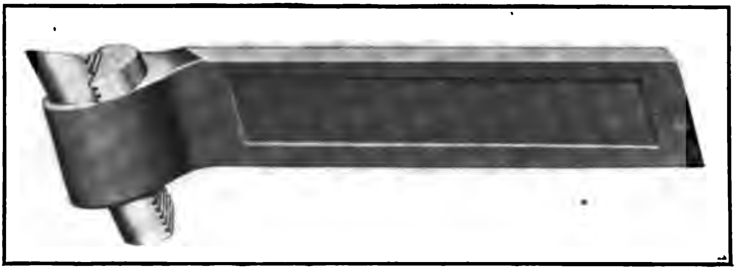


Fig. 43. Heavy Inserted-cutter Turning Tool

if the latter is at all flexible. The end of a brass tool is sometimes ground flat for turning large rigid work, such as brass pump linings, etc., so that a coarse feed can be used without leaving a rough surface. The tools at *N* and *O* are for boring or finishing drilled or cored holes. Two sizes are shown, which are intended for small and large holes, respectively.

The different tools referred to in the foregoing might be called the standard types because they are the ones generally used, and as Fig.

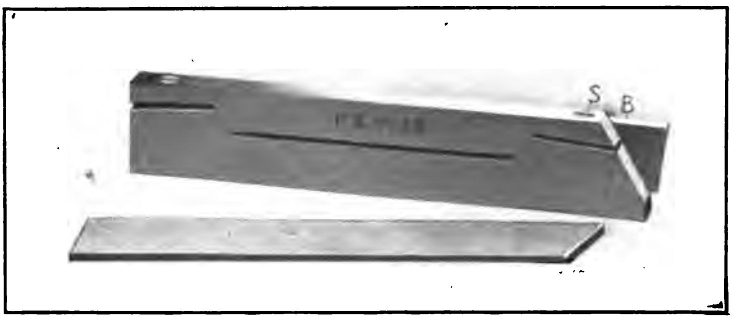


Fig. 44. Parting Tool with Inserted Blade

42 indicates, they make it possible to turn an almost endless variety of forms. Occasionally some special form of tool is needed for doing odd jobs, having, perhaps, an end bent differently or a cutting edge shaped to some particular form. Tools of the latter type, which are known as "form tools," are sometimes used for finishing surfaces that are either convex, concave, or irregular in shape. The cutting edges of these tools are carefully filed or ground to the required shape, and

the form given the tool is reproduced in the part turned. Ornamental or other irregular surfaces can be finished very neatly by the use of such tools. It is very difficult, of course, to turn convex or concave surfaces with a regular tool; in fact, it would not be possible to form a true spherical surface, for instance, without special equipment, because the tool could not be moved along a true curve by simply using the longitudinal and cross feeds. Form tools should be sharpened by

Fig. 45. Boring Tool with Inserted Cutter and Adjustable Bar

grinding entirely on the top surface, as any grinding on the end or flank would alter the shape of the tool.

Tool-holders with Inserted Cutters

All of the tools shown in Fig. 41 are forged from the bar, and when the cutting ends have been ground down considerably it is necessary to forge a new end. To eliminate the expense of this continual dressing of tools and also to effect a great reduction in the amount of tool

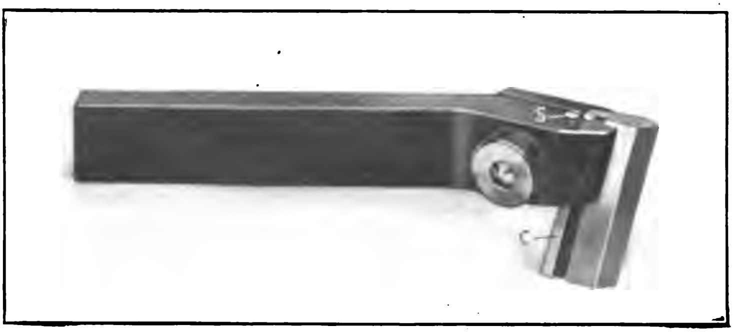


Fig. 46. Threading Tool

steel required, tool-holders having small inserted cutters are used in many shops.

A tool-holder of this type for outside turning is shown in Fig. 40. The cutter *C* is held in a fixed position by the set-screw shown, and it is sharpened, principally, by grinding the end, except when it is desired to give the top of the cutter a different slope from that due to its angular position. Another inserted-cutter turning tool is shown in Fig. 43, which is a heavy type intended for roughing. The cutter in this case, has teeth on the rear side engaging with corresponding teeth cut in the clamping block which is tightened by a set-screw on the side opposite that shown. With this arrangement, the cutter can be adjusted upward as the top is ground away.

A parting tool of the inserted blade type is shown in Fig. 44. The blade *B* is clamped by screw *S* and also by the spring of the holder when the latter is clamped in the tool-post. The blade can, of course, be moved outward when necessary. Fig. 45 shows a boring tool consisting of a holder *H*, a bar *B* that can be clamped in any position, and an inserted cutter *c*. With this type of boring tool, the bar can be extended beyond the holder just far enough to reach through the hole to be bored, which makes the tool very rigid. A thread tool of the holder type is shown in Fig. 46. The angular edge of the cutter *C* is accurately ground by the manufacturers, so that the tool is sharpened by simply grinding it flat on the top. As the top is ground away, the cutter is raised by turning screw *S* which can also be used for setting the tool to the proper height.

CHAPTER VII

STEADY- AND FOLLOW-RESTS

Occasionally long slender shafts, rods, etc., which have to be turned, are so flexible that it is necessary to support them at some point between the lathe centers. An attachment for the lathe known as a steadyrest is often used for this purpose. A steadyrest is composed of a frame containing three jaws *J* (Fig. 47), that can be adjusted in or out radially by turning screws *S*. The frame is hinged at *h*, thus allowing the upper half to be swung back (as shown by the dotted lines) for inserting or removing the work. The bolt-clamp *c* holds the hinged part in the closed position. The base of the frame has

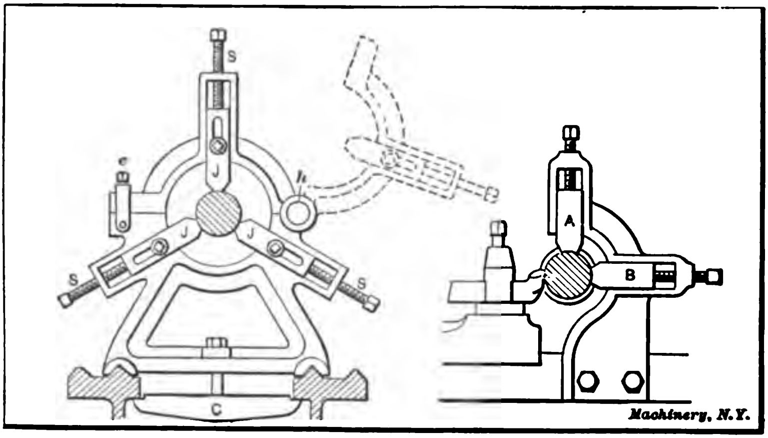


Fig. 47. Steady- and Follow-rests for Supporting Flexible Parts while Turning

V-grooves in it that fit the ways of the lathe bed. When the steadyrest is in use, it is secured to the bed by clamp *C*, and the jaws *J* are set in against the work, thus supporting or steadying it during the turning operation. The steadyrest must, of course, be located at a point where it will not interfere with the turning tool.

Supporting Flexible Work with a Steadyrest

Fig. 48 shows the application of the steadyrest to a long forged rod, having one small end, which makes it too flexible to be turned without support. As this forging is rough, a true surface *n* a little wider than the jaws *J* (Fig. 47) is first turned as a bearing for the jaws. This should be done very carefully to prevent the work from mounting the tool. A sharp pointed tool should be used and very light cuts taken. The steadyrest is next clamped to the lathe bed opposite the turned surface, and the jaws are adjusted in against the work, thus forming a kind of bearing. Care should be taken not to set up the jaws too tight as the work should turn freely but without play. The large part of the rod and central collar are then turned to size, this half being machined while the small part is in the rough and as stiff as possible. The rod is then reversed and the steady-rest is applied to the part just finished, as shown at *B*, thus supporting

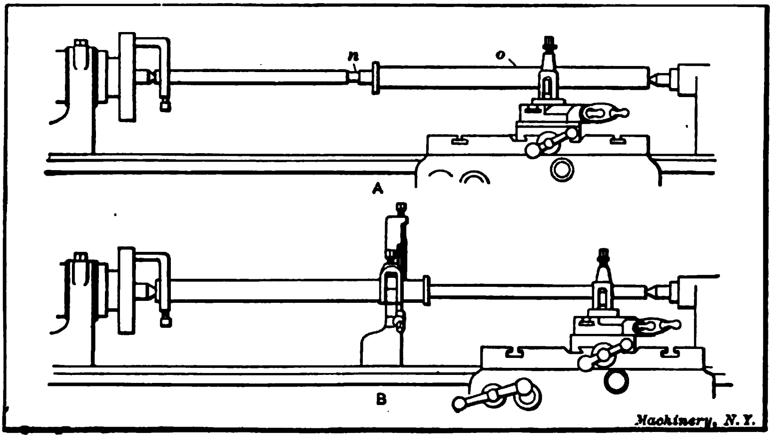


Fig. 48. Application of Steadyrest

the work while the small end is being turned. That part against which the jaws bear should be kept well oiled and if the surface is finished, it should be protected by placing a strip of emery cloth beneath the jaws with the emery side out; a strip of belt leather is also used for this purpose, the object in each case being to prevent the jaws from scratching and marring the finished surface, as they tend to do, especially if at all rough.

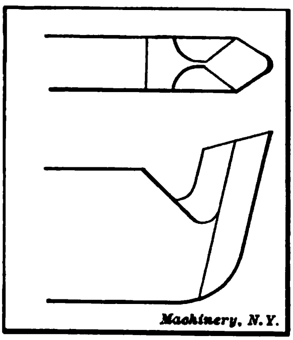


Fig. 49. Diamond-point Turning Tool

If the work were too flexible to permit turning a spot at *n*, this could be done by first "spotting" it at some point *o*, and placing the steady-rest at that point while turning another spot at *n*. The tool shown in Fig. 49 is a good form to use for work of this kind because of its narrow point. This is known as a "diamond point," and is frequently used for light turning. The shape of this tool is clearly shown in the illustration. The V-shaped cutting edge is usually rounded slightly at the point, and the top slopes backward from the cutting edge, as shown.

Sometimes it is desirable to apply a steady-rest to a surface that does not run true and one which is not to be turned; in such a case a device called a "cat-head" is used. This is simply a sleeve *S* (Fig. 51) which is placed over the untrue surface to serve as a bearing for the steadyrest. The sleeve is made to run true by adjusting the four set-screws at each end, and the jaws of the steadyrest are set against it, thus supporting the work.

Application of Steadyrest when Boring—Use of "Bridles" or "Hold-backs"

Another example illustrating the use of the steadyrest is shown in Fig. 50. The rod *R* is turned on the outside and a hole is to be bored in the end (as shown by dotted lines) true with the outer surface. If the centers used for turning the rod are still in the ends, as they would be ordinarily, this work could be done very accurately by the following method: The rod is first placed between the centers as for turning, with a driving dog *D* attached, and the steady-rest jaws *J* are set against it near the outer end, as shown.

Before any machine work is done, means must be provided for holding

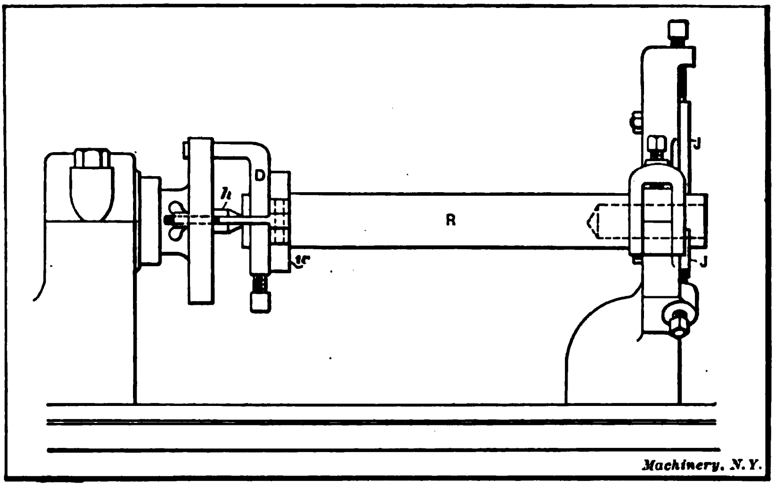


Fig. 50. Shaft supported by Steadyrest for Drilling and Boring End

the rod back against the headstock center *h*, because, for an operation of this kind, the outer end cannot be supported by the tailstock center; consequently the work tends to shift to the right. One method of accomplishing this is shown in the illustration. A hard-wood piece *w*, having a hole somewhat larger than the work, is clamped against the dog, in a crosswise position, by the swinging bolts and thumb-screws shown. If the dog is not square with the work, the wood piece should be canted so that the bearing will not be all on one side. For large heavy parts a similar "bridle" or "hold-back"—as this is commonly called—is made by using steel instead of wood for the part *w*. Another very common method which requires no special equipment is illustrated in Fig. 52. Ordinary leather belt lacing *L* is attached to the work and faceplate while the latter is screwed off a few turns as shown. Then the lacing is drawn up by hand and tied, and the faceplate is screwed on the spindle, thus tightening the lacing and drawing the work against the headstock center. The method of applying the lacing is quite clearly indicated in the illustration. If a small driving faceplate is used, it may be necessary to drill holes for the belt lacing, as shown.

A hole is next drilled in the end of the rod by using a twist drill and the tailstock, as explained in connection with Fig. 34, Chapter V. If the hole is finished by boring, a depth mark should be made on the

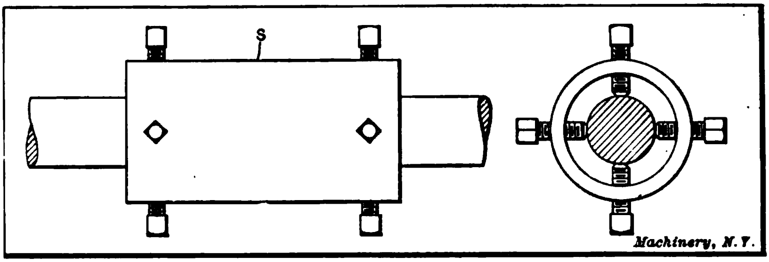


Fig. 51. Cat-head which is sometimes used as Bearing for Steadyrest

tool shank that will warn the workman of the cutting end's approach to the bottom. A chuck can also be used in connection with a steady-rest for doing work of this kind as shown in Fig. 53, the end of the rod being held and driven by the chuck *C*. If the work is centered, it can be held on these centers while setting the steadyrest and adjusting the chuck, but if the ends are without centers, a very good way is to make light centers in the ends with a punch; after these are properly

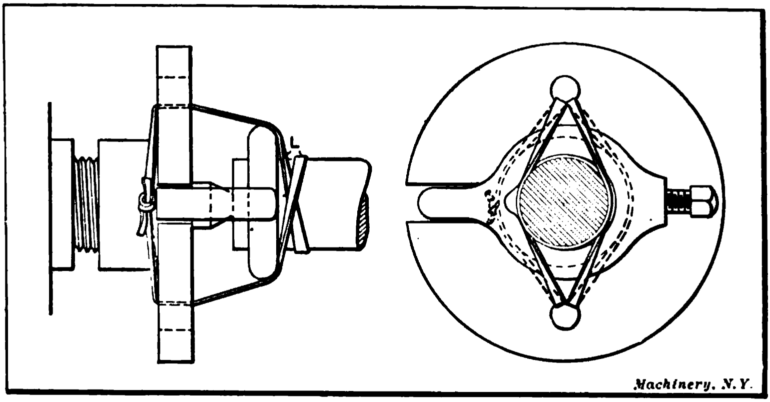


Fig. 52. Hold-back used when Outer End of Work is held in Steadyrest

located they are used for holding the work until the steadyrest and chuck jaws have been adjusted. In case it is necessary to have the end hole very accurate with the outside of the finished rod, a test indicator *I* should be applied to the shaft as shown. This is an instrument which shows with great accuracy whether a rotating part runs true and it is also used for many other purposes in machine shops. The indicator is held in the lathe toolpost and the contact point beneath the dial is brought against the work. If the latter does not run true, the hand of the indicator vibrates and the graduations on the dial show how much the work is out in thousandths of an inch.

The Follow-rest

For certain classes of long slender work, such as shafts, etc., a follow-rest is often used for supporting the work while turning. The follow-rest differs from the steadyrest in that it is attached to and travels with the lathe carriage. The type illustrated to the right in

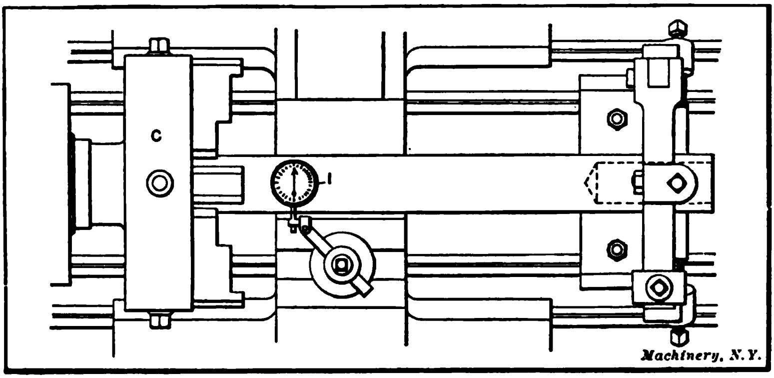


Fig. 53. Testing Work with Dial Indicator

Fig 47 has two adjustable jaws which are located nearly opposite the turning tool, thus providing support where it is most needed. In using this rest, a cut is started at the end and the jaws are adjusted to this turned part. The tool is then fed across the shaft, which cannot spring away from the cut because of the supporting jaws. Some follow-rests have, instead of jaws, a bushing bored to fit the diameter being turned, different bushings being used for different diameters. The bushing forms a bearing for the work and holds it rigidly. Whether a bushing or jaws are used, the tool is slightly in advance of the supporting member.

CHAPTER VIII

HOW TO CUT A THREAD IN A LATHE

When threads are cut in the lathe a tool *t* is used (see Fig. 55), having a point corresponding to the shape of the thread, and the carriage is moved along the bed a certain distance for each revolution of the work (the distance depending on the number of threads to the inch being cut) by the lead-screw *S* which is rotated by gears *a*, *b* and *c*, which receive their motion from the spindle. As the rate of the carriage travel per revolution of the work, and, consequently, the number of threads per inch that is cut, depends on the size of the gears *a* and *c* (called change gears) the latter have to be changed for cutting different threads. The proper change gears to use for cutting a given number of threads to the inch, is ordinarily determined

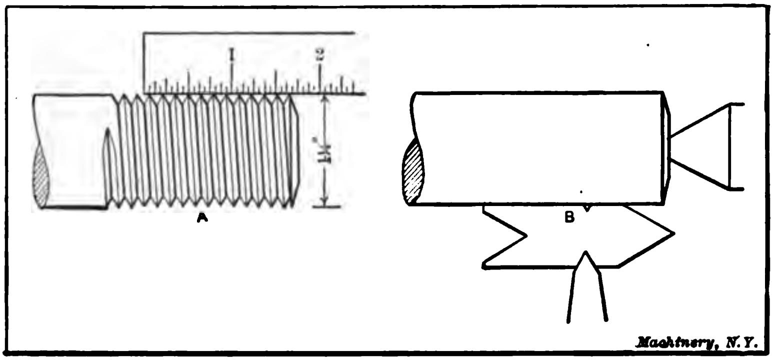
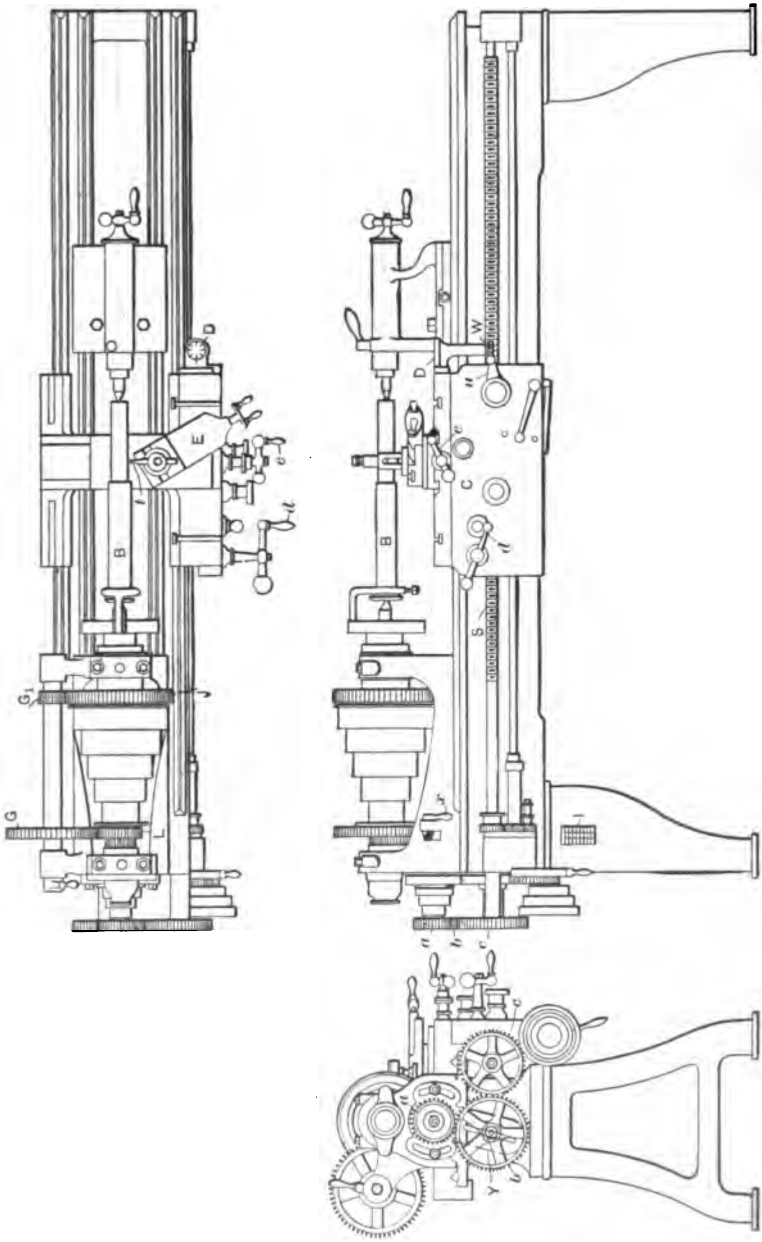


Fig. 54. Measuring Number of Threads per Inch—Setting Thread Tool

by referring to a table or "index plate" *I* which shows what the size of gears *a* and *c* should be, or the number of teeth each should have, for cutting any given number of threads per inch.

Selecting the Change Gears

Suppose a V-thread is to be cut on the end of the bolt *B*, having a diameter of 1¼ inch and seven threads per inch of length, as shown at *A* in Fig. 54, which is a standard number for that diameter. First the change gears to use are found on plate *I* which is shown enlarged in Fig. 56. This plate has three columns: The first contains different numbers of threads to the inch, the second the size gear to place on the "spindle" or "stud" at *a* for different threads, and the third the size of gear *c* for the lead-screw. As the thread selected as an example has seven threads per inch, gear *a* should have 48 teeth, this being the number given in the second column opposite figure 7 in the first. By referring to the last column, we find that the lead-screw gear should



Machinery, N.Y.

Fig. 55. Plan and Elevations of Engine Lathe

have 84 teeth. These gears are selected from an assortment provided with the lathe and they are placed on the spindle and lead-screw, respectively. Intermediate gear *b* does not need to be changed as it is simply an "idler" for connecting gears *a* and *c*. Gear *b* is mounted on a swinging yoke *Y* so that it can be adjusted to mesh properly with different gear combinations; after this adjustment is made, the lathe is geared for cutting seven threads to the inch. (The change gears of many modern lathes are so arranged that different combinations are obtained by simply shifting a lever. A lathe having this quick-change gear mechanism is described in Chapter VI of MACHINERY's Reference Book No. 92.) The work *B* is then placed between the centers just as it would be for turning, with the end to be threaded turned to a diameter of 1¼ inch, which is the outside diameter of the the thread.

16" LATHE

THREAD	SPINDLE	SCREW
2	96	48
3	96	72
4	48	48
5	48	60
6	48	72
7	48	84
8	48	96
9	48	108
10	24	60
11	24	66
11½	24	69
12	24	72
13	24	78
14	24	84
16	24	96
18	24	108
20	24	120

Machinery, N.Y.

Fig. 56. Index Plate showing Gear Changes for Threading

The Thread Tool

The form of tool used for cutting a V-thread is shown at *A*, Fig. 57. The end is ground V-shaped and to an angle of 60 degrees, which corresponds to the angle of a standard V-thread. The front or flank *f* of the tool is ground back to an angle to provide clearance, but the top is left flat or without slope. As it is very important to grind the end to exactly 60 degrees, a gage *G* is used, having 60-degree notches to which the tool-point is fitted. The tool is clamped in the toolpost as shown in the plan view, Fig. 55, square with the work, so that both sides of the thread will be cut to the same angle with the axis of the work. A very convenient way to set a thread tool square is illustrated at *B*, Fig. 54. The thread gage is placed against the part to be threaded, as shown, and the tool is adjusted until the angular sides of the point bear evenly in the 60-degree notch of the gage. The top of the tool point should also be at the same height as the lathe centers, as otherwise the angle of the thread will not be correct.

Cutting the Thread

The lathe is now ready for cutting the thread. This is done by taking several cuts, as indicated at *A*, *B*, *C* and *D* in Fig. 58, the tool being fed in a little farther for each successive cut until the thread is finished. When these cuts are being taken, the carriage is moved along the bed ,as previously explained, by the lead-screw *S*, Fig. 55. The carriage is engaged with the lead-screw by turning lever *u* which causes the halves of a split nut to close around the screw. The way a lathe is handled when cutting a thread is as follows: After the lathe is started, the carriage is moved until the tool-point is slightly beyond the right end of the work, and the tool is fed in far enough to take the first cut. The carriage is then engaged with the lead-screw, by operating lever *u*, and the tool moves to the left (in this case 1/7 inch for each revolution of the work) and cuts

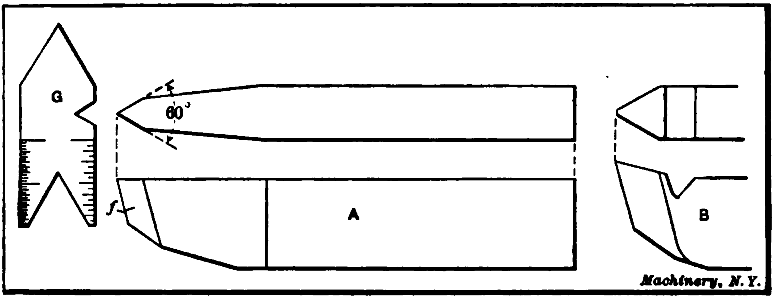


Fig. 57. Thread Tools and Gage for Testing Angle of End

a winding groove as at *A*, Fig. 58. When the tool has moved as far as the thread is wanted, it is withdrawn by a quick turn of handle *e*, and the carriage returned to the starting point for another cut. The tool is then fed in a little farther and a second cut is taken as at *B*, and this operation is repeated as at *C* and *D* until a "full" thread is cut or until the top of the thread is sharp. The thread is then tested for size, but before referring to this part of the work, the way the carriage is returned to the starting point after each cut, should be explained.

When the tool is withdrawn at the end of the first cut, if the carriage is disengaged from the lead-screw and returned by hand, the tool may or may not follow the first cut when the carriage is again engaged with the lead-screw. If the number of threads to the inch being cut is a multiple of the number on the lead-screw *S*, then the carriage can be returned by hand and engaged with the lead-screw at random and the tool will follow the first cut. For example, if the lead-screw has six threads per inch, and 6, 12, 18 or any number of threads is being cut that is a multiple of six, the carriage can be engaged at any time and the tool will always follow the original cut. This is not the case, however, when the number of threads being cut is not a multiple of the number on the lead-screw. One method of bringing the carriage back to the starting point when cutting threads which are not multiples, is to reverse the lathe (by shifting the overhead driving belts) in order to bring the tool back to the starting point without disengaging the carriage; in this way the tool is kept in the same relation to the work, and the carriage is not disengaged from the lead-screw until the thread is finished. This is a good method when cutting short threads having a length of say two or three inches; but when they are longer, and especially when the diameter is comparatively large (which means a slower speed), it is rather slow as considerable time is wasted while the tool is moving back to its starting point. This is due to the fact that the carriage is moved slowly by the lead-screw, but when disengaged, it can be traversed quickly by turning handle *d*, Fig. 55.

A method of returning the carriage by hand when the number of threads being cut is not a multiple of the number on the lead-screw is as follows: The tool is moved a little beyond the right end of the work and the carriage is engaged. The lathe is then turned forward by hand to take up any lost motion, and a line is made on the lathe bed showing the position of the carriage. The positions of the spindle and lead-screw are also marked by chalking a tooth on both

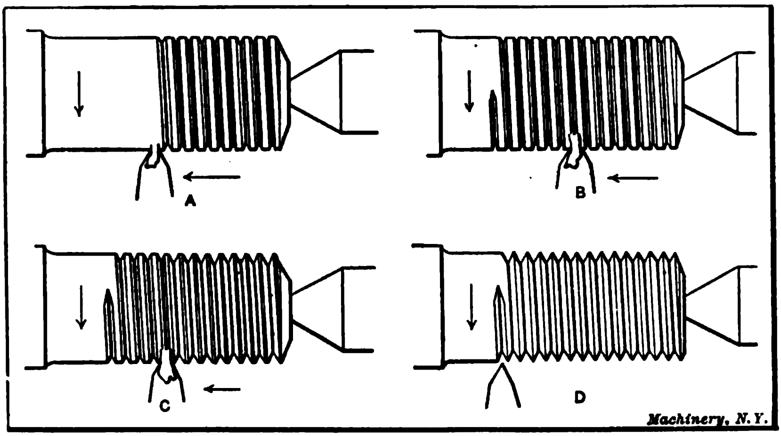


Fig. 58. Thread is formed by taking a number of Successive Cuts

the spindle and lead-screw gears, which happens to be opposite a corner or other point on the bed. After a cut is taken, the carriage is returned by hand to the original starting point as shown by the line on the bed, and is again engaged when the chalk marks show that the spindle and lead-screw are in their original position; the tool will then follow the first cut. If the body of the tailstock is moved against the bridge of the carriage before starting the first cut, the carriage can be located for each following cut by moving it back against the tailstock, and it will not be necessay to have a line on the bed.

Indicator or Chasing Dial for Catching Threads

On some lathes there is an indicator for "catching threads," as this is called in shop language. This is a simple device attached to the carriage and consists of a graduated dial *D* and a worm-wheel *W* (see Figs. 55 and 59) which meshes with the lead-screw, so that the dial is revolved by the lead-screw when the carriage is stationary, and when the carriage is moved by the screw, the dial remains stationary.

The indicator is used by engaging the carriage when one of the graduation lines is opposite the arrow mark; after a cut is taken the carriage is returned by hand and when one of the graduation lines again moves opposite the arrow, the half-nuts are thrown into mesh, as before, and this is repeated for each successive cut, thus causing the tool to always come right with the thread. If the number of threads per inch is even, engagement can be made when any line is opposite the arrow, but for odd numbers such as 3, 7, 9, 11, etc., one of the four long or numbered lines must be used. Of course, if the thread being cut is a multiple of the number on the lead-screw, engagement can be made at any time.

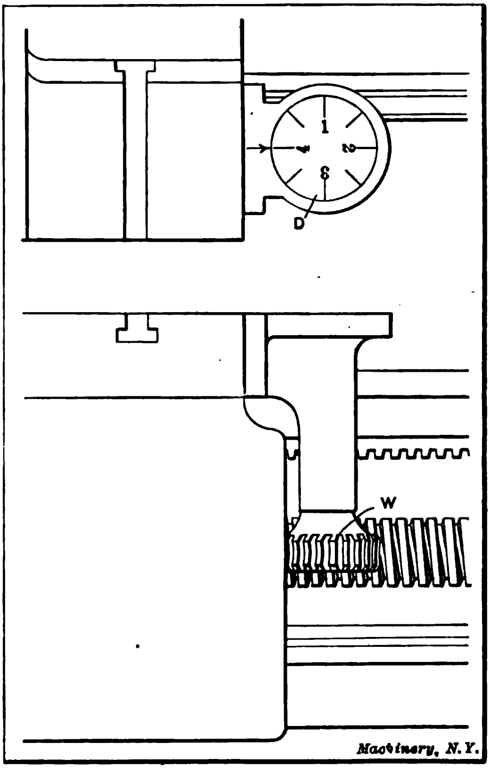


Fig. 59. Indicator used when Cutting Threads

Having considered the use of the indicator, its principle will be explained. The number of teeth in worm-wheel *W* is some multiple of the number of threads per inch of the lead-screw, and the number of teeth in the wheel, divided by the pitch of the screw, equals the number of graduations on the dial. For example, if the lead-screw has six threads per inch, the worm-wheel could have twenty-four teeth, in which case the dial would have four divisions, each representing an inch of carriage travel, and by sub-dividing the dial into eighths (as shown) each line would correspond to ½ inch of travel. The dial, therefore, would enable the carriage to be engaged with the lead-screw at points equal to a travel of one-half inch. To illustrate the advantage of this, suppose ten threads per inch are being cut and (with the lathe stationary) the carriage is disengaged and moved 1/6 inch or one thread on the lead-screw; the tool point will also have moved 1/6 inch, but it will not be opposite the next thread groove in the work as the pitch is 1/10 inch. If the carriage is moved another thread on the lead-screw, or 2/6 inch, the tool will still be out of line with the thread on the work, but when it has moved three threads, or

½ inch, the tool will then coincide with the original cut because it has passed over exactly five threads. This would be true for any number of threads per inch that is divisible by 2. If the thread being cut had nine threads per inch, or any other odd number, the tool would only coincide with the thread at points 1 inch apart. Therefore, the carriage can only be engaged when one of the four graduations representing an inch of travel is opposite the arrow, when cutting odd threads; whereas even numbers can be "caught" by using any one of the eight lines.

This indicator can also be used for "catching" fractional threads. As an illustration, suppose 11½ threads per inch are being cut, and the carriage is engaged the first time when graduation line 1 is opposite the arrow; engagement would then be made for each successive cut, when either line 1 or 3 were opposite the arrow, or in other words

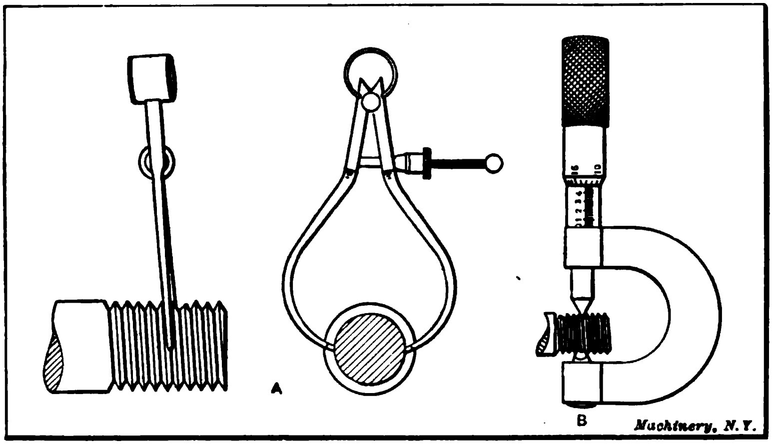


Fig. 60. Testing Diameter of Thread with Calipers and Micrometer

at spaces equal to a carriage movement of 2 inches. As the use of the indicator when cutting fractional threads is liable to result in error, it is better to keep the half-nuts in engagement and return the carriage by reversing the lathe.

Testing the Size of the Thread

When the thread tool has been fed in far enough to form a complete thread as at *D*, Fig. 58, the thread is then tested for size. If we assume that the bolt is being threaded for a standard 1¼ nut, it would be removed from the lathe and the test made by screwing a nut on the end. If the thread were too large, the nut might screw on very tightly or not at all; in either case, the work would again be placed in the lathe and a light cut taken over it to reduce the thread to the proper size. When replacing a threaded part between the centers, it should be put back in the original position, that is, with the tail of the driving dog in the same slot of the faceplate previously occupied. As it is difficult to tell just when a thread is cut to the exact size, special thread calipers having wedge-shaped ends are sometimes used for measuring the diameter of the thread at the bottom of the grooves, or the root diameter, as shown at *A*, Fig. 60. These calipers can be set from a tap corresponding to the size of the thread being cut, or from a previously threaded piece of the right size. Another form of caliper for testing threads is shown at *B*. This is one of the micrometer type and is intended for very accurate work. The spindle of this micrometer has a conical end and the "anvil" is

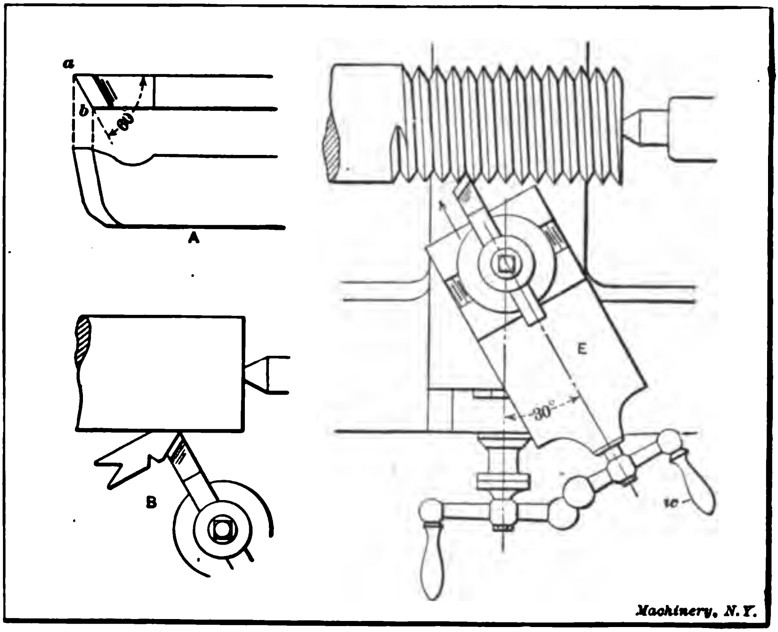


Fig. 61. Cutting Thread by using Compound Rest

V-shaped, and these ends bear on the sides of the thread or the surfaces which form the bearing when the screw is inserted in a nut or threaded hole.

Replacing Sharpened Tool—Tool for Roughing

If it is necessary to sharpen the thread tool before the thread is finished, it should be re-set square with the work by testing with the thread gage as at *B*, Fig. 54. The carriage is then engaged with the lead-screw and the lathe is turned forward to bring the tool opposite the partly finished thread and also to take up any backlash or lost motion in the gears or half-nut. If the tool-point is not in line with the thread groove previously cut, it can be shifted sidewise by feeding the compound rest *E* in or out, provided the latter is set in an angular position as shown in the plan view, Fig. 55.

If the thread tool is ground flat on the top as at *A*, Fig. 57, it is not a good tool for removing metal rapidly as neither of its two cutting edges has any slope. In order to give each cutting edge a backward slope, it would be necessary to grind the top surface hollow or concave, which would be impracticable. When a coarse thread is to be cut, a tool shaped as at *B* can be used to advantage for rough turning the thread groove, which is afterward finished to the correct depth and angle by tool *A*. This roughing tool is ground with a backward slope from the point and the latter is rounded to make it stronger.

Use of Compound Rest for Thread Cutting

Another form of thread tool is shown at *A*, Fig. 61, which is very good, especially for cutting coarse threads. When this tool is used, the compound rest *E* is set to an angle of 30 degrees, as shown, and it is fed in for the successive cuts by handle *w* in the direction indicated by the arrow. It will be seen that the point *a* of the tool moves at an angle of 60 degrees with the axis of the work, thus forming one side of the thread, and the cutting edge *a—b*, which can be set as shown at *B*, forms the opposite side and does all the cutting. As this edge is given a backward slope, as shown, it cuts easily and enables threading operations to be performed quickly. Threads cut in this way are often finished by taking a light cut with a regular thread tool. The cutting edge *a—b* is ground to an angle of 60 degrees (or slightly less, if anything) with the side, as shown by the top view.

All the threads that have been illustrated in connection with the foregoing description have been of the simple V-form. There are, however, several other forms of threads in use and these various threads and the way in which they are cut is explained in Chapter IV of MACHINERY's Reference Book No. 92.

When cutting threads in steel or wrought iron, some sort of lubricant is usually applied to the tool to preserve the cutting end and give a smooth finish to the thread. Sperm or lard oil is commonly used for this purpose. If the thread is small, the lubricant may be applied from an ordinary oil can, but when cutting comparatively large threads, it is better to have a stream of oil constantly playing upon the toolpoint. This constant flow may be obtained by mounting a can having a spout leading to the tool on a bracket at the rear of the carriage.

It should be mentioned in this connection that cooling compounds are also used on regular turning tools cutting steel or wrought iron. Cast iron and brass are machined dry. A compound that is widely used is composed of water in which a quantity of sal soda has been dissolved. The use of cooling water permits higher cutting speeds, and gives a smoother finish, known as a "water" finish. To secure the best results, a rather large flow of soda water should be applied continuously on the chip at the point where it is being severed by the tool.

CHAPTER IX

CALCULATING CHANGE GEARS FOR THREAD CUTTING

As explained in Chapter VIII, the change gears for cutting threads of various pitches are shown by a table attached to the lathe. The proper gears to be used can be calculated, but the use of the table saves time and tends to avoid mistakes. Every machinist, however, should know how to determine the size of gears used for cutting any number of threads to the inch, but before referring to any rules, let us first consider why a lathe cuts a certain number of threads to the inch and how this number is changed by the use of different gears.

As the carriage *C* and the tool are moved by the lead-screw *S*, Fig. 55, which is geared to the spindle, the number of threads to the inch that are cut depends, in every case, on the number of turns the work makes while the lead-screw is moving the carriage one inch. If the lead-screw has six threads per inch, it will make six revolutions while the carriage and the thread tool travel one inch along the piece to be threaded. Now if the change gears *a* and *c* are so proportioned that the spindle makes the same number of revolutions as the lead-screw, in a given time, it is evident that the tool will cut six threads per inch. If the spindle revolved twice as fast as the lead-screw, it would make twelve turns while the tool moved one inch, and consequently twelve threads per inch would be cut; but to get this difference in speeds it is necessary to use a combination of gearing that will cause the lead-screw to revolve once while the lathe spindle and work make two revolutions.

Suppose that nine threads to the inch are to be cut and the lead-screw has six threads per inch. In this case the work must make nine revolutions while the lead-screw makes six and causes the carriage and thread tool to move one inch, or in other words, one revolution of the lead-screw corresponds to one and one-half revolution of the spindle; therefore, if the lead-screw gear has 36 teeth, the gear on the spindle stud should have only 24 teeth. The spindle stud will then revolve one and one-half times faster than the lead-screw, provided it rotates at the same rate of speed as the main lathe spindle. The number of teeth in the change gears that is required for a certain pitch, can be found by multiplying the number of threads per inch of the lead-screw, and the number of threads per inch to be cut, by the same multiplier. The formula which expresses the relation between threads per inch of lead screw, threads per inch to be cut, and the number of teeth in the change gears, is as follows:

$$\frac{\text{threads per inch of lead-screw}}{\text{threads per inch to be cut}} = \frac{\text{teeth in gear on spindle stud}}{\text{teeth in gear on lead-screw}}$$

Applying this to the example given, we have $\frac{6}{9} = \frac{24}{36}$ The values of 36 and 24 are obtained by multiplying 6 and 9, respectively, by 4, which, of course, does not change the proportion. Any other number could be used as a multiplier, and if gears having 24 and 36 teeth were not available, this might be necessary. For example, if there were no gears of this size, some other multiplier as 5 or 6 might be used.

A general rule for finding change gears by this method would be as follows: Place the number of threads in the lead-screw in the numerator and the number to be cut in the denominator and then multiply both numerator and denominator by some number, until numbers are obtained which correspond to the numbers of teeth in gears that are available. The number obtained by multiplying the numerator represents the gear for the spindle stud, and the number obtained by multiplying the denominator, the gear for the lead-screw. As an example, suppose the number of teeth in the change gears supplied with the lathe are 24, 28, 32, 36, etc., increasing by four teeth up to 100, and assume that the lead-screw has six threads per inch and that ten threads per inch are to be cut. Then,

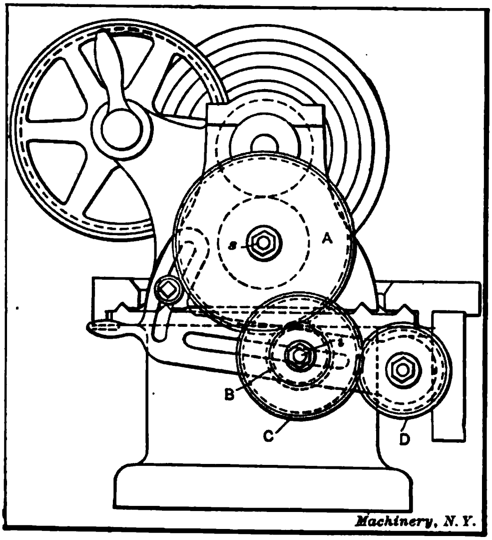


Fig. 62. Lathe having Compound Gears

$$\frac{6}{10} = \frac{6 \times 4}{10 \times 4} = \frac{24}{40}$$

By multiplying both numerator and denominator by 4, we obtain two available gears having 24 and 40 teeth, respectively. The 24-tooth gear goes on the spindle stud and the 40-tooth gear on the lead-screw. The number of teeth in the intermediate gear *b* which connects the stud and lead screw gears, is of no consequence.

We have assumed in the foregoing that the spindle stud (on which gear *a* is mounted) and the spindle made the same number of revolutions. In some lathes, however, these two members do not rotate at the same speed, so that if equal gears were placed on the lead-screw and spindle stud, the spindle would not make the same number of revolutions as the lead-screw. A very convenient way to determine the gears to use in such a case is as follows: First find the number of threads per inch cut when gears of the same size are placed on the lead-screw and spindle, either by actual trial or by referring to the index plate. Then use this number as the numerator instead of the actual number of threads per inch in the lead-screw, and proceed as previously described.

Change Gears for Lathes with Compound Gearing

When gearing is arranged as shown in Fig. 55, it is referred to as simple gearing, but sometimes it is necessary to introduce two gears (*B* and *C*) between the stud and screw as in Fig. 62, which is termed compound gearing. The method of figuring compound gearing is practically the same as that for simple gearing, except that the numerator and denominator are divided into two factors, each of which is multiplied by the same number to obtain the number of teeth in the change gears, as before.

Suppose the lathe has a lead-screw with six threads per inch and that the numbers of teeth in the gears available are 30, 35, 40 and so on, increasing by 5 up to 100. If for example, 24 threads per inch are to be cut, 6 is placed in the numerator and 24 in the denominator as before. The numerator and denominator are then divided into factors and each pair of factors is multiplied by the same number to find the gears, thus:

$$\frac{6}{24} = \frac{2 \times 3}{4 \times 6} = \frac{(2 \times 20) \times (3 \times 10)}{(4 \times 20) \times (6 \times 10)} = \frac{40 \times 30}{80 \times 60}$$

The last four numbers indicate the gears which should be used. The upper two, having 40 and 30 teeth, are the driving gears and the lower two having 80 and 60 teeth, are the driven gears. The driving gears are gear *A* on the spindle stud and gear *C* on the intermediate stud, meshing with the lead-screw gear, and the driven gears are gears *B* and *D*. It makes no difference which of the driving gears is placed on the spindle stud, or which of the driven is placed on the lead-screw. As another illustration, suppose we are to cut 1¾ thread per inch on a lathe with a lead-screw having six threads per inch, and that the numbers of teeth in the gears range from 24 to 100, increasing by 4.

$$\frac{6}{1\frac{3}{4}} = \frac{2 \times 3}{1 \times 1\frac{3}{4}} = \frac{(2 \times 36) \times (3 \times 16)}{(1 \times 36) \times (1\frac{3}{4} \times 16)} = \frac{72 \times 48}{36 \times 28}$$

The gear having 72 teeth is placed on the spindle stud *s*, the one with 48 on the intermediate stud *i*, meshing with the lead-screw gear. These two gears (72 and 48 teeth) are the driving gears. The gears with 36 and 28 teeth are placed on the lead-screw and on the intermediate stud and are the driven gears.

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OPERATION OF MACHINE TOOLS

By FRANKLIN D. JONES

SECOND EDITION

THE LATHE

PART II

CONTENTS

CHAPTER I

TAPER TURNING

It is often necessary, in connection with lathe work, to turn parts tapering instead of straight or cylindrical. If the work is mounted between the centers, one method of turning a taper is to set the tailstock center out of alignment with the headstock center. When both of these centers are in line, the movement of the tool is parallel to the axis of the work and, consequently, a cylindrical surface is produced; but if the tailstock h_1 is set out of alignment as shown in

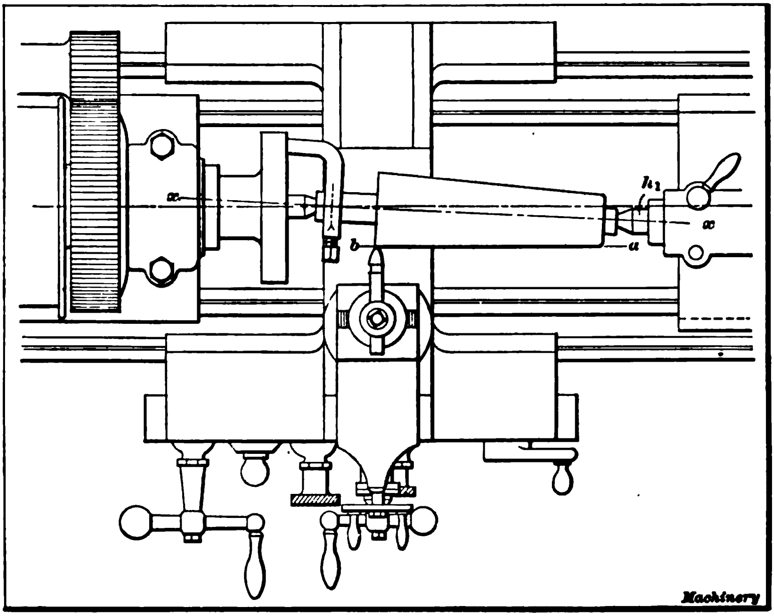


Fig. 1. Taper Turning by the Offset-center Method

Fig. 1, the work will then be turned tapering as the tool is traversed from *a* to *b*, because the axis *x*—*x* is at an angle with the movement of the tool. Furthermore the amount of taper or the difference between the diameters at the ends for a given length, will depend on how much center h_1 is set over from the central position.

The amount of taper is usually given on drawings in inches per foot, or the difference in the diameter at points twelve inches apart. For example, the taper of the piece shown at *A*, Fig. 2, is 1 inch per foot, as the length of the tapering surface is just twelve inches and the difference between the diameters at the ends is 1 inch. The conical roller shown at *B* has a total length of 9 inches and a tapering surface 6 inches long, and in this case the taper per foot is also 1 inch, there being a difference of ½ inch in a length of 6 inches or 1 inch in twice that length. When the taper per foot is known, the amount that the tailstock center should be set over for turning that taper, can easily be estimated, but it should be remembered that the setting obtained in this way is not absolutely correct, and is only intended to locate the center approximately. When a taper needs to be at all accurate, it is tested with a gage, or by other means, after taking a trial cut, as will be explained later, and the tailstock

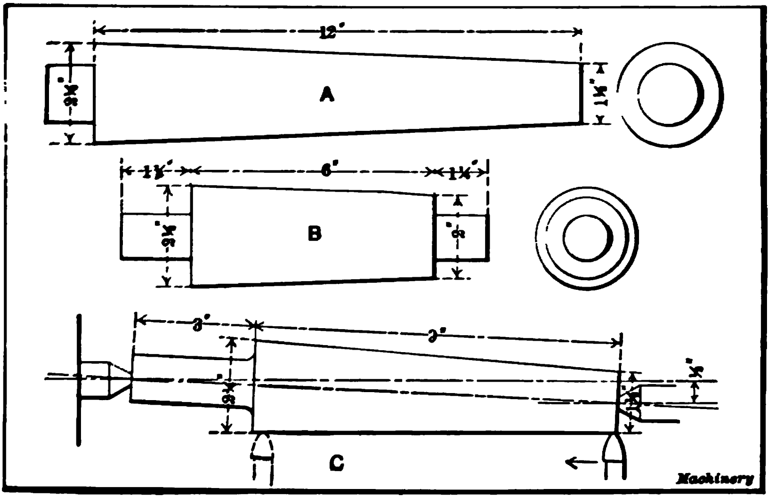


Fig. 2. Examples of Taper Work

center is re-adjusted accordingly. There are also more accurate methods of setting the center, than by figuring the amount of offset, but as the latter is often convenient, this will be referred to first.

Setting Tailstock Center for Taper Turning

Suppose the tailstock center is to be set for turning part *C*, Fig. 2, to a taper of approximately 1 inch per foot. In this case the center would simply be moved toward the front of the machine ½ inch, or one-half the required taper per foot, because the total length of the work happens to be just 12 inches. This setting, however, would not be correct for all work requiring a taper of 1 inch per foot, as the adjustment depends not only on the *amount* of the taper but on the *total length* of the piece.

For example, the taper roller *B* has a taper of 1 inch per foot, but the center, in this case, would be offset less than one-half the taper per foot, because the total length is only 9 inches. For lengths longer or shorter than twelve inches, the taper per inch should be found first; this is then multiplied by the *total* length of the work (not the length of the taper) which gives the taper for that length, and one-half this taper is the amount to set over the center. For example, the taper per inch of part *B* equals 1 inch divided by 12 = 1/12 inch. The total length of 9 inches multipled by 1/12 inch = 3/4 inch, and ½ of ¾ = ⅜, which is the distance that the tailstock center should be offset. In this example if the taper per foot were not known, and only the diameters of the large and small ends of the tapered part were given, the difference between these diameters should first be found (2½ — 2 = ½); this difference should then be divided by the length of the taper (½ ÷ 6 = 1/12 inch) to obtain the taper per inch. The taper per inch times the *total* length represents what the taper would be if it extended throughout the entire length, and one-half of this equals the offset, which is ⅜ inch.*

Example of Taper Turning

As a practical example of taper turning let us assume that the piece *A*, Fig. 4, which has been centered and rough turned as shown, is to be made into a taper plug, as indicated at *B*, to fit a ring gage as at *C*. If the required taper is 1½ inch per foot and the total length is 8 inches, the tailstock center would be offset ½ inch.

To adjust the tailstock, the nuts *N* (Fig. 3) are first loosened and then the upper part *A* is shifted sidewise by turning screw *S*. Scales are provided on some tailstocks for measuring the amount of this adjustment; if there is no scale, draw a line across the movable and stationary parts *A* and *B*, when the tailstock is set for straight turning. The movement of the upper line in relation to the lower will then show the offset, which can be measured with a scale.

Fig. 3. Detail View of Lathe Tailstock

When the adjustment has been made, nuts *N* are tightened and the work, with a dog attached, is placed between the centers the same as for straight turning. The taper end is then reduced by turning, but before it is near the finished size, the work is removed and the taper tested by inserting it in the gage. If it is much out, this can be felt, as the end that is too small can be shaken in the hole. Suppose the plug did not taper enough and only the small end came in contact with the gage, as shown somewhat exaggerated at *D;* in that case the center would be shifted a little more towards the front, whereas if the taper were too steep, the adjustment would, of course, be in the opposite direction. A light cut would then be taken, to be followed by another test. If the plug should fit the gage so well that there was no perceptible shake, it could be tested more closely as follows: Draw three or four chalk lines along

*See also MACHINERY'S Reference Book No. 18, "Shop Arithmetic for the Machinist."

the tapering surface, place the work in the gage and turn it a few times. The chalk marks will then show whether the taper of the plug corresponds to that of the gage; for example, if the taper is too great, the marks will be rubbed out on the large end, but if the taper is correct, the lines throughout their length will be partially erased.

Another and more accurate method of testing tapers, is to apply a thin coat of Prussian-blue to one-half of the tapering surface, in a lengthwise direction. The work is then inserted in the hole or gage and turned to mark the bearing. If the taper is correct, the bearing marks will be evenly distributed, whereas if the taper is incorrect, they will appear at one end. Tapering pieces that have to be driven tightly into a hole, as a piston-rod, can be tested by the location of the bearing marks produced by actual contact.

After the taper is found to be correct, the plug is reduced in size until it just enters the gage as at *C*. The final cut should leave it slightly above the required size, so that a smooth surface can be

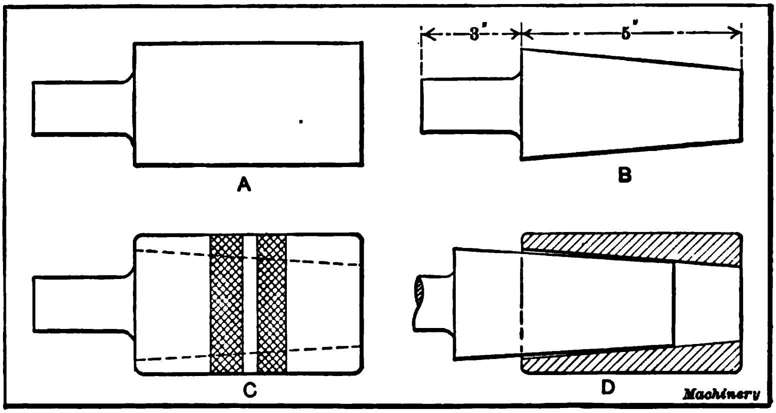


Fig. 4. Taper Plug and Gage

obtained by filing. It should be mentioned that on work of this kind the final finish is very often obtained by grinding in a regular grinding machine instead of by filing. When this method is employed, a lathe is used merely to rough turn the part close to size.

When the amount that the tailstock center should be offset is determined by calculating, as in the foregoing example, it is usually necessary to make slight changes afterward, and the work should be tested before it is too near the finished size so that in case one or more trial cuts are necessary, there will be material enough to permit this. When there are a number of tapered pieces to be turned to the same taper, the adjustment of the tailstock center will have to be changed unless the total length of each piece and the depth of the center holes are the same in each case.

Setting the Tailstock Center with a Caliper Tool

Another method of setting the tailstock center for taper turning is illustrated in Fig. 5. The end of a rod is to be made tapering as at *A* and to dimensions *a*, *b*, *c* and *d*. It is first turned with the centers in line as at *B*. The end *d* is reduced to diameter *b* up to the beginning of the taper and it is then turned to diameter *a* as far as the taper part *c* extends. The tailstock center is next set over by guess and a caliper tool is clamped in the toolpost. This tool,

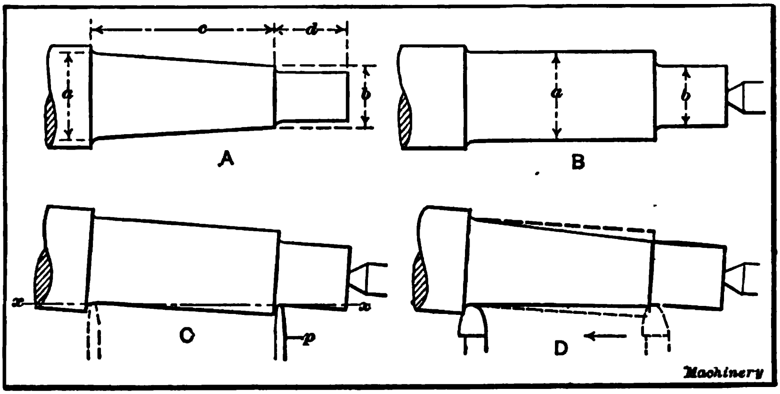


Fig. 5. Setting Work for Taper Turning by use of Caliper Gage

a side view of which is shown in Fig. 6, has a pointer *p* that is free to swing about pivot *r*, which should be set to about the same height as the center of the work. The tailstock center is adjusted until this pointer just touches the work when in the positions shown by the full and dotted lines at *C*, Fig. 5; that is, until the pointer makes

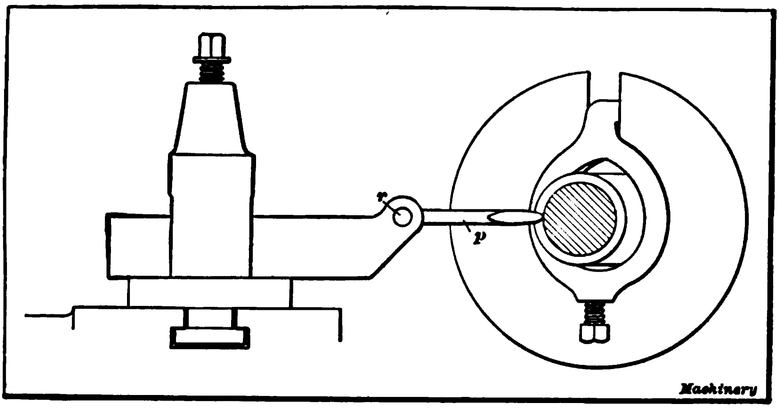


Fig. 6. Side View showing Relative Positions of Gage and Work

contact at the beginning and end of the taper part. The travel of the carriage will then be parallel to a line *x—x*, representing the taper; consequently, if a tool is started at the small end, as shown by the dotted lines at *D*, with the nose just grazing the work, it will also just graze it when fed to the extreme left as shown. Of course, if the taper were at all steep, more than one cut would be taken. If these various operations are carefully performed, a fairly accurate taper can be produced. The straight end *d* is reduced to size after the tail-center is set back to the central position. Some mechanics turn notches or grooves at the beginning and end of the tapering part, having diameters equal to the largest and smallest part of the taper; the work is then set by these grooves with a caliper tool. The advantage of the first method is that most of the metal is removed while the centers are in alignment.

Setting the Tailstock Center with a Square

Still another method of adjusting the tailstock for taper turning, which is very simple and eliminates all figuring, is as follows: The part to be made tapering is first turned cylindrical or straight

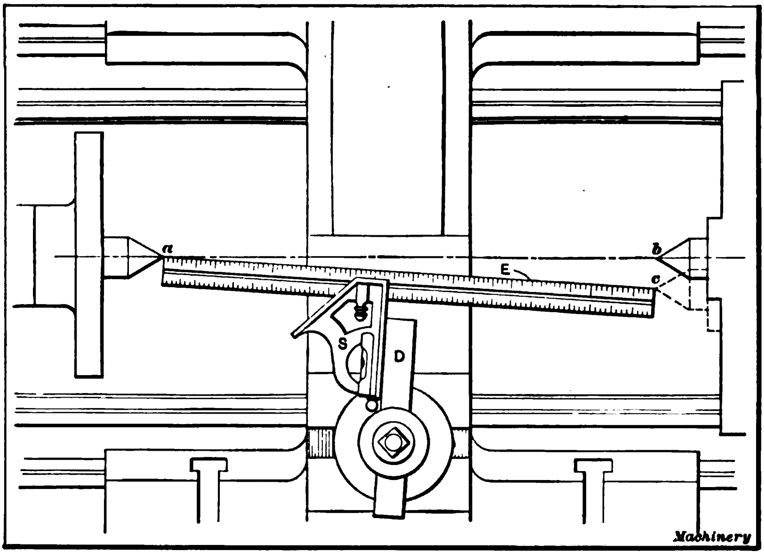


Fig. 7. Obtaining Tailstock Center Adjustment by use of Square

for 3 or 4 inches of its length, after the ends have been properly centered and faced square. The work is then removed and the tailstock is shifted along the bed until the distance *a*—*b* between the extreme points of the centers, is exactly 1 foot. The center is next offset a distance *b*—*c* equal to one-half the required taper per foot, after which a parallel strip *D*, having true sides, is clamped in the toolpost. Part *D* is then set at right angles to a line passing from one center point to the other. This can be done conveniently by holding a 1-foot square (preferably with a sliding head) against one side of *D* and adjusting the latter in the toolpost until edge *E* of the square blade is exactly in line with both center points. After part *D* is set, it should be clamped carefully to prevent changing the position. The angle between the side of *D* and an imaginary line which is perpendicular to axis *a*—*b*, is now equal to one-half the angle of the required taper. The axis of the part to be turned should be set parallel with line *E*, which can be done by setting the cylindrical surface which was previously finished, at right angles to the side of *D*. In order to do this the work is first placed between centers, the tailstock being shifted along the bed if necessary; the tail-center is then adjusted laterally until the finished cylindrical surface is square with the side of *D*. A small try-square can be used for testing the position of the work, as indicated in Fig. 8. If the length of the work is less than 1 foot, it will be necessary to move the center toward the rear of the machine, and if the length is greater than 1 foot, the adjustment is, of course, in the opposite direction. (This method has been described in MACHINERY by Mr. H. C. Lord.)

The Taper Attachment

Turning tapers by setting over the tailstock center has some objectionable features. When the lathe centers are not in alignment,

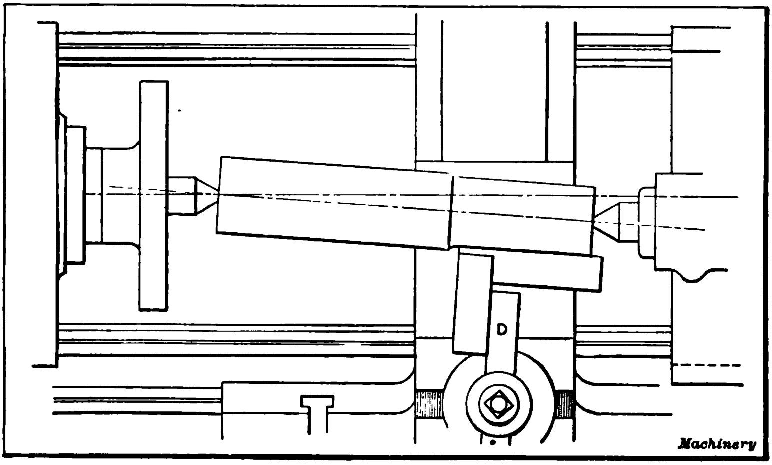


Fig. 8. Second Step in Adjusting Tailstock Center by use of Square

as when set for taper turning, they bear unevenly in the work centers because the axis of the work is at an angle with them; this causes the work centers to wear unevenly and results in inaccuracy. Furthermore, the adjustment of the tailstock center must be changed when turning duplicate tapers, unless the length of each piece and the depth of the center holes are the same. To overcome these objections, many modern lathes are equipped with a special device for turning tapers, known as a taper attachment, which permits the lathe centers to be kept in alignment, and enables more accurate work to be done.

Taper attachments, like lathes, vary some in their construction, but all operate on the same principle. An improved form of taper attachment is illustrated in Figs. 9 and 10, which show a plan view of a lathe carriage with an attachment fitted to it, and also a sectional view. This attachment has an arm *A* on which is mounted a slide *S* that can be turned about a central pivot by adjusting screw *D*. The arm *A* is supported by, and is free to slide on a bracket *B* (see also sectional view) that is fastened to the carriage, and on one end of the arm there is a clamp *C* that is attached to the lathe bed when turning tapers. On the slide *S* there is a shoe *F* that is connected to bar *E* which passes beneath the tool slide. The rear end of the cross-feed screw is connected to this bar, and the latter is clamped to the tool-slide when the attachment is in use.

When a taper is to be turned, the carriage is moved opposite the taper part and clamp *C* is fastened to the bed; this holds arm *A* and slide *S* stationary so that the carriage, with bracket *B* and shoe *F* can be moved with relation to the slide. If this slide *S* is set at an angle, as shown, the shoe as it moves along, causes the tool-slide and tool to move in or out, but if the slide is set parallel to the carriage travel, the tool-slide remains stationary. Now if the tool, as it feeds lengthwise of the work, is also gradually moved crosswise, it will turn a taper, and as this crosswise movement is caused by the angularity of slide *S*, different tapers are obtained by setting the slide to different positions. By means of a graduated scale at *G*, just what taper would be obtained for any angular position of the slide, is shown. On some attachments there are two sets of graduations, one giving the taper in inches per foot and the other in degrees. While tapers are ordinarily given in inches per foot on drawings, sometimes the taper is given in degrees instead. Fig. 11 shows an enlarged view of the scale with the slide set for turning a taper of 1 inch per foot. The attachment is set for turning tapers by adjusting slide *S* until pointer *p* is opposite the division or fractional part of a division representing the taper. The whole divisions on the scale represent taper in inches per foot, and by means of the subdivisions, the slide can be set for turning frac-

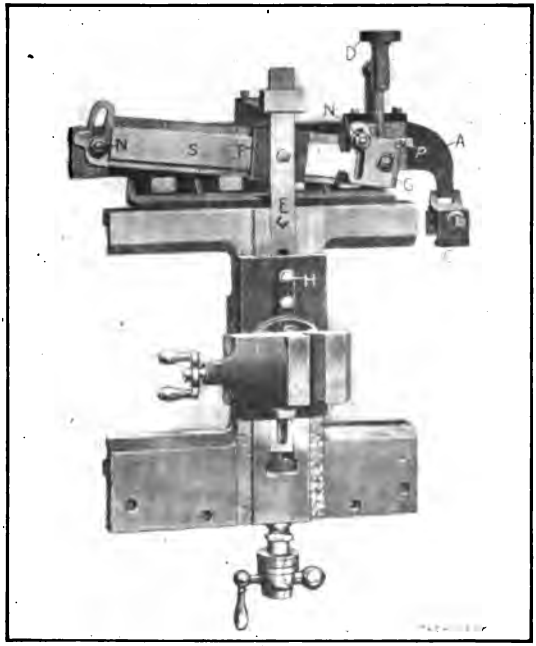


Fig. 9. A Lathe Taper Attachment

tional parts of an inch per foot. When slide S is properly set, it is clamped to arm A by the nuts N. Bar E is also clamped to the tool-slide by bolt H, as previously stated. The attachment is disconnected

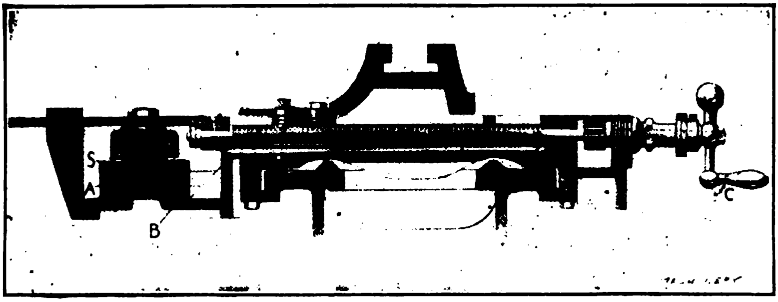


Fig. 10. Sectional View of Taper Attachment

for straight turning by simply loosening clamp C and the bolt H. An example of taper turning with the attachment is given in Chapter II.

Height of Tool when Turning Tapers

The cutting edge of the tool, when turning tapers, should be at the same height as the center or axis of the work, whether an attachment is used or not. The importance of this will be apparent by referring to Fig. 12. To turn the taper shown, the tool T would be moved back a distance x (assuming that an attachment is used) while traversing the length l. If the tool could be placed as high as point a, for the sake of illustration, the setting of the attachment remaining as before, it would again move back a distance x, while moving a distance l, but the large end would be undersized (as shown exaggerated by the dotted line) if the diameters of the small ends were the same in each case. Of course, if the tool point were only slightly above or below the center, the resulting error would also be small. The tool can easily be set central by comparing the height of the cutting edge at the point of the tool with one of the lathe centers before placing the work in the lathe.

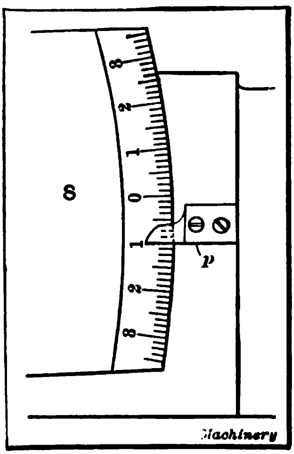


Fig. 11. Scale of Taper Attachment

Taper Turning with the Compound Rest

The amount of taper that can be turned by setting over the tail-stock center and by the taper attachment, is limited, as the centers can only be offset a certain distance, and the slide S of the attachment cannot be swiveled beyond a certain position. For steep tapers, the compound rest E is swiveled to the required angle and used as indicated in Fig. 14, which shows a plan view of a rest set for turning the valve *V*. This compound rest is an upper slide mounted on the lower or main cross-slide *D*, and it can be turned to any angular position so that the tool, which ordinarily is moved either lengthwise

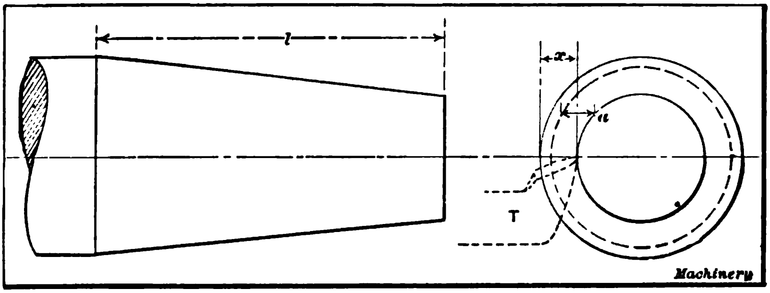


Fig. 12. Tool Point should be in same Horizontal Plane as Axis of Work for Taper Turning

or crosswise of the bed, can be fed at an angle. The base of the compound rest is graduated in degrees and the position of these graduations shows to what angle the upper slide is set. Suppose the seat of valve *V* is to be turned to an angle of 45 degrees with the axis or center, as shown on the drawing at *A*, Fig. 13. To set the compound rest, nuts *n* on either side, which hold it rigidly to the lower slide, are first loosened and the slide is then turned until

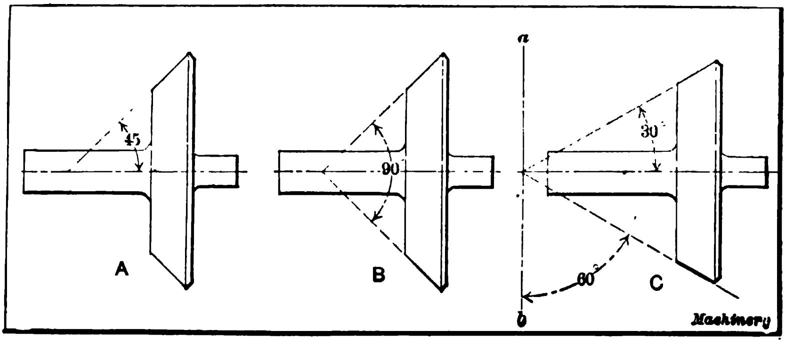


Fig. 13. Example of Taper Work Turned by using Compound Rest

the 45 degree graduation is exactly opposite the zero line; the slide is then tightened in this position. A cut is next taken across the valve by operating handle *w* and feeding the tool in the direction of the arrow.

In this particular instance the compound rest is set to the same angle given on the drawing, but this is not always the case. If the draftsman had given the included angle of 90 degrees, as shown at *B*, which would be another way of expressing it, the setting of the compound rest would, of course, be the same as before, or to 45 degrees, but the number of degrees marked on the drawing does not correspond with the angle to which the rest must be set. As another illustration, suppose the valve were to be turned to an angle of 30 degrees with the axis as shown at *C*. In this case the compound rest would not be set to 30 degrees but to 60 degrees, because in order to turn the work to an angle of 30 degrees, the rest must be 60 degrees from its zero position, as shown. From this it will be seen that the number of degrees marked on the drawing does not necessarily correspond to the angle to which the rest must be set, as the gradu-

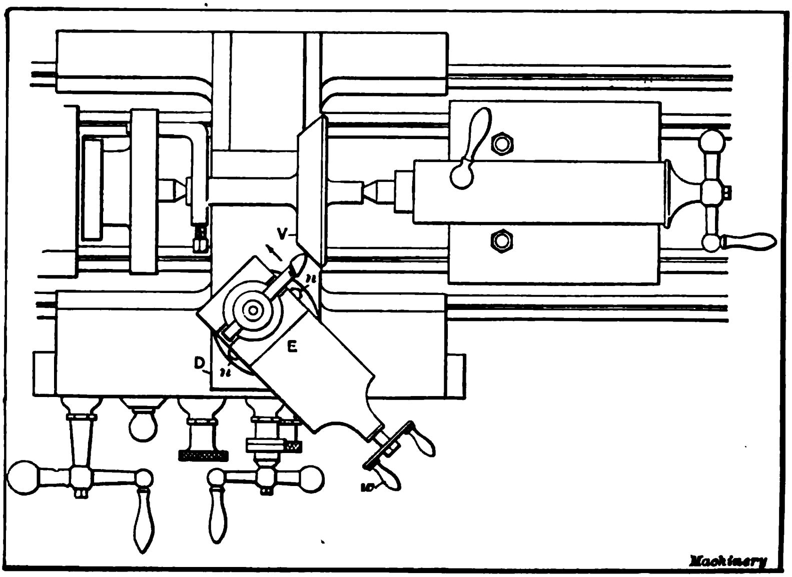


Fig. 14. Plan View showing method of Turning a Taper with the Compound Rest

ations on the rest show the number of degrees that it is moved from its zero position, which corresponds to the line *a—b*. The angle to which the compound rest should be set can be found, when the drawing is marked as at *A* or *C*, by subtracting the angle given from 90 degrees. When the included angle is given, as at *B*, subtract one-half the included angle from 90 degrees to obtain the required setting. Of course, when using a compound rest, the lathe centers are set in line as for straight turning, as otherwise the angle will be incorrect. The compound rest can also be used for boring taper holes by setting it to the angle that would give the right taper and then feeding the boring tool by hand, as when turning.

CHAPTER II

EXAMPLES OF CYLINDRICAL AND TAPER TURNING, BORING AND THREAD CUTTING

A practical example of lathe work which requires both straight and and taper turning, thread cutting, taper boring, reaming, and turning by the use of a mandrel, is illustrated in Fig. 15, which represents the drawing of an engine piston and rod. The various steps connected with turning these two parts in an ordinary engine lathe will be explained.

The piston is usually bored and reamed before the rod is turned so that the latter can afterward be fitted to it. The first turning opera-

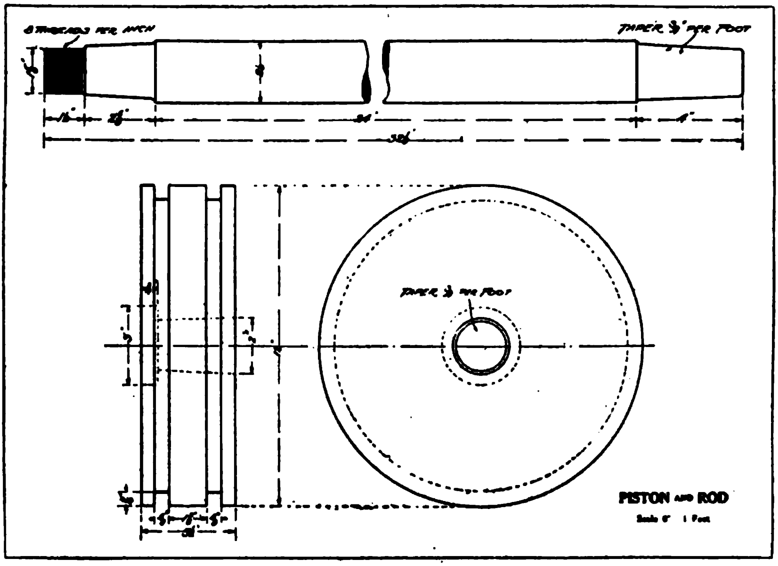


Fig. 15. Drawing of Engine Piston and Rod

tion consists in boring the hole into which the rod is to be fitted; therefore, the casting must be held either in a chuck *C*, as in Fig. 16, or on a faceplate if too large for the chuck. The side of the casting (after it has been "chucked") should run true and also the circumference, unless the cored hole for the rod is considerably out of center, in which case the work should be shifted to divide the error. The side of the casting for a short space around the hole is faced true with a round nose turning tool, after which the rough cored hole is bored with an ordinary boring tool *t*, and then it is finished with a reamer to exactly the right size and taper. If the lathe has a taper attachment, the hole can be bored to the right taper, by setting the attachment to the taper given on the drawing, which, in this example, is ¾ inch per foot. This is done, as will be recalled, by loosening nuts *N* and turning slide *S* until pointer *P* is opposite the ¾-inch division on the scale; the attachment is then ready, after bolt *H* and nuts *N* are tightened, and clamp *C* is fastened to the lathe bed. The hole is bored just as though it were straight, and as the carriage advances, the tool is gradually moved inward by the attachment.

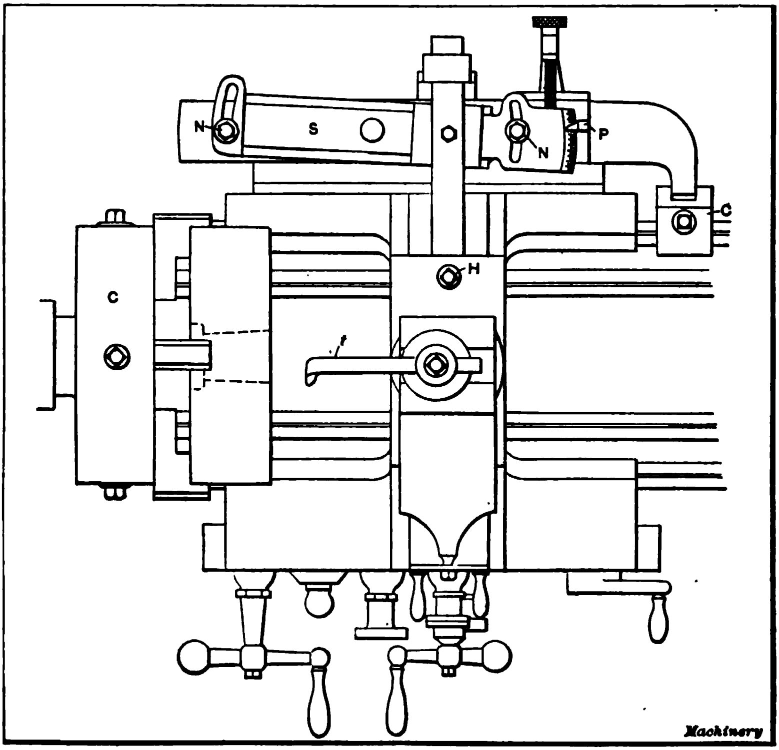


Fig. 16. Lathe with Taper Attachment arranged for Boring Taper Hole

If the lathe is without an attachment, the hole must be bored by using the compound rest. A convenient way to set the compound rest to the required angle is illustrated in Fig. 17. A bevel protractor *P* is first set to the taper of the reamer; this protractor is then placed against the finished spot on the casting as shown in Fig. 17, or against the faceplate, if the casting has not been chucked, and the compound rest is adjusted to the same angle as the protractor blade. The tool is set for boring by adjusting the carriage and cross-slide *D*, and it is fed by hand through the hole by compound slide *E*.

The hole is bored slightly under the finished size, and then a reamer is placed in the hole. The outer end of the reamer, which should have a deep center hole, is supported by the tailstock center. The lathe is run very slow for reaming and the reamer is fed into the hole by feeding out the tailstock spindle. The reamer can be kept from revolving with the work, either by attaching a heavy dog to the end or, if the end is squared, by the use of a wrench. A common method is to clamp a dog to the reamer shank, and then place the tool-rest beneath it to prevent rotation. If the shank of a tool is clamped to the toolpost so that the dog rests against it, the reamer will be prevented from slipping off the center as it tends to do; with this arrangement, the carriage is gradually moved along as the tailstock spindle is fed outward. A reamer of the type illustrated at *B*, Fig. 18, is fed in until the stop collar *S* comes against the finished side of the casting. By having this stop, the holes in any number of

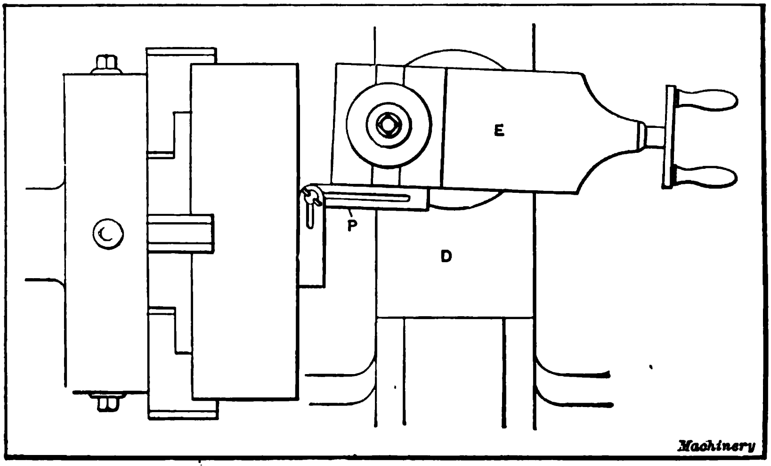


Fig. 17. Setting Compound Rest to Required Angle by using Bevel

pistons can be reamed to the same size. If a plain reamer *A* were used, the hole would probably be tested by inserting a plug gage.

After the reaming operation, the casting is removed from the chuck and a taper mandrel is driven into the hole for turning the outside of the piston. This mandrel should run true on its centers, as otherwise the outside surface of the piston will not be true with the bored hole. The mandrel *M* and the casting are next mounted between the lathe centers as shown in Fig. 19, after the chuck has been replaced with a faceplate. The driving dog *D*, especially for large work of this kind, should be heavy and stiff, because light flexible clamps or dogs vibrate and frequently cause chattering. For such heavy work it is also preferable to drive at two points on opposite sides of the faceplate, but the driving pins must be carefully adjusted to secure a uniform bearing on both sides. The outside of the piston might be turned either to the diameter given on the drawing, or be fitted to the cylinder of the engine for which the piston is intended. When turning work of this diameter, it must revolve quite slowly as otherwise the turning tool will be quickly dulled, and it is for such large work that the slow speeds obtained by driving through the back-gears are used. Ordinarily a piston casting could be reduced to finished diameter by taking one roughing and one light finishing cut, though

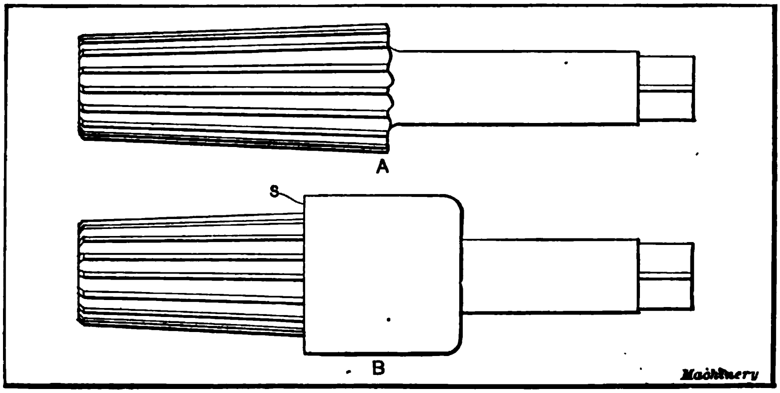


Fig. 18. Plain Reamer—Reamer with Stop Sleeve

this would depend, of course, on the diameter of the rough casting.

After turning the outside, grooves for the packing rings are laid out, as shown at *A*, Fig. 20, by scribing arcs from a central point *a*, that are the same distance apart as the grooves. The dimensions are

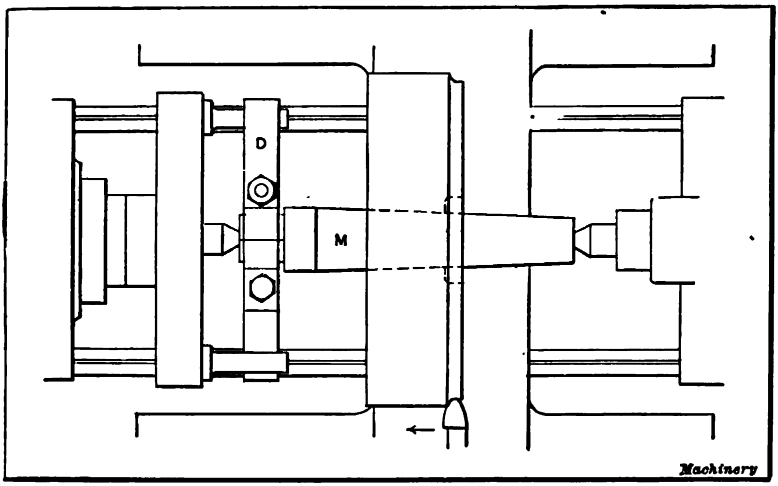


Fig. 19. Piston Mounted on Mandrel, in Position for Turning

obtained from the drawing, and the lines should be marked by light punch marks as shown. One method of cutting these grooves would be to use a square-nosed tool *t* (similar in shape to a parting tool) for turning them to depth, and side tools for finishing the sides. Grooves that are quite wide would be formed by first taking a cut on each side and then turning away the central part, as shown at *B*. The grooves should then be finished to the required width either by using right- and left-hand side tools, or a "square nose" ground to the right size. The width of the grooves should be exactly the same, and ordinarily they are fitted to some form of gage *g*. This particular style is double-ended, the upper end being used to measure the packing rings that fit into the grooves. When the grooves are finished, the outside of the piston is filed to make it smooth.

The final operation is to finish the pocket for the rod nut, which can be done by using a bent square-nosed tool t_1. It may be necessary to grind part of the under side of this tool away to provide

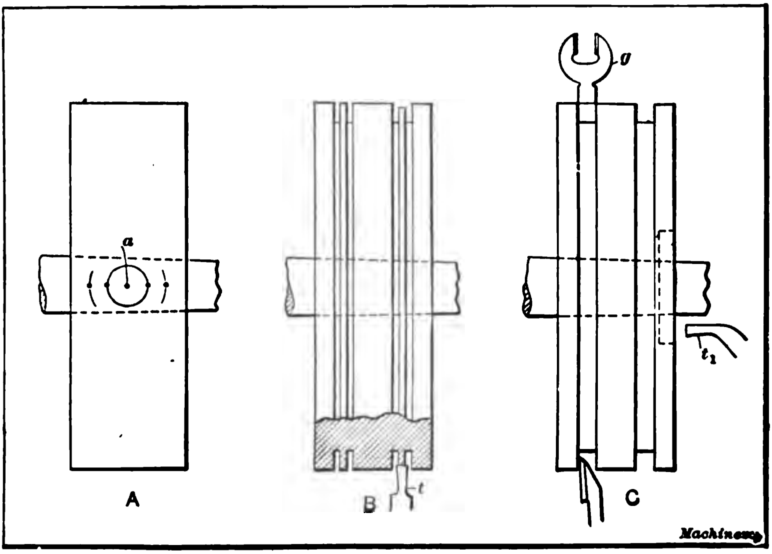


Fig. 20. Successive Steps in Turning Packing-ring Grooves

clearance, or in other words, to make a kind of special tool that would be kept for this particular job.

The foregoing method of machining a piston is one that would ordinarily be followed when using a standard engine lathe, and it would, perhaps, be as economical as any if only one piston were being made; but where such work is done in large quantities, time could be saved by proceeding in a different way. For example, the boring and reaming operation could be performed much faster in a turret lathe, which is a type designed for just such work, but a turret lathe cannot be used for as great a variety of work as a lathe of the regular type. There are also many other classes of work that can be turned more quickly in special types of machines, but as more or less time is required for arranging these special machines and often special tools have to be made, the ordinary lathe is frequently indispensable when only a few parts are needed; in addition, it is better adapted to some turning operations than any other machine.

Turning the Piston-rod

The stock for the piston-rod is cut off to the right length (probably in a hacksaw machine), and the ends are centered. The work is then placed between the lathe centers with a driving dog *D* (Fig. 21) attached to the faceplate end, and the tailstock center, after being oiled, is adjusted rather snugly but not tight enough to prevent a free rotary movement of the work. The body of the rod is first rough turned say 1/16 inch above the finished size, the cut being continued until the tool is near the driving dog. Light punch marks *a* and *b* are then made on the rod to mark the location of the shoulders or the length of the rod body which, in this case, is 24 inches. The

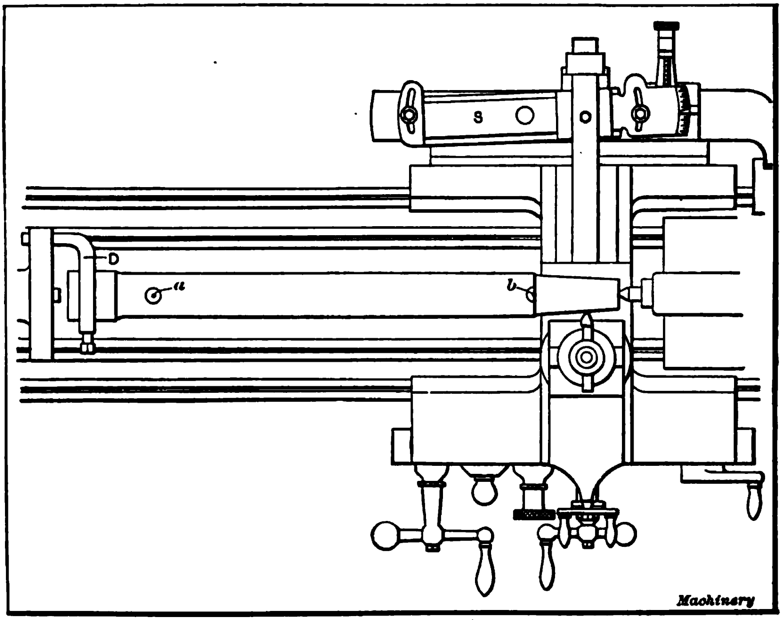


Fig. 21. Taper Attachment Set for Turning Taper End of Rod

marks should also be the right distance from the ends. The right-hand mark is laid out for the crosshead end which is to be fitted first. The taper attachment is next set to turn a taper of ¾ inch per foot, as marked on the drawing. While this taper corresponds to the taper of the hole in the piston, slide *S* will have to be re-set to the ¾-inch division on the opposite side of the central zero mark (see Fig. 11, Chapter I) because the taper of the hole decreased in size during the boring operation whereas the rod is smallest at the beginning of the cut, so that the tool must move outward rather than inward as it advances. The taper part is turned practically the same as a cylindrical part; that is, the power feed is used and, as the carriage moves along the bed, the tool is gradually moved outward by the taper attachment. If the rod is being fitted directly to the crosshead, as is usually the case, the approximate size of the taper end could be determined by calipering, the calipers being set to the size of the hole at a point 4 inches (in this case) from the shoulder or face side. If the crosshead was bored originally to fit a standard plug gage, the taper on the rod could be turned with reference to this gage, but, whatever the method, the taper should be tested before turning too close to the finished size. The test is made by removing the rod from the lathe and driving it tightly into the crosshead. This shows how near the taper is to size, and when the rod is driven out, the bearing marks show whether the taper is exactly right or not. If the rod could be driven in until the shoulder is say 1/8 inch from the crosshead face, it would then be near enough to finish to size by filing. When filing, the lathe is run much faster than for turning, and the most filing should be done where the bearing marks are the heaviest, to distribute the bearing throughout the length of the taper. Care should be taken when driving the rod in or out, to protect the center-holes in the ends by using a "soft" hammer or by holding a piece of soft metal against the driving end.

After the crosshead end is finished, the rod is reversed in the lathe for turning the piston end. The dog *D* is clamped to the finished

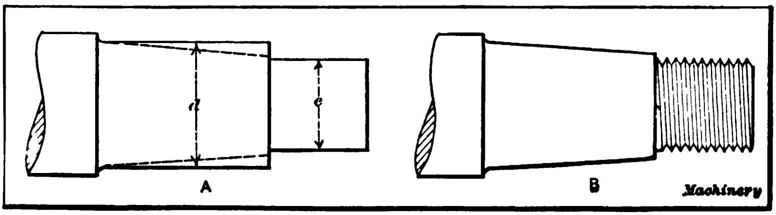


Fig. 22. Final Operations on Piston Rod

end, preferably over a piece of sheet copper to prevent the surface from being marred, and the end is then rough turned as at *A*, Fig. 22, diameter *d* being made slightly greater than the largest diameter of the taper, and *e* equal to the diameter of the thread. The attachment is then engaged and the taper part turned to the same taper as the opposite end, as called for on the drawing. When turning this end, either the piston reamer or the finished hole in the piston can be calipered. The size and angle of the taper are tested by driving the rod into the piston, and the end should be fitted so that by driving tightly, the shoulder will just come up against the finished face of the piston. When the taper is finished, the attachment is disengaged and a finishing cut is taken over the body of the rod with a sharp tool and rather fine feed to obtain a smooth surface.

The next and final turning operation is that of threading the end as at *B*. As there are eight threads per inch (see drawing, Fig. 15) the lathe is geared for cutting that number, and the thread is cut as explained in Part I of this treatise. (See Chapter VIII, MACHINERY'S Reference Book, No. 91.) The final operation consists in filing and polishing the body of the rod, the file being used first to take off the ridges left by the tool, and then emery cloth to polish the surface.

CHAPTER III

CUTTING SPEEDS AND FEEDS

In all turning operations there are two very important questions that must be considered: One has to do with the cutting speed that is used, and the other relates to the feed of the tool and depth of the cut. The cutting speed is the number of feet per minute that the tool point passes over, or practically speaking, it is equivalent to the length of a chip which would be turned in one minute. The term cutting speed should not be confused with revolutions per minute, because the cutting speed depends not only on the speed of the work but also on its diameter. The feed of a tool is the amount it moves across the surface of the work for each revolution; that is, when turning a cylindrical piece, the feed is the amount that the tool moves sidewise for each revolution of the work. Evidently the time required for turning is governed largely by the cutting speed, the feed, and the depth of the cut; therefore, these elements should be carefully considered. It is impossible to give any definite rule for determining either the speed, feed, or depth of cut, because these must be varied to suit existing conditions. We shall, however, point out some of the underlying principles which must be considered in determining the proper speed and feed.

TABLE OF CUTTING SPEEDS FOR TURNING STEEL

Depth of Cut in Inches	Feed in Inches	Cutting Speed in Feet per Minute for a Tool which is to last 1 Hour and 30 Minutes before Regrinding		
		Soft Steel	Medium Steel	Hard Steel
3/32	1/64	476	238.0	108.0
	1/32	325	162.0	73.8
	1/16	222	111.0	50.4
	3/32	177	88.4	40.2
3/16	1/64	352	176.0	80.0
	1/32	240	120.0	54.5
	1/16	164	82.0	37.8
	3/32	131	65.5	29.8
	1/8	112	56.0	25.5
3/8	1/64	264	132.0	60.0
	1/32	180	90.2	41.0
	1/16	122	61.1	27.8

The cutting speed is governed principally by the hardness of the metal to be turned; the kind of steel of which the turning tool is made; the shape of the tool and its heat treatment; the feed and depth of cut; the power of the lathe and also its construction. It is the durability of the turning tool, or the length of time that it will turn effectively without grinding, that limits the cutting speed; and the hardness of the metal being turned combined with the quality of the tool, are the two factors which largely govern the time that a tool can be used before grinding is necessary. The cutting speed for very soft steel or cast iron can be three or four times faster than the speed for hard steel or hard castings, but whether the material is hard or soft, the kind of tool to use must also be considered as the speed for a tool made of ordinary carbon steel will have to be much slower than for a tool made of modern "high-speed" steel.

When the cutting speed is too high, even though high-speed steel is used, the point of the tool is softened to such an extent by the heat resulting from the pressure and friction of the chip, that the cutting edge is ruined in too short a time. On the other hand, when the speed is too slow, the heat generated is so slight as to have little

TABLE OF CUTTING SPEEDS FOR TURNING CAST IRON

Depth of Cut in Inches	Feed in Inches	Cutting Speed in Feet per Minute for a Tool which is to last 1 Hour and 30 Minutes before Regrinding		
		Soft Cast Iron	Medium Cast Iron	Hard Cast Iron
$\frac{3}{32}$	$\frac{1}{32}$	169.0	84.6	49.4
	$\frac{1}{16}$	122.0	61.2	35.7
	$\frac{1}{8}$	86.4	43.2	25.2
	$\frac{3}{16}$	70.1	35.1	20.5
$\frac{3}{16}$	$\frac{1}{32}$	137.0	68.6	40.1
	$\frac{1}{16}$	99.4	49.7	29.0
	$\frac{1}{8}$	70.1	35.0	20.5
	$\frac{3}{16}$	56.8	28.4	16.6
$\frac{3}{8}$	$\frac{1}{32}$	111.0	55.4	32.8
	$\frac{1}{16}$	80.0	40.0	23.4
	$\frac{1}{8}$	56.4	28.2	16.5
	$\frac{3}{16}$	45.8	22.9	13.4

effect and the tool point is dulled by being slowly worn or ground away by the action of the chip. A tool operating at such a low speed can, of course, be used a comparatively long time without re-sharpening, but this is more than offset by the fact that too much time is required for removing a given amount of metal when the work is revolving so slowly. Generally speaking, the speed should be such that a fair amount of work can be done before the tool requires regrinding. Evidently it would not pay to grind a tool every few minutes in order to maintain a high cutting speed; neither would it be economical to use a very slow speed and waste considerable time in turning, just to save the few minutes required for grinding. For example, if a number of roughing cuts had to be taken over a heavy rod or shaft, time might be saved by running at such a speed that the tool would have to be sharpened (or be replaced by a tool previously sharpened) when it had traversed half-way across the work; that is, the time required for sharpening or changing the tool would be short as compared with the gain effected by the high work speed.

On the other hand, it might be more economical to run a little slower and take a continuous cut across the work with one tool.

Sometimes the work speed cannot be as high as the tool will permit, because of the chattering that often results when the lathe is old and not massive enough to absorb the vibrations, or when there is unnecessary play in the working parts. The shape of the tool used also effects the work speed, and as there are so many things to be considered, the proper cutting speed is best determined by experiment. The two accompanying tables, giving cutting speeds for hard, medium, and soft steel and cast iron will be found useful, in a general way, in determining the most economical speed. These tables represent a few of the experiments conducted by Mr. Fred W. Taylor, and the figures given are based on the use of a tool correctly ground and made of a good grade of high-speed steel, properly heat treated.

It will be noted that the cutting speed is much slower for cast iron than for steel, and also that the feed and depth of cut have a very decided effect on the speed. Cast iron is cut with less pressure or resistance than soft steel, but the slower speed for cast iron is probably because the pressure of the chip is concentrated closer to the cutting edge, combined with the fact that cast iron wears the tool faster than steel, the wear occurring close to the cutting edge.

The number of revolutions required to give any desired cutting speed can be found by multiplying the cutting speed, in feet per minute, by 12 and dividing the product by the circumference of the work in inches. Expressing this as a formula we have

$$R = \frac{C \times 12}{\pi d}$$

in which

R = revolutions per minute;
C = the cutting speed in feet per minute;
π = 3.1416; and
d = the diameter in inches.

For example if a cutting speed of 60 feet per minute is wanted and the diameter of the work is 5 inches, the required speed for the work would be found as follows:

$$R = \frac{60 \times 12}{3.1416 \times 5} = 46 \text{ revolutions per minute.}$$

If the diameter is simply multiplied by 3 and the fractional part is omitted, the calculation can easily be made, and the result will be close enough for practical purposes. In case the cutting speed, for a given number of revolutions and diameter, is wanted, the following formula can be used:

$$C = \frac{R \pi d}{12}$$

Of course, machinists that operate lathes do not know, ordinarily, what cutting speeds in feet per minute are used for different classes of work, but are guided entirely by past experience.

The amount of feed and depth of cut also vary, like the cutting speed, with different conditions. Ordinarily coarser feeds and a greater depth of cut can be used for cast iron than for soft steel because cast iron offers less resistance to turning, but in any case, with a given depth of cut, metal can be removed more quickly by using a coarse feed and the necessary slower speed, than by using a fine feed and the accompanying higher speed. When the turning operation is simply to remove metal, coarse feeds and deep cuts are taken, but sometimes the cut must be comparatively light, either because the work is too fragile and springy to withstand the strain of a heavy cut, or the lathe has not sufficient pulling power. The difficulty with light slender work is that a heavy cut may cause the part being turned to bend under the strain, thus causing the tool to gouge in which would probably result in spoiling the work. Steady-

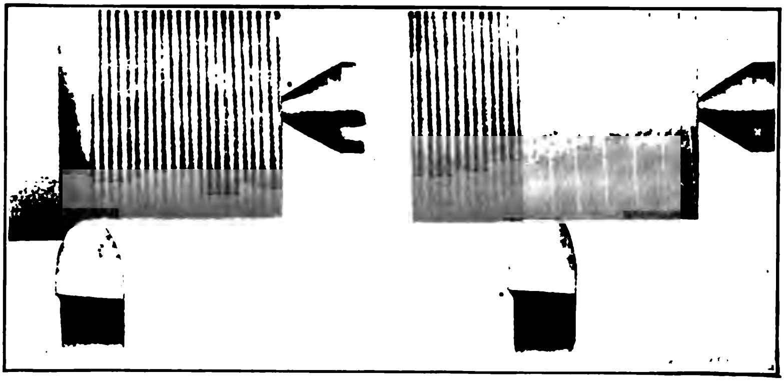


Fig. 23. Roughing Cut—Light Finishing Cut and Coarse Feed

rests can often be used to prevent flexible parts from springing, but there are many kinds of light work to which the steadyrest cannot be applied to advantage.

The amount of feed to use for a finishing cut might, properly, be either fine or coarse. Ordinarily fine feeds are used for finishing steel, especially if the work is at all flexible, but a finishing cut in cast iron is often accompanied by a coarse feed. Fig. 23 illustrates the feeds that are often used when turning cast iron. The view to the left shows a deep roughing cut and the one to the right, a finishing cut. By using a broad flat cutting edge set parallel to the tool's travel, and a coarse feed for finishing, a smooth cut can be taken in a comparatively short time. Some castings which are close to the finished size in the rough, can be finished by taking one cut with a broad tool, provided the work is sufficiently rigid. It is not always practicable to use these broad tools and coarse feeds, as they sometimes cause chattering, and when used on steel, a broad tool tends to gouge or "dig in" unless the part being turned is rigid. Heavy steel parts, however, are sometimes finished in this way. Much of the work that is turned, at the present time, is afterwards finished in a grinding machine so that often it is not necessary to take a finishing cut to secure a smooth surface.

CHAPTER IV

THREADS OF DIFFERENT FORM AND METHODS OF CUTTING

Three forms of threads which are very common in this country are shown in Fig. 24; these are the V-thread *A*, the U. S. standard *B*, and the square thread *C*. The shapes of these threads are shown by the sectioned parts. The V-thread has straight sides which make an angle of 60 degrees with each other and a like angle with the axis of the screw. The U. S. standard thread is similar to the V-thread except that the top of the thread and bottom of the groove is left flat, as shown, and the width of these flats is made equal to 1/8 of the pitch. The square thread is square in section, the width *a*, depth *b* and space *c* being all equal. All of these threads are right-hand, which means that the grooves wind around to the right so that a nut will have to be turned toward the right to enter it on the thread. A left-hand thread winds in the other direction, as shown at *D*, and a nut is screwed on by turning it to the left. Threads, in addition to being right- and left-handed, are single, as at *A*, *B*, *C*, and *D*, double, as at *E*, and triple, as at *F*, and for certain purposes quadruple threads are employed. A double thread is different from a single thread in that it has two grooves, starting diametrically opposite, whereas a triple thread has three grooves cut as shown at *F*. The object in having these multiple threads is to obtain an increase in lead without weakening the screw. For example, the threads shown at *C* and *E*, have the same pitch, but the lead of the double-threaded screw is twice that of the one with a single thread so that a nut would advance twice as far in one revolution, which is often a very desirable feature. To obtain the same lead with a single thread, the pitch would have to be double, thus giving a much coarser thread, which would weaken the screw, unless its diameter were increased. (The lead is the distance *l* that one thread advances in a single turn, or the distance that a nut would advance in one turn, and it should not be confused with the pitch *p*, which is the distance between the centers of adjacent threads. The lead and pitch of a single thread are the same.)*

Cutting a U. S. Standard Thread

A U. S. standard thread is cut in the same way described for a V-thread, in Chapter VIII, MACHINERY'S Reference Series No. 91, but as it has a different form, a tool of corresponding shape is used. This tool is first ground to an angle of 60 degrees, as it would be for cutting a V-thread, and then the point is made flat as shown in Fig. 25. As the width of this flat is equal to 1/8 of the pitch, it varies, of course, for different pitches. By using a gage like the one shown at *G*, the tool can easily be ground for any pitch, as the notches around the

*See also MACHINERY'S Reference Book No. 31: "Screw Thread Tools and Gages."

periphery of the gage are marked for different pitches and the tool-point is fitted into the notch corresponding to the pitch wanted.

When the cutting the thread, the tool is set square with the blank, and a number of successive cuts are taken, the tool being fed in until the width *w* of the flat at the top of the thread is equal to the width at the bottom. The thread will then be the right size provided the outside diameter *D* is correct. As it would be difficult to measure

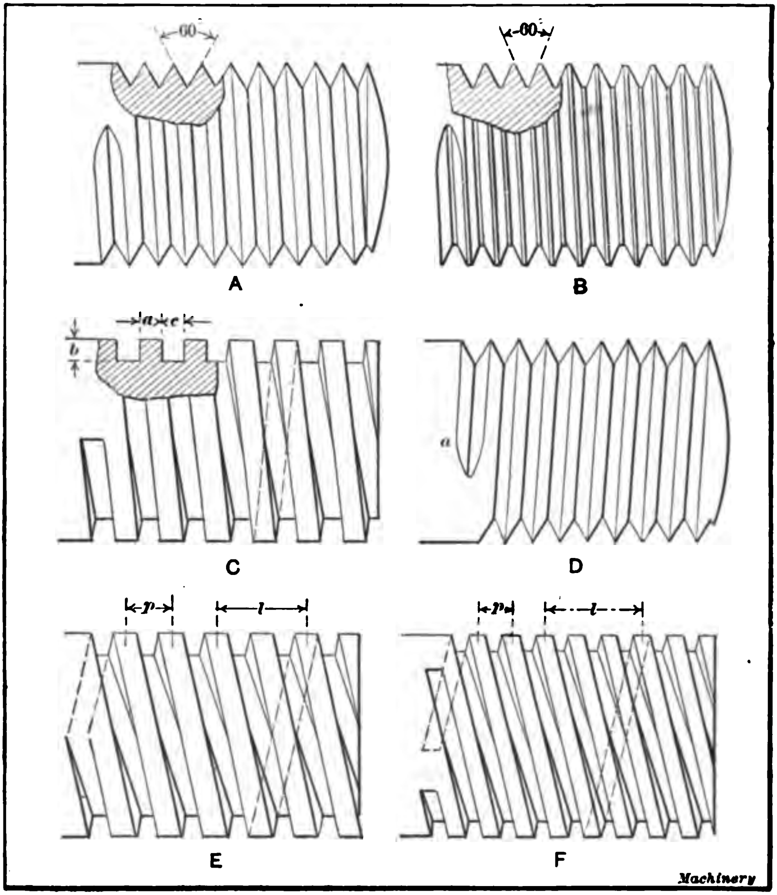


Fig. 24. (A) V-thread. (B) U. S. Standard Thread. (C) Square Thread. (D) Left-hand Thread. (E) Double Square Thread. (F) Triple Square Thread

the width of this flat accurately, the thread can be tested by screwing a standard nut over it if a standard thread is being cut. If it is being fitted to a tapped hole, the tap itself is a very convenient gage to use, the method being to caliper the tap and then compare its size with the work. Calipers or micrometers, such as illustrated in Fig. 60 (Part I), can be used.

A good method of cutting a U. S. standard thread to a given size is as follows: First turn the outside of the blank accurately to diameter *D*, and then turn a small part on the end to diameter *r* of the thread at the root. The finishing cut for the thread is then taken with the tool point set to just graze diameter *r*. If ordinary calipers were set to diameter *r* and measurements taken in the thread groove, the size might be incorrect owing to the angularity of the groove, which makes it necessary to hold the calipers at an angle when meas-

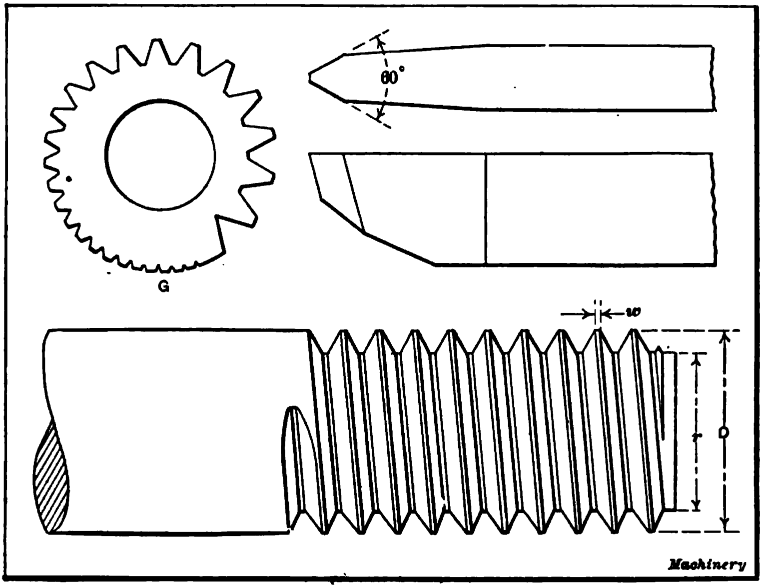


Fig. 25. U. S. Standard Thread, Thread Tool, and Gage

uring. A table, giving root diameters for various pitches, is convenient to have, but this diameter can be found by the following formula:

$$D - \left(\frac{1.299}{N}\right) = r$$

in which *D* equals outside diameter, *N* the number of threads per inch, and *r* the root diameter. The number 1.299 is a constant that is always used.

Cutting a Left-hand Thread

The only difference between cutting left-handed and right-handed threads in the lathe, is in the movement of the tool with relation to the work. When cutting a right-hand thread, the tool moves from right to left, but this movement is reversed for left-hand threads because the thread winds around in the opposite direction. To make the carriage travel from left to right, the lead-screw is rotated backwards by means of reversing gears *a* and *b* (Fig. 26) located in the headstock. Either of these gears can be engaged with the spindle gear by changing the position of lever *R*. When gear *a* is in engagement, as shown, the drive from the spindle to gear *c* is through gears *a* and *b*, but when lever *R* is raised thus shifting *b* into mesh, the drive is direct and the direction of rotation is reversed. The thread is cut by starting the tool at *a*, Fig. 24, instead of at the end.

Cutting a Square Thread

The form of tool used for cutting a square thread is shown in Fig. 27. The width *w* is made equal to one-half the pitch of the thread to be cut and the end *E* is at an angle with the shank, which corresponds to the inclination *x–y* of the threads. This angle *A* depends on the diameter of the screw and the lead of the thread; it can be determined graphically by laying off a line *a–b* equal to the circumference of the screw to be cut, and a line *b–c*, at right angles, equal to the lead of the thread. The angle *a* between lines *a–b* and

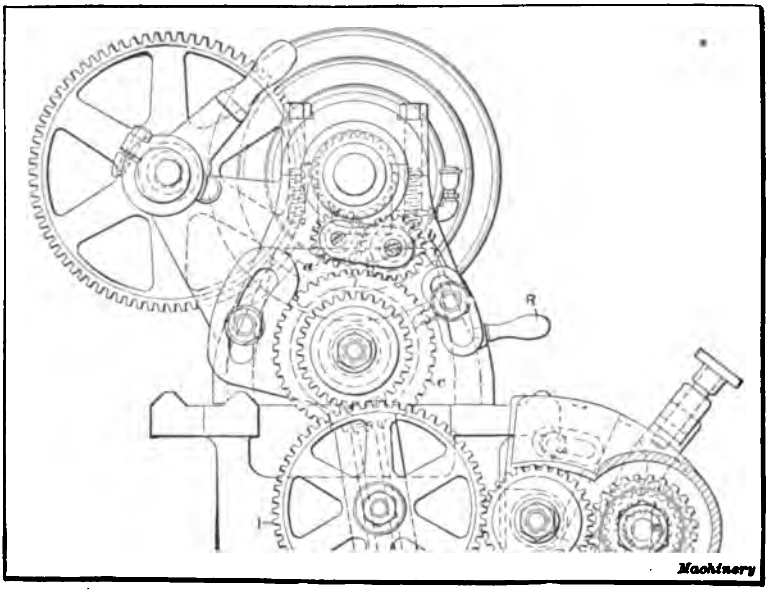


Fig. 26. End View of Lathe Headstock

a–c will be the required angle *A*. It is not necessary to have this angle accurate, ordinarily, as it is simply to prevent the tool from binding against the sides of the thread. The end of a square thread tool is shown in section to the right to illustrate its position with relation to the threads. The sides *e* and e_1 are ground to slope inward, as shown, to provide additional clearance.

When cutting multiple threads, which, owing to their increased lead, incline considerably with the axis of the screw, the angles for each side of the tool can be determined independently as follows: Lay off *a–b* equal to the circumference of the thread, as before, to obtain the required angle *f* of the rear or following side e_1; the angle *l* of the opposite or leading side is found by making *a–b* equal to the circumference at the root of the thread. The tool illustrated is for cutting right-hand threads; if it were intended for a left-hand thread, the end, of course, would incline in the opposite direction. The square thread is cut so that the depth *d* is equal to the width.

Cutting Multiple Threads

When a multiple thread is to be cut, as a double or triple thread, the lathe is geared with reference to the number of single threads to the inch. For example, the lead of the double thread, shown at *B*, Fig. 28, is one-half inch, or twice the pitch, and the number of single threads to the inch equals $1 \div \frac{1}{2} = 2$.

Therefore, the lathe is geared for cutting two threads per inch. The first cut is taken just as though a single thread were being cut, leaving the work as shown at *A*. When this cut is finished the work is turned one-half a revolution (for a double thread) without disturbing the position of the lead-screw or carriage, which brings the tool midway between the grooves of the single thread as indicated by

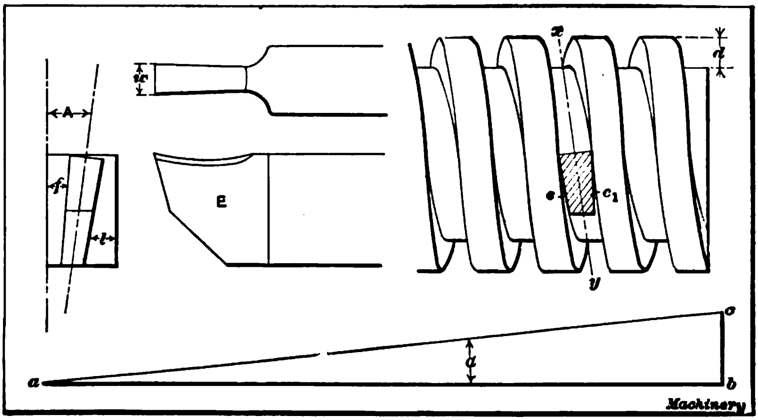


Fig. 27. End of Square Thread Tool, and Graphic Method of Determining Helix Angle of Thread

dotted lines. The second groove is then cut, producing a double thread as shown at *B*. In the case of a triple thread, the work would be indexed one-third of a revolution after turning the first groove, and then another third revolution to locate the tool for cutting the last groove. Similarly, for a quadruple thread, it would be turned one-quarter revolution after cutting each successive groove or thread.

There are different methods of indexing work when cutting multiple threads. Some machinists, when cutting a double thread, simply remove the work from the lathe and turn it one-half a revolution by placing the tail of the driving dog in the opposite slot of the faceplate. This is a very simple method, but if the slots are not directly opposite or 180 degrees apart, the last thread will not be central with the first. Another and better method is to disengage the idler gear from the gear on the stud, turn the spindle and work one-half, or one-third, of a revolution, as the case might be, and then connect the gears. For example, if the stud gear had 96 teeth, the tooth meshing with the idler gear would be marked with chalk, the gears disengaged, and the spindle turned until the chalked tooth had made the required part of a revolution, which could be determined by counting the teeth. When this method is used, the number of teeth in the stud gear must be evenly divisible by two if a double thread is being cut, or by three for a triple thread. If the stud is not geared to the spindle so that each makes the same number of revolutions, the ratio of the gearing must be considered.

Special faceplates are sometimes used for multiple thread cutting, that enable work to be easily and accurately indexed. One of these is illustrated in Fig. 29, and consists of two parts *A* and *B*, part *A* being free to rotate in relation to *B* when bolts *C* are loosened. The driving pin for the lathe dog is attached to plate *A*. When one

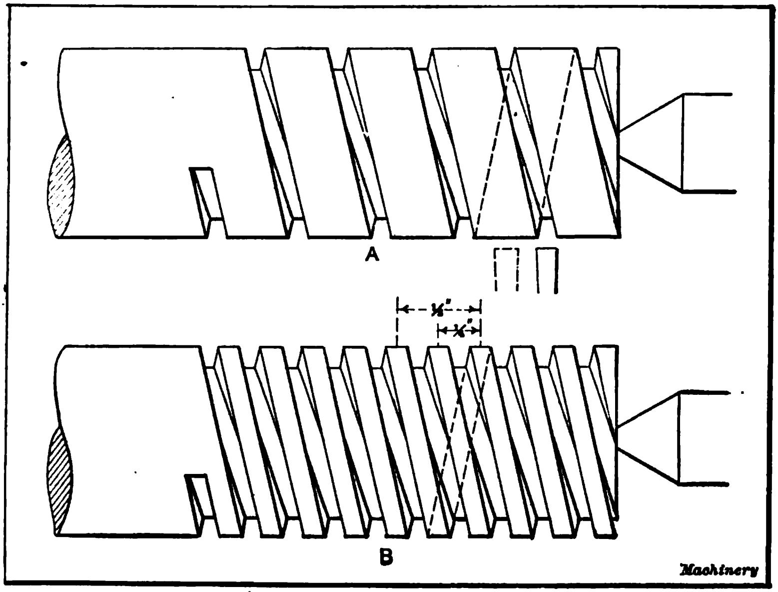


Fig. 28. Views illustrating how a Double Square Thread is Cut

groove of a multiple thread is finished, bolts *C* are loosened and plate *A* is turned around an amount corresponding to the type of thread being cut. The periphery of plate *A* is graduated in degrees, as shown, and for a double thread it will be turned one-half revolution or 180 degrees, for a triple thread 120 degrees, etc. This is a very good arrangement where multiple thread cutting is done frequently.

Taper Threading

When a taper thread is to be cut, the tool should be set square with axis *a—a* as at *A*, Fig. 30, and not by the tapering surface as at *B*. If there is a cylindrical part, the tool can be set as indicated by the dotted lines. All taper threads should be cut by the use of taper attachments. If the tailstock is set over to get the required taper, the curve of the thread will not be true, or in other words the thread will not advance at a uniform rate; this is referred to by machinists as a "drunken thread."

Internal Threading

Internal threading, or cutting threads in holes, is an operation performed on work held in the chuck or on a faceplate, as for boring. The tool used is similar to a boring tool except that the working end is shaped to conform to the thread to be cut. An internal threading

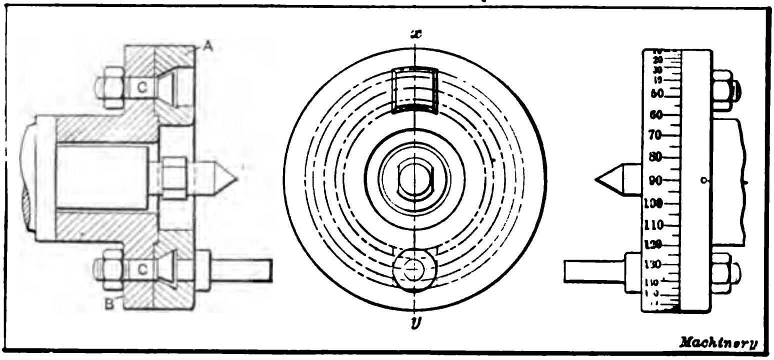


Fig. 29. Indexing Faceplate used for Multiple Thread Cutting

tool for cutting a V-thread is shown in Fig. 31. The method of procedure, when cutting an internal thread, is similar to that for outside work, as far as handling the lathe is concerned. The hole to be threaded is first bored to the root diameter of the thread that is to fit into it. The tool-point is then set square by holding a gage *G* against the true side of the work and adjusting the point to fit the notch in the gage as shown. Very often the size of a threaded hole

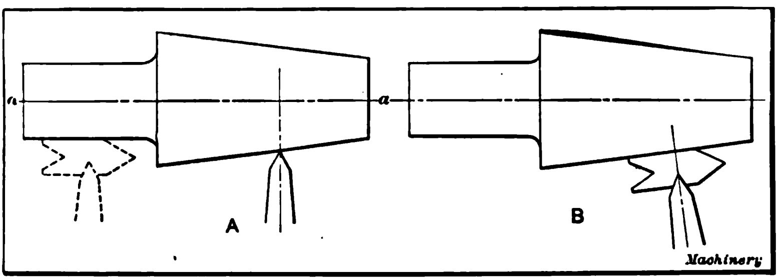


Fig. 30. Correct and Incorrect Positions of Tool for Taper Thread Cutting

can be tested by using as a gage the threaded part that is to fit into it. When making such a test, the tool is, of course, moved back out of the way. It is rather difficult to cut an accurate thread in a small hole, especially when quite deep, owing to the flexibility of the tool; for this reason threads are sometimes cut slightly under size with the tool, after which a tap with its shank end held straight by the tailstock center, is run through the hole. In such a case, the tap should be calipered and the thread made just small enough with the tool to give the tap a light cut. Small square-threaded holes are often finished in this way, and if a number of pieces are to be threaded, the use of a tap makes the holes uniform in size.

Stop for Thread Tools

When cutting a thread, it is rather difficult to feed in the tool just the right amount for each successive cut, because the tool is moved in before it feeds up to the work. A stop is sometimes used for threading which overcomes this difficulty. This stop consists of a screw which enters the tool slide and passes through a block clamped in front of the slide. The hole in the block through which the stop-screw passes is not threaded, but is large enough to permit the screw to move freely. When cutting a thread, the tool is set for the first cut and the

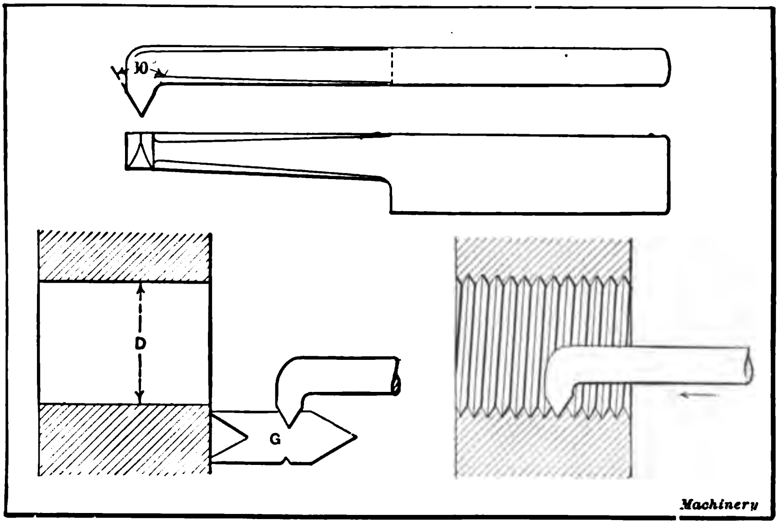


Fig. 31. Inside Thread Tool—Method of Setting and Using

screw is adjusted until the head is against the fixed block. After taking the first cut, the stop-screw is backed out, say one-half revolution, which allows the tool to be fed in far enough for a second cut. If this cut is about right for depth, the screw is again turned about one-half revolution and this is continued for each successive cut until the thread is finished. By using a stop of this kind, there is no danger of feeding the tool in too far as is often done when the tool is set by guess. If this form of stop is used for internal threading, the screw, instead of passing through the fixed block, is placed in the slide so that the end or head will come against the stop. This change is made because the tool is fed outward when cutting an internal thread.

Rivett-Dock Threading Tool

A special form of thread tool, which overcomes a number of disadvantages common to an ordinary single-point thread tool, is shown in Fig. 32. This tool has a circular-shaped cutter *C*, having ten teeth around its circumference, which, beginning with tooth No. 1, gradually increase in height, cutter No. 2 being higher than No. 1, etc. This cutter is mounted on a slide *S*, that is fitted to the frame *F*, and can be moved in or out by lever *L*. The hub of this lever has an eccentric stud which moves slide *S* and locks it when in the forward or cutting position. The action of the lever in moving the slide, engages the cutter with pawl *P*, thus rotating the cutter one tooth at a time and presenting a different tooth to the work for each movement of the lever. When the slide is moved forward, the heel or underside of the tooth which is in the working position, rests on a stop that takes the thrust of the cut. When the tool is in use, it is mounted on the tool-block of the lathe as shown in the illustration. The cutter is

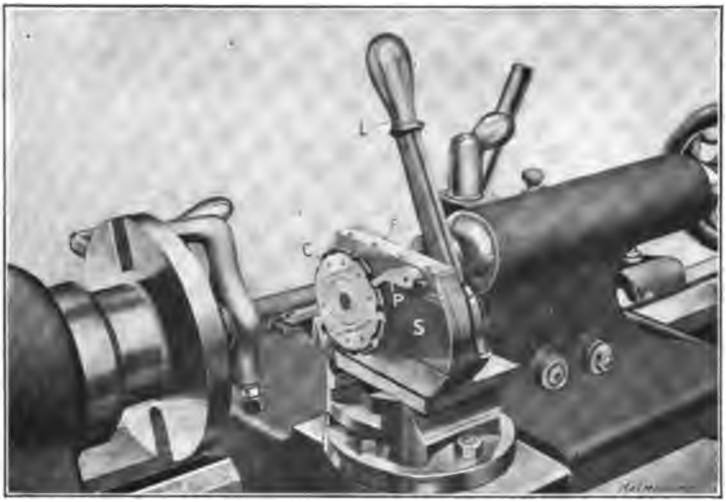


Fig. 32. Rivett-Dock Circular Threading Tool in Working Position

set for height by placing a tooth in the working position and setting the top level with the lathe center. The cutter is also set square with the work by using an ordinary square, and it is tilted slightly from the vertical to correspond with the angle of the thread to be cut, by adjusting frame *F*. At first a light cut is taken with lever *L* moved forward and tooth No. 1 on the stop. After this is completed, the lever is reversed which rotates the cutter one tooth, and the return movement places tooth No. 2 in the working position. This operation is repeated until the tenth tooth finishes the thread. It is often necessary, when using a single-point thread tool, to re-sharpen it before taking the finishing cut, but with a circular tool this is not necessary for by using the different teeth successively, the last tooth, which only takes finishing cuts, is kept in good condition. This tool has a micrometer adjustment which enables threads to be cut to the same size without the use of a gage.

CHAPTER V

TOOL GRINDING

In the grinding of lathe tools, there are three things of importance to be considered: First, the cutting edge of the tool (as viewed from the top) needs to be given a certain shape; second, there must be a sufficient amount of clearance; and third, tools, with certain exceptions, are ground with a backward slope or a side slope, or with a combination of these two slopes on that part against which the chip bears when the tool is in use.

Meaning of Terms Used in Tool Grinding

In Fig. 33 a few of the different types of tools which are used in connection with lathe work are shown. This illustration also

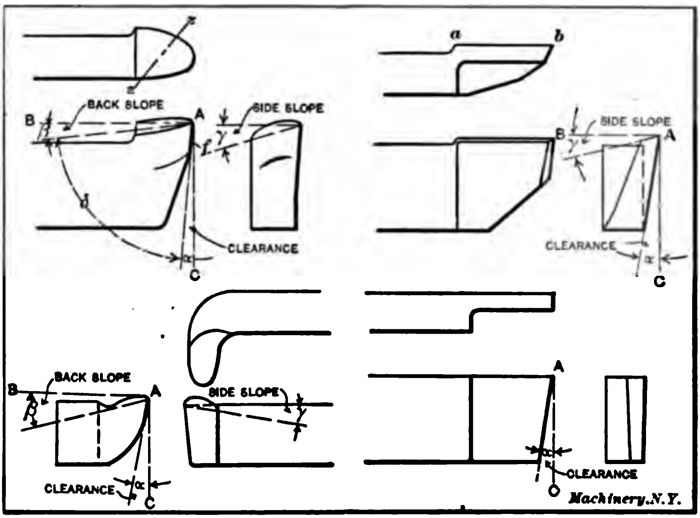


Fig. 33. Illustration showing the Meaning of Terms used in Tool Grinding as applied to Tools of Different Types

indicates the meaning of the various terms used in tool grinding. As shown, the clearance of the tool is represented by the angle α, the back slope is represented by the angle β, and the side slope by the angle γ. The angle δ for a tool without side slope, is known as the lip angle or the angle of keenness. When, however, the tool has both back and side slopes, this lip angle would more properly be the angle between the flank f and the top of the tool, measured diagonally along a line z—z. It will be seen that the lines A—B and A—C from which the angles of clearance and back slope are measured, are parallel with the top and sides of the tool shank, respectively. For lathe tools, however, these lines are not necessarily located in this way when the tool is in use, as the height of the tool point with relation to the work center determines the position of these lines so that the *effective* angles of back slope, clearance and keenness are changed as the tool point is lowered or raised. The way the position of the tool effects these angles will be explained later.

While tools must, of necessity, be varied considerably in shape to adapt them to various purposes, there are certain underlying principles governing their shape which apply generally; so in what follows we shall not attempt to explain in detail just what the form of each tool used on the lathe should be, as it is more important to understand how the cutting action of the tool and its efficiency is affected when it is improperly ground. When the principle is understood, the grinding of tools of various types and shapes is comparatively easy.

Shape or Contour of Cutting Edge

In the first place we shall consider the shape or contour of the cutting edge of the tool as viewed from the top, and then take up the

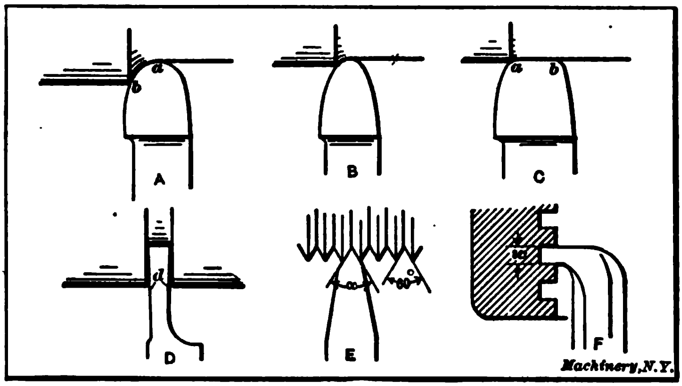


Fig. 34. Plan View of Lathe Turning and Threading Tools

question of clearance and slope, the different elements being considered separately to avoid confusion.

The contour of the cutting edge depends primarily upon the purpose for which the tool is intended. For example, the tool *A*, in Fig. 34, where a plan view of a number of different lathe tools is shown, has a very different shape from that of, say, tool *D*, as the first tool is used for rough turning, while tool *D* is intended for cutting grooves or severing a turned part. Similarly, tool *E* is V-shaped because it is used for cutting V-threads. Tools *A*, *B* and *C*, however, are regular turning tools, that is, they are all intended for turning plain cylindrical surfaces, but the contour of the cutting edges varies considerably, as shown. In this case it is the characteristics of the work and the cut that are the factors which determine the shape. To illustrate, tool *A* is of a shape suitable for rough turning large and rigid work, while tool *B* is adapted for smaller and more flexible parts. The first tool is well shaped for roughing because experiments have shown that a cutting edge of a large radius is capable of higher cutting speed than could be used with a tool like *B*, which has a smaller point. This increase in the cutting speed is due to the fact that the tool *A* removes a thinner chip for a given feed than tool *B*. Therefore, the speed may be increased without injuring the cutting edge to the same extent. If, however, tool *A* were to be used for turning a long and flexible part, chattering would result. Consequently, a tool *B* having a point with a smaller radius would be preferable, if not absolutely necessary. The character of the work also affects the shape of tools. The tool shown at *C* is used for taking light finishing cuts with a wide feed. Obviously, if the straight or flat part of the cutting edge is in line with the travel of the tool, the cut will be smooth and free from ridges, even though the feed is coarse, and by using a coarse feed the cut is taken in less time; but such a tool cannot be used on work that is not rigid, as chattering would result. Therefore, a smaller cutting point and a reduced feed would have to be employed. Tools with broad flat cutting edges and coarse feeds are often used for taking finishing cuts in cast iron, as this metal offers less resistance to cutting than steel, and is less conducive to chattering.

The shape of a tool (as viewed from the top) which is intended for a more specific purpose than regular turning, can be largely determined by simply considering the tool under working conditions. This point may be illustrated by the parting tool *D* which, as previously stated, is used for cutting grooves, squaring corners, etc. Evidently this tool should be widest at the cutting edge; that is, the sides *d* should have a slight amount of clearance so that they will not bind as the tool is fed into a groove. As the tool at *E* is for cutting a V-thread, the angle *a* between its cutting edges must equal the angle between the sides of a V-thread, or 60 degrees. The tool illustrated at *F* is for cutting inside square threads. In this case the width *w* should be made equal to one-half the pitch of the thread, and the sides should be given a slight amount of side clearance, the same as with the parting tool *D*. So we see that the outline of the tool, as viewed from the top, must conform to and be governed by its use.

Direction of Top Slope for Turning Tools

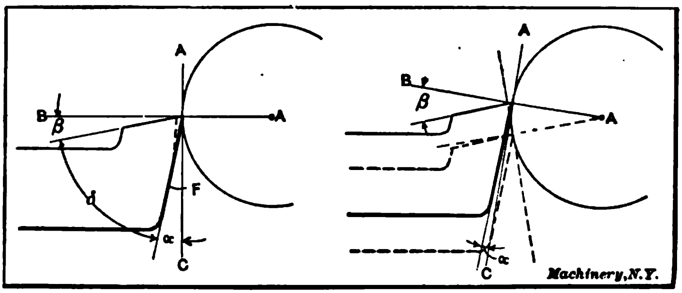
Aside from the question of the shape of the cutting edge as viewed from the top, there remains to be determined the amount of clearance that the tool shall have, and also the slope (and its direction) of the top of the tool. By the top is meant that surface against which the chip bears while it is being severed. It may be stated, in a general way, that the direction in which the top of the tool should slope should be away from what is to be the *working part* of the cutting edge. For example, the working edge of a roughing tool *A* (Fig. 34), which is used for heavy cuts, would be, practically speaking, between points *a* and *b*, or in other words, most of the work would be done by this part of the cutting edge; therefore the top should slope back from this part of the edge. Obviously, a tool ground in this way will have both a back and a side slope. When most of the work is done on the point or nose of the tool, as for example, with the lathe finishing tool *C* which takes light cuts, the slope should be back from the point or cutting edge *a–b*. As the side tool shown in

Fig. 33 does its cutting along the edge *a–b*, the top is given a slope back from this edge as shown in the end view. This point should be remembered, for when the top slopes in the right direction, less power is required for cutting. Tools for certain classes of work, such as thread tools, or those for turning brass or chilled iron, are ground flat on top, that is, without back or side slope.

Clearance for the Cutting Edge

Now, in order that the cutting edge may work without interference, it must have clearance; that is, the flank *f* (Fig. 33) must be ground to a certain angle α so that it will not rub against the work and make the cutting edge ineffective. This clearance should be just enough to permit the tool to cut freely. A clearance angle of eight or ten degrees is about right for lathe turning tools.

The back slope of a tool is measured from a line *A–B* which is parallel to the shank, and the clearance angle, from a line *A–C* at right angles to line *A–B*. These lines do not, however, always occupy this position with relation to the tool shank when the tool is in use.



Figs. 35 and 36. Illustrations showing how Effective Angles of Slope and Clearance change as Tool is raised or lowered

As shown in Fig. 35, the base line *A–B* for a turning tool in use, intersects with the point of the tool and center of the work, while the line *A–C* remains at right angles to the first. It will be seen then, that by raising the tool, as shown to the right (Fig. 36), the *effective* clearance angle α will be diminished, whereas lowering it, as shown by the dotted lines, will have the opposite effect.

A turning tool for brass or other soft metal, particularly where considerable hand manipulation is required, could advantageously have a clearance of twelve or fourteen degrees, as it would then be easier to feed the tool into the metal; but, generally speaking, the clearance for turning tools should be just enough to permit them to cut freely. Excessive clearance weakens the cutting edge and may cause it to crumble under the pressure of the cut.

Angle of Tool-point and Amount of Top Slope

The lip angle or the angle of keenness δ (Fig. 33) is another important consideration in connection with tool grinding, for it is upon this angle that the efficiency of the tool largely depends. By referring to the illustration it will be seen that this angle is governed by the clearance and the slope β, and as the clearance remains practically the same, it is the slope which is varied to meet different conditions. Now, the amount of slope a tool should have depends on the work for which it is intended. If, for example, a turning tool is to be used for roughing medium or soft steel, it should have a back slope of eight degrees and a side slope ranging from fourteen to twenty degrees, while a tool for cutting very hard steel should have a back slope of five degrees and a side slope of nine degrees. The reason for decreasing the slope and thus increasing the lip angle for harder metals is to give the necessary increased strength to the cutting edge to prevent it from crumbling under the pressure of the cut. The tool illustrated at *A*, Fig. 37, is much stronger than it would be if ground as shown at *B*, as the former is more blunt. If a tool ground as at *A*, however, were used for cutting very soft steel, there would be a greater chip pressure on the top and, consequently, a greater resistance to cutting, than if a keener tool had been employed; furthermore the cutting

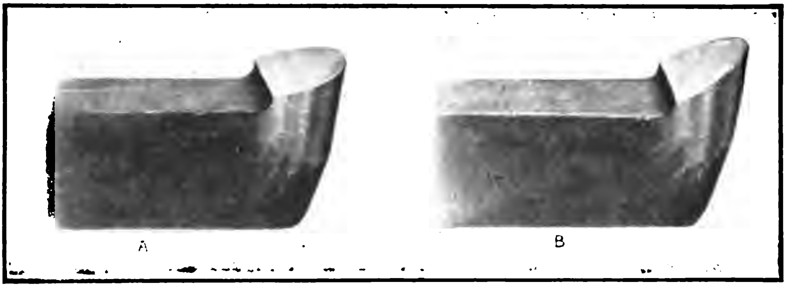


Fig. 37. (A) Blunt Tool for Turning Hard Steel. (B) Tool-point Ground to Give Keenness

speed would have to be lower, which is of even greater importance than the chip pressure; therefore, the lip angle, as a general rule, should be as small as possible without weakening the tool so that it cannot do the required work. In order to secure a strong and well-supported cutting edge, tools used for turning very hard metal, such as chilled rolls, etc., are ground with practically no slope and with very little clearance. Brass tools, while given considerable clearance, as previously stated, are ground flat on top or without slope; this is not done, however, to give strength to the cutting edge, but rather to prevent the tool from gouging into the work, which it is likely to do if the part being turned is at all flexible and the tool has top slope.

Experiments conducted by Mr. F. W. Taylor to determine the most efficient form for lathe roughing tools, the results of which have already been published in MACHINERY (January to August, 1907, engineering edition), showed that the nearer the lip angle approached sixty-one degrees, the higher the cutting speed. This, however, does not apply to tools for turning cast iron, as the latter will work more efficiently with a lip angle of about sixty-eight degrees. This is because the chip pressure, when turning cast iron, comes closer to the cutting edge which should, therefore, be more blunt to withstand the abrasive action and heat. Of course, the foregoing remarks concerning lip angles apply more particularly to tools used for roughing.

The way a turning tool is held while the top surface is being ground is shown in Fig. 38. By inclining the tool with the wheel face, it will be seen that both the back and side slopes may be ground at the same time. When grinding the flank of the tool it should be held on the tool-rest of the emery wheel or grindstone, as shown in Fig. 39. In order to form a curved cutting edge, the tool is turned about the face of the stone while it is being ground. This rotary movement can be effected by supporting the inner end of the tool with one hand while the shank is moved to and fro with the other.

Often a tool which has been ground properly in the first place, is greatly mis-shapen after it has been sharpened a few times. This is usually the result of attempts on the part of the workman to resharpen it hurriedly; for example, it is easier to secure a sharp edge on the turning tool shown in Fig. 35, by grinding the flank as indi-

Figs. 38 and 39. Grinding the Top and Flank of a Turning Tool

cated by the dotted line, than by grinding the entire flank. The clearance is, however, reduced and the lip angle changed.

There is great danger when grinding a tool of burning it or drawing the temper from the fine cutting edge, and, aside from the actual shape of the cutting end, this is the most important point in connection with tool grinding. If a tool is pressed hard against an emery or other abrasive wheel, even though the latter has a copious supply of water, the temper will sometimes be drawn.

When grinding a flat surface, to avoid burning, the tool should be frequently withdrawn from the stone so that the cooling water (a copious supply of which should be provided) can have access to the surface being ground. A moderate pressure should also be applied, as it is better to spend an extra minute or two in grinding, than to ruin the tool by burning it in an attempt to sharpen it quickly. Of course, what has been said about burning, applies more particularly to carbon steel, but even self-hardening steels are not improved by being overheated at the stone.

In some shops tools are ground to the theoretically correct shape in special machines instead of by hand. The sharpened tools are then kept in the tool-room and are given cut as they are needed.

CHAPTER VI

QUICK CHANGE-GEAR TYPE OF LATHE

A type of lathe that is much used at the present time is shown in Fig. 40. This is known as the quick change-gear type, because it has a system of gearing which makes it unnecessary to remove the change gears and replace them with different sizes for cutting threads of various pitches. Changes of feed are also obtained by the same mechanism, but the feeding movement is transmitted to the carriage by the rod *R*, whereas the screw S_1 is used for screw cutting. As previ-

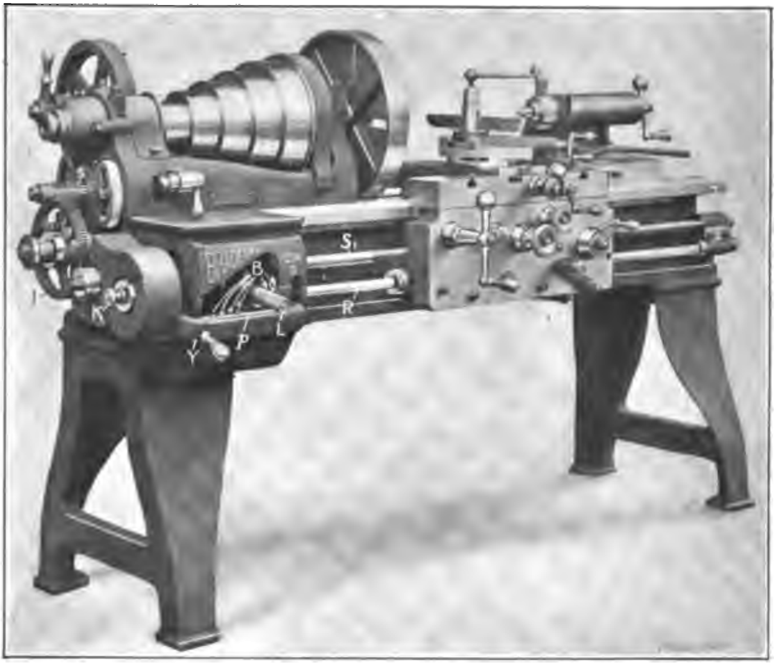


Fig. 40. Lathe Having Quick Change-gear Mechanism

ously explained the idea of using the screw exclusively for threading is to prevent it from being worn excessively, as it would be if continually used in place of rod *R*, for feeding the carriage when turning.

The general construction of this quick change gear mechanism and the way the changes are made for cutting threads of different pitch, will be explained in connection with Figs. 40, 41 and 42, which are marked with the same reference letters for corresponding parts. Referring to Fig. 40, the movement is transmitted from gear *s* on

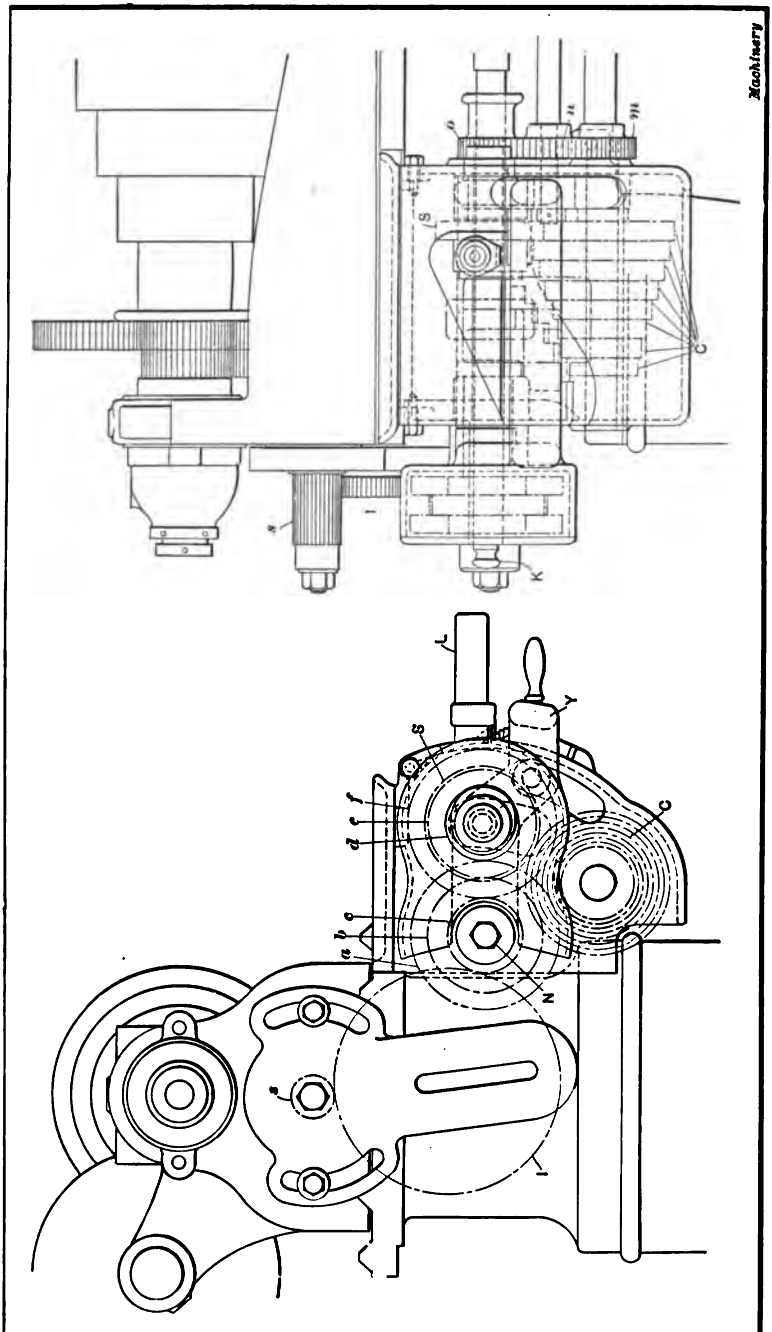


Fig. 41. End and Side Views of Quick Change-gear Mechanism

the spindle stud through idler gear *I*, which can be moved sidewise to mesh with either of the three gears *a*, *b* or *c*, Fig. 41. This cone of three gears engages gears *d*, *e* and *f*, any one of which can be locked with shaft *T* (Fig. 42) by changing the position of knob *K*. On shaft *T* there is a gear *S* which can be moved along the shaft by hand lever *L* and, owing to the spline or key *t*, both the sliding gear and shaft rotate together. Shaft *T*, carrying gears *d*, *e* and *f* and the sliding gear *S*, is mounted in a yoke *Y*, which can be turned about shaft *N*, thus making it possible to lower sliding gear *S* into mesh with any one of a cone of eight gears *C*, Fig. 41. The shaft on which the eight gears are mounted, has at the end a small gear *m* meshing with gear *n* on the feed-rod, and the latter, in turn, drives the lead-screw, unless gear *o* is shifted to the right out of engagement, which is its position

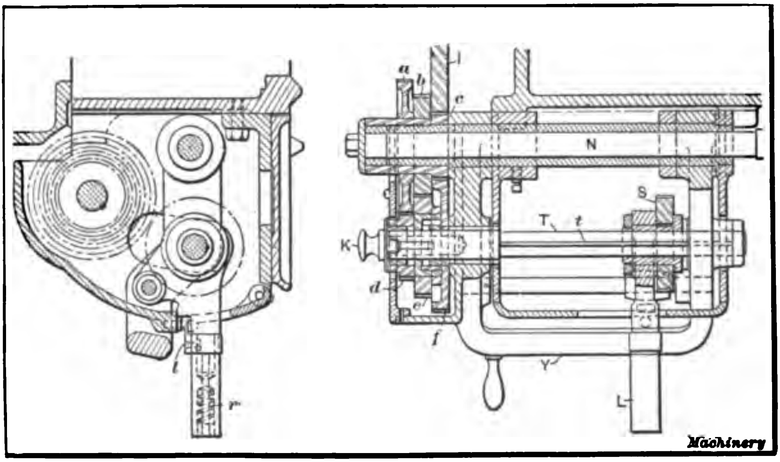


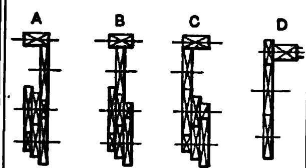
Fig. 42. Sectional Views of Quick Change-gear Mechanism

except when cutting threads. With this mechanism, eight changes for different threads or feeds are obtained by simply placing gear *S* into mesh with the various sized gears in cone *C*. As the speed of shaft *T* depends on which of the three gears *d*, *e* and *f* are locked to it, the eight changes are tripled by changing the position of knob *K*, making twenty-four. Now by shifting idler gear *I*, three speed changes may be obtained for gears *a*, *b* and *c*, which rotate together, so that the twenty-four changes are also tripled, giving a total of seventy-two variations without removing any gears, and if a different sized gear *s* were placed on the spindle stud, an entirely different range could be obtained, but such a change would rarely be necessary. As shown in Fig. 40, there are eight hardened steel buttons *B*, or one for each gear of the cone *C*, placed at different heights in the casing. When lever *L* is shifted sidewise to change the position of sliding gear *S*, it is lowered onto one of these buttons (which enters a pocket on the under side) and in this way gear *S* is brought into proper mesh with any gear of the cone *C*. To shift lever *L*, the handle is pulled outward against the tension of spring *r* (Fig. 42) which disengages latch

I and enables the lever to be lifted clear of the button; yoke *Y* is then raised or lowered, as the case may be, and lever *L* with the sliding gear is shifted to the required position.

The position of lever *L* and knob *K* for cutting threads of different pitches, is shown by an index plate or table attached to the lathe and arranged as shown in Fig. 43. The upper section *a* of this table shows the different numbers of threads to the inch that can be obtained when idler gear *I* is in the position shown by the diagram *A*. Section *b* gives the changes when the idler gear is moved, as shown at *B*, and, similarly, section *c* gives the changes for position *C* of the idler. The horizontal row of figures from 1 to 8 below the word "stops", represents the eight positions for lever *L* which has a plate *p* (Fig. 40) just beneath it with corresponding numbers, and the column to the left shows whether knob *K* should be out, in a central position, or in. In order to find what the position of lever *L* and knob *K* should be for cutting any given number of threads to the inch, find what "stop" number is directly above the number of threads to be cut, which will indicate the location of lever *L*, and also what position should be occupied by knob *K*, as shown in the column to the left. For example, suppose the lathe is to be geared for cutting eight threads to the inch. By referring to section *a* we see that lever *L* should be in position 4 and knob *K* in the center, provided the idler gear *I* were in position *A*, as it would be ordinarily, because all standard numbers of threads per inch (U. S. standard) from ¼ inch up to and including 4 inches in diameter, can be cut with the idler gear in that position. As another illustration, suppose we want to cut twenty-eight threads per inch. This is listed in section *c*, which shows that lever *L* must be placed in position 3 with knob *K* pushed in and the idler gear shifted to the left as at *C*.

DIRECTIONS FOR COMPOUNDING



POSITION OF KNOB	STOPS							
	1	2	3	4	5	6	7	8
	THREADS WITH COMP. A							
OUT	3	3 1/4	3 1/2	4	4 1/2	5	5 1/2	5 3/4
CENT	6	6 1/2	7	8	9	10	11	11 1/2
IN	12	13	14	16	18	20	22	23
	THREADS WITH COMP. B							
OUT	4 1/2	4 7/8	5 1/4	6	6 3/4	7 1/2	8 1/4	8 5/8
CENT	9	9 3/4	10 1/2	12	13 1/2	15	16 1/2	17 1/4
IN	18	19 1/2	21	24	27	30	33	34 1/2
	THREADS WITH COMP. C							
OUT	6	6 1/2	7	8	9	10	11	11 1/2
CENT	12	13	14	16	18	20	22	23
IN	24	26	28	32	36	40	44	46

Fig. 43. Index Plate showing Positions of Control Levers for Cutting Threads of Different Pitch

The simplicity of this method as compared with the time-consuming operation of removing and changing gears, is apparent. The diagram *D* to the right, shows an arrangement of gearing for cutting nineteen threads per inch. A 20-tooth gear is placed on the spindle stud (in place of the regular one having 16 teeth) and one with 95 teeth on the end of the lead-screw, thus driving the latter direct as with ordinary change gears.

CHAPTER VII

MISCELLANEOUS POINTS ON LATHE WORK

The production of accurate lathe work depends partly on the condition of the lathe used and also on the care and judgment exercised by the man operating it. Even though a lathe is properly adjusted and in good condition otherwise, errors are often made which are due to other causes which should be carefully avoided.

If the turning tool is clamped so that the cutting end extends too far from the supporting block, the downward spring of the tool, owing to the thrust of the cut, sometimes results in spoiled work, especially when an attempt is made to turn close to the finished size by taking a heavy roughing cut. Suppose the end of a cylindrical part is first

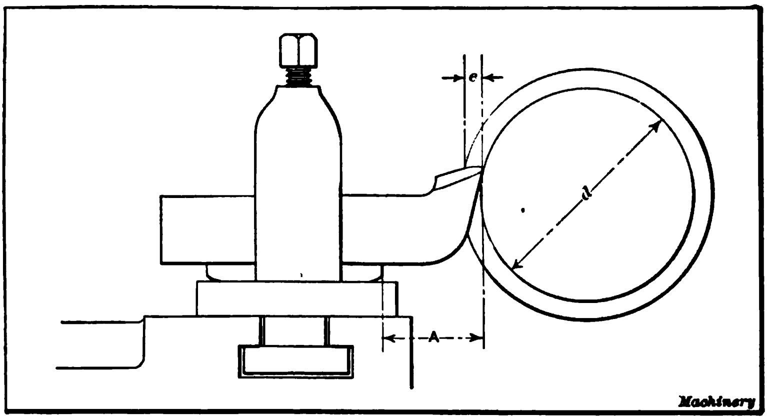


Fig. 44. To avoid springing, Overhang A of Tool should not be too great

reduced for a short distance by taking several trial cuts until the diameter *d*, Fig. 44, is slightly above the finished size and the power feed is then engaged. When the tool begins to take the full depth *e* of the cut, the point, which ordinarily would be set above the center, tends to spring downward into the work, and if there were considerable springing action, the part would probably be turned below the finished size, the increased reduction beginning at the point where the full cut started. This springing action, as far as the tool is concerned, can be practically eliminated by locating the tool so that the distance *A* between the tool-block and cutting end, or the "overhang," is as short as possible. Even though the tool has little overhang it may tilt downward because the tool-slide is loose on its ways, and for this reason the slide should have a snug adjustment that will permit an easy movement without unnecessary play.

When roughing cuts are to be taken, the tool should also be located so that any change in its position caused by the pressure of the cut, will not spoil the work. This point is illustrated at *A* in Fig. 45. Suppose the end of a rod has been reduced by taking a number of trial cuts, until it is 1/32 inch above the finished size. If the power feed is then engaged with the tool clamped in an oblique position, as shown, when the full cut is encountered at *c*, the tool, unless very tightly clamped, may be shifted backward by the lateral thrust of the cut, as indicated by the dotted lines. The point will then begin turning smaller than the finished size and the work will be spoiled. To prevent any change of position, it is good practice, especially when roughing, to clamp the tool square with the surface being turned, or in other words, at right angles to its direction of movement. Occasionally, however, there is a decided advantage in having the tool

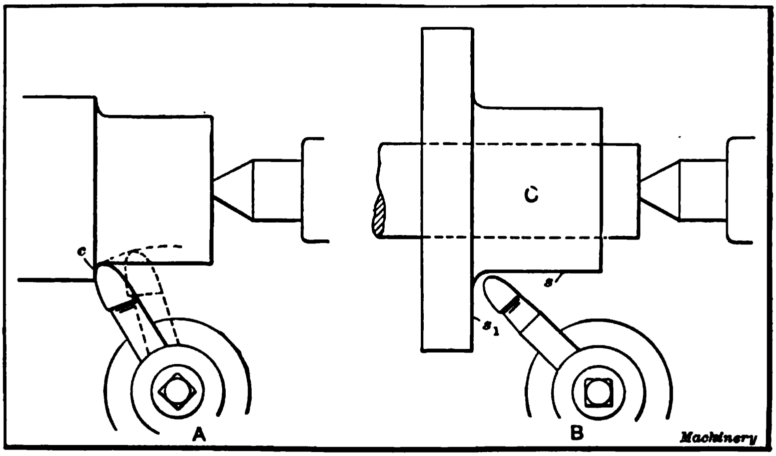


Fig. 45. (A) The Way in which Tool is sometimes displaced by Thrust of Cut, when set at an Angle. (B) Tool Set for Finishing Cylindrical and Radial Surfaces

set at an angle. For example, if it is held about as shown at *B*, when turning the flange casting *C*, the surfaces *s* and s_1 can be finished without changing the tool's position.

Work that is held in a chuck is sometimes sprung out of shape by the pressure of the chuck jaws so that when the part is bored or turned, the finished surfaces are untrue after the jaws are released and the work has resumed its normal shape. This applies more particularly to frail parts, such as rings, thin cylindrical parts, etc. Occasionally the distortion can be prevented by so locating the work with relation to the chuck jaws that the latter bear against a rigid part. When the work cannot be held tightly enough for the roughing cuts without springing it, the jaws should be released somewhat before taking the finishing cut, to permit the part to spring back to its natural shape.

Work that is turned between centers is sometimes driven by a dog which is so short for the faceplate that the bent driving end bears against the bottom *a* of the faceplate slot, as shown at *A*, Fig. 46. If the dog is nearly the right length, it may allow the headstock center to enter the center in the work part way, with the result that the turned surface is not true with the centers. When a driving dog of this type is used, care should be taken to see that it moves freely in the faceplate slot and does not bind against the bottom. By using a straight dog (*B*), which is driven by a pin *b* bolted to the faceplate, all danger from this source is eliminated. The straight dog, however, is used more particularly to do away with the leverage *l* of a bent dog, as this leverage tends to spring the part being turned. Straight dogs are also made with two driving ends which engage pins on opposite sides of the faceplate. This type is preferable because it applies the power required for turning, evenly to the work, which still further reduces the tendency to spring it out of shape. The principal objec-

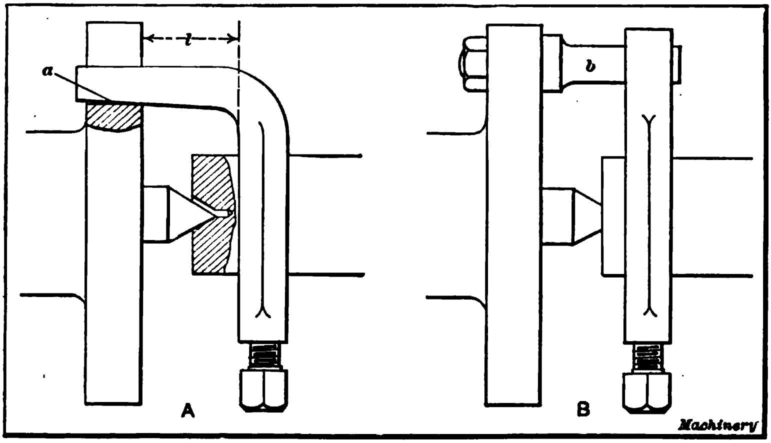


Fig. 46. (A) Dog that is too Short for Faceplate. (B) Straight Driving Dog

tion to the double-ended type lies in the difficulty of adjusting the driving pins so that each bears with equal pressure against the dog.

The lathe centers should receive careful attention especially when accurate work must be turned. If the headstock center does not run true as it revolves with the work, a round surface may be turned, but if the position of the driving dog with reference to the faceplate is changed, the turned surface will not run true because the turned surface is not true with the work centers. Furthermore, if it is necessary to reverse the work for finishing the dogged or driving end, the last part turned will be eccentric to the first. Therefore, the lathe centers should be kept true in order to produce turned surfaces that are true or concentric with the centered ends, as it is often necessary to change the part being turned "end for end" for finishing, and any eccentricity between the different surfaces would, in many cases, spoil the work.

Some lathes are equipped with hardened centers in both the head- and tail-stock and others have only one hardened center which is in the tailstock. The object in having a soft or unhardened headstock center is to permit its being trued by turning, but as a soft center is quite easily bruised and requires truing oftener than one that is hard, it is better to have both centers hardened. Special grinders are used for truing these hardened centers. One type that is very simple and easily applied to a lathe is shown in Fig. 47. This grinder is held in the lathe toolpost and is driven by a wheel *A* that is held in contact with the cone-pulley. The emery wheel *B* is moved to a position for grinding by adjusting the carriage and cross-slide, and it is traversed across the conical surface of the center by handle *C*. As the grinding proceeds, the wheel is fed inward slightly by manipulating the cross-slide. This grinder is set to the proper angle by placing the two centered ends *D* and D_1 between the lathe centers, which should be aligned as for straight turning. The grinding spindle will then be 30 degrees from the axis of the lathe spindle. The grinder should be carefully clamped in the toolpost so that it will remain

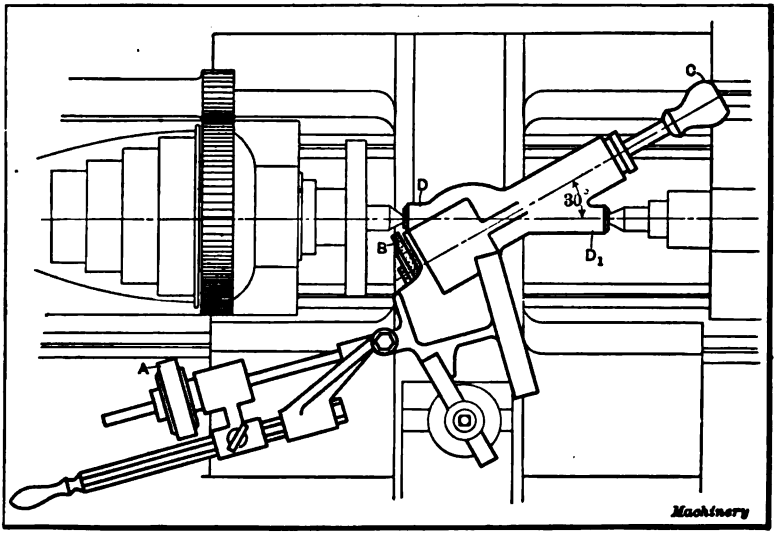


Fig. 47. Lathe Center Grinder

as located by the centered ends. The tailstock center is next withdrawn and the emery wheel is adjusted for grinding. As the wheel spindle is 30 degrees from the axis of the lathe spindle, the lathe center is not only ground true but to an angle of 60 degrees, which is the standard angle for lathe centers. There are many other styles of center grinders on the market, some of which are driven by a small belt from the cone-pulley and others by electric motors which are connected with ordinary lighting circuits. The tailstock center is ground by inserting it in the spindle in place of the headstock center. Before a center is replaced in its spindle, the hole should be perfectly clean as even a small particle of dirt may seriously affect the alignment.

When a rod or shaft must be turned cylindrical or to the same diameter throughout its entire length, it is good practice to test the alignment of the centers, before inserting the work. The position of the tailstock center for cylindrical turning may be indicated by the coincidence of graduation marks on the base, but if accuracy is necessary, the relative position of the two centers should be determined in a more positive way. A very simple and convenient method of testing the alignment is shown at *A* in Fig. 48. The work is first turned for a short distance, near the dogged end, as shown, and the tool is left as set for this cut; then the tailstock center is withdrawn and the work is moved sufficiently to permit running the tool back to the tailstock end without changing its original setting. A short cut is then taken at this end and the diameters d and d_1 are carefully compared. In case there is any variation, the tailstock center is

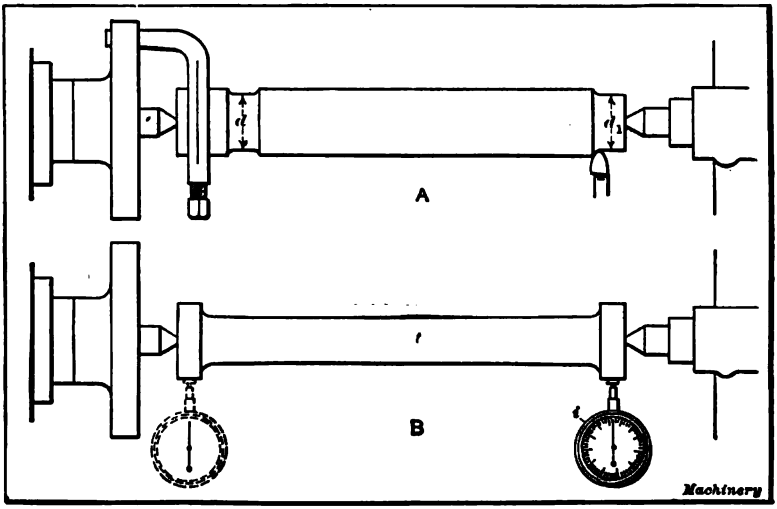


Fig. 48. Two Methods of Aligning Centers for Cylindrical Turning

adjusted laterally, other trial cuts are taken, and the test repeated.

Another method is illustrated at *B*, which requires the use of a test-bar *t*. This bar should have accurately made centers and the ends finished to exactly the same diameter. The lathe centers are aligned by placing the bar between them and then testing the position of the ends. This can be done by comparing each end with a tool held in the toolpost and moved from one to the other by shifting the carriage, but a better method is to clamp a test indicator *i* in the toolpost and bring it in contact with first one end of the bar and then the other. If the dial does not register the same at each end, it shows that the lathe centers are not in line.

Even when centers are correctly set, lathes that have been in use a long time do not always turn cylindrical or straight because if the ways that guide the carriage are worn unevenly, the tool as it moves along does not remain in the same plane and this causes a variation in the diameter of the part being turned.

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NUMBER 93

OPERATION OF MACHINE TOOLS

By FRANKLIN D. JONES

SECOND EDITION

PLANER—SHAPER—SLOTTER

CONTENTS

CHAPTER I

CONSTRUCTION AND OPERATION OF A PLANER

The planer is used principally for producing flat surfaces. The construction or design of planers of different makes varies somewhat, and special types are built for doing certain kinds of work. There is, however, what might be called a standard type which is found in all machine shops and is adapted to general work. A typical planer of small size is illustrated in Fig. 1. The principal parts are the bed *B*, the housings *H* which are bolted to the bed, the table or platen *P* to which the work is attached, the cross-rail *C*, and the toolhead *T*

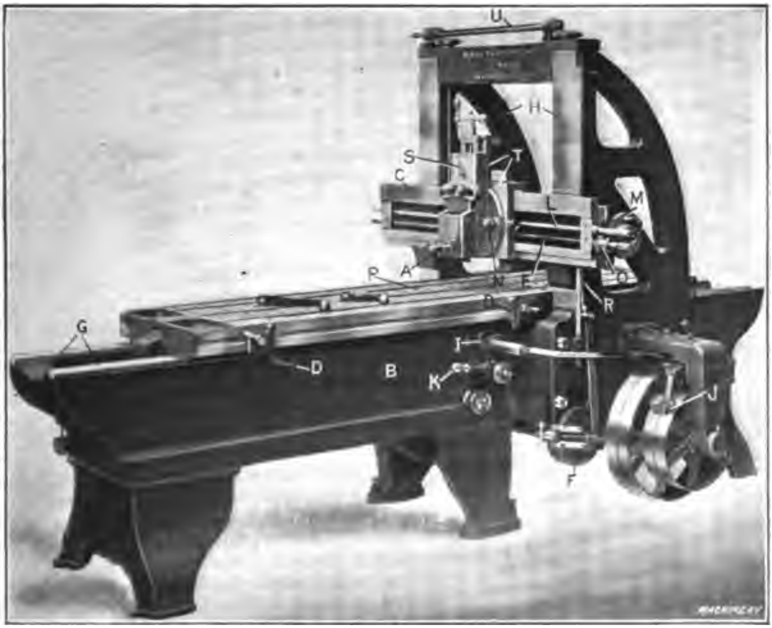

Fig. 1. Flather Single-head Planer

which is mounted on the cross-rail. When the planer is in operation, the platen slides back and forth on the bed in V-shaped grooves *G* which cause it to move in a straight line. While this reciprocating movement takes place, the work, which is clamped to the platen, is planed by a tool held in position by clamps *A*. This tool remains stationary except at the end of each stroke of the platen, when the toolhead and tool feed slightly for a new cut. The amount of feed for each stroke can be varied to suit the conditions, as will be explained later. The movement of the table or of the length of its stroke is governed by the position of the dogs D and D_1. These dogs may be adjusted along the groove shown and they serve to reverse the table movement by engaging tappet I. Before explaining just how the movement of tappet I controls the point of reversal, the arrangement of the driving mechanism, a plan view of which is shown in Fig. 2, will be explained.

The Driving and Reversing Mechanism

The shaft on which the belt pulleys f, f_1, and r, r_1 are mounted carries a pinion a that meshes with a gear on shaft b. This shaft drives, through the gears c and d, a second shaft which carries a pinion e, and

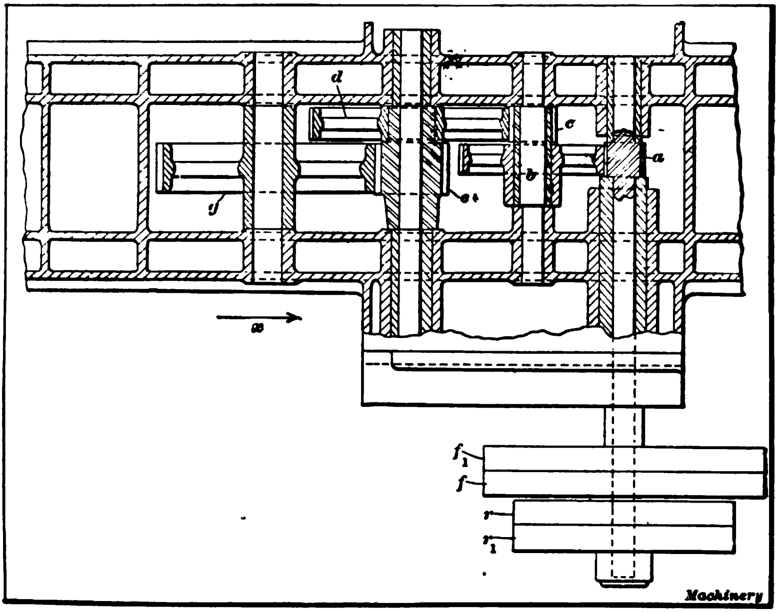

Fig. 2. Driving Mechanism of a Spur-geared Planer

which meshes with a large gear g. This large gear, which is called the "bull-wheel," in turn engages a rack attached to the under side of the table, and, as the gear revolves, the table moves along the ways of the bed. There are two pairs of driving pulleys and also two driving belts connecting with an overhead countershaft. One pulley of each set is keyed to the shaft and the other is loose and revolves freely. The belt operating on the large pulleys f and f_1 is "open" whereas the belt for the smaller pulleys r and r_1 is crossed, which gives a reverse motion. The position of both belts is controlled by guides J (one of which is seen in Fig. 1) which are operated by tappet I. Now when the open belt is running on the tight pulley f, the reverse belt is on the loose pulley r_1, and the table moves as shown by the arrow x, which is in the direction for the cutting stroke. When the table is advanced far enough to bring dog D (Fig. 1) into engagement with tappet I, the latter is pushed over, which shifts the open belt on loose pulley f_1 and the cross belt on the tight pulley r. The pulley shaft and the entire train of driving gears is then rotated in the opposite direction by the crossed belt and the table movement is reversed. This is the return stroke, during which the planing tool glides back over the work to the starting point for a new cut. To change the length of the stroke, it is simply necessary to shift dogs D and D_1 as their position determines the point of reversal. When the workman desires to reverse the table by hand or stop it temporarily, this can be done by operating hand lever K. It will be noted that there is considerable difference in the diameter of the two sets of belt pulleys, those for the forward or cutting stroke being much

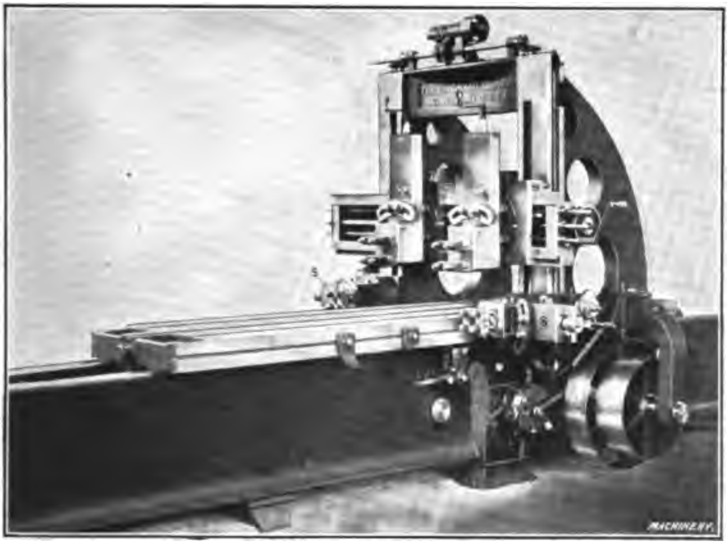

Fig. 3. Cincinnati Four-head Planer

larger than those for the return movement. As the size of the countershaft pulleys is in the reverse order, the speed of the table is much less when the large pulley is driving than when the cross belt is shifted to the small pulley. The result is that the table is returned quickly after the cutting stroke in order to reduce the idle time that elapses between the end of one cut and the beginning of the next.

The Feeding Mechanism

The feeding movement of the tool takes place just before the cutting stroke begins. If a horizontal surface is being planed, the tool has a crosswise movement parallel to the platen, but if the surface is vertical, the tool is fed downward at right angles to the platen. In the first case, the entire toolhead T moves along the cross-rail C, but for vertical planing, slide S moves downward. Surfaces which are at an angle with the table can also be planed by loosening nuts N and swiveling slide S to the required angle as shown by graduations on the circular base. The horizontal and vertical movements of the tool can be effected by hand or automatically. The hand feed is used principally for adjusting the tool to the proper position for starting a cut. The tool can be set to the right height by a crank at the top of the tool-head, and the crosswise position of the tool and head can be varied by turning horizontal feed-screw *E*. This screw is turned for a hand adjustment by placing a crank on the squared outer end. The automatic feeding movement is derived from a feed disk *F*, which turns part of a revolution at each end of the stroke and is connected to a rack *R*. This rack slides up and down with each movement of the crank and imparts its motion to gear *M* by means of an inner pinion which it engages. Gear *M*, in turn, meshes with a gear *O* placed on the feed-screw. The feeding movement is engaged, disengaged or reversed by a pawl attached to gear *M* (on this particular planer) and the amount of feed per stroke is varied by adjusting the crankpin of the disk *F*, to or from the center. The vertical feed is operated by a splined shaft *L* which transmits its motion to the toolhead feed-screw through gearing. This shaft is also driven by gear *O* which is removable and is placed on it when an automatic vertical feed is desired.

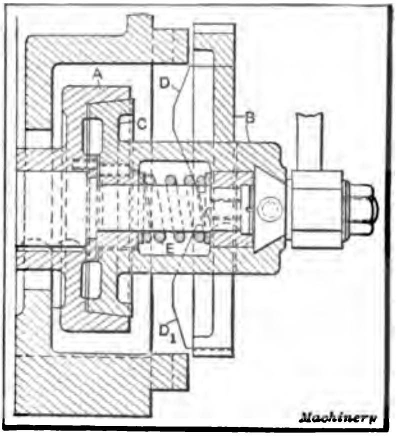

Fig. 4. Friction Feed Disk

The friction disk *F* is turned by pinion shaft *c* (Fig. 2), of the driving mechanism. The number of revolutions made by this pinion shaft for each stroke depends, of course, on the length of the stroke, but the feed disk is so arranged that it only rotates part of a revolution at each end of the stroke, so that the feeding movement is not governed by the length of the stroke. In other words the feed disk is disengaged from the driving shaft after being turned part of a revolution. One type of feed disk is shown in the sectional view Fig. 4. The cup-shaped part *A* having an inner tapering surface is attached to the main pinion shaft. Crank-disk *B* has a tapering hub *C* which fits into part *A* as shown. If the hub is engaged with cup *A* when the planer is started, the crank-disk is turned until a tapered projection *D* strikes a stationary taper boss on the bed which disengages hub *C* from the driving member by moving it outward against the tension of spring *E*. The disk then stops turning and remains stationary until the driving member *A* reverses at the end of the stroke. The hub then springs back into engagement and the disk turns in the opposite direction until another taper projection D_1, on the opposite side, strikes a second boss on the bed which again arrests the feeding movement. It will be seen that this simple mechanism causes the disk to oscillate through the same arc whether the stroke is long or short.

Double Head Planers—Use of Side-heads—Two-speed Planer

Modern planers, with the exception of comparatively small sizes, are ordinarily equipped with two tool-heads on the cross-rail, as shown in Fig. 3, so that two tools can be used at the same time. Some planers also have side-heads *S* mounted on the housings below the cross-rail for planing vertical surfaces or for doing other work on the sides of a casting. These side-heads have an automatic vertical feed and can often be used while the other tools are planing the top surface, the method being to start first the regular tools (which usually have the largest surfaces to plane) and then the side-heads. If the planing on the side requires hand manipulation, as when forming narrow grooves,

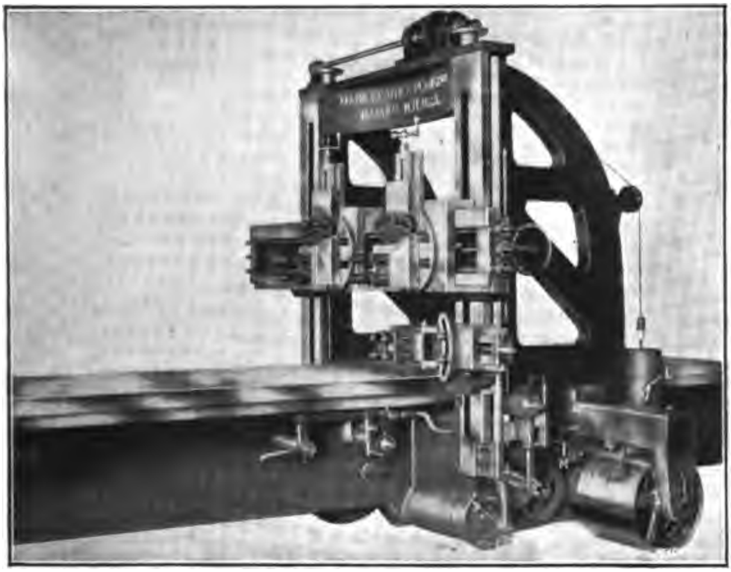

Fig. 5. Flather Two-speed Planer

etc., the planing would be done on first one side and then the other, assuming that both sides required machining, but when the surfaces are broad the automatic feed enables both side-heads to be used at the same time, on some classes of work. These side-heads often greatly reduce the time required for planing and they also make it possible to finish some parts at one setting, whereas the work would have to be set up in one or two different positions if a planer without side-heads were used.

The planer illustrated in Fig. 5 has two speeds for the "cutting stroke" of the table, instead of a single speed. This feature is very desirable as it enables the cutting speed to be varied in accordance with the kind of material to be planed or the character of the work. The speed is changed from fast to slow or *vice versa* by operating lever *L* which, through a segment pinion and rack *M*, shifts sliding gears which are located inside the bed and form a part of the driving train.

CHAPTER II

EXAMPLES OF PLANER WORK AND ADJUSTMENT OF MACHINE

A simple example of planing is illustrated in Fig. 6. The work *W* is a base casting, the top surface of which is to be planed true. The casting is first fastened to the table by bolts and clamps *C* and C_1, and it is further held from shifting by stop-pins *S*. The platens of all planers are provided with a number of slots and holes for the

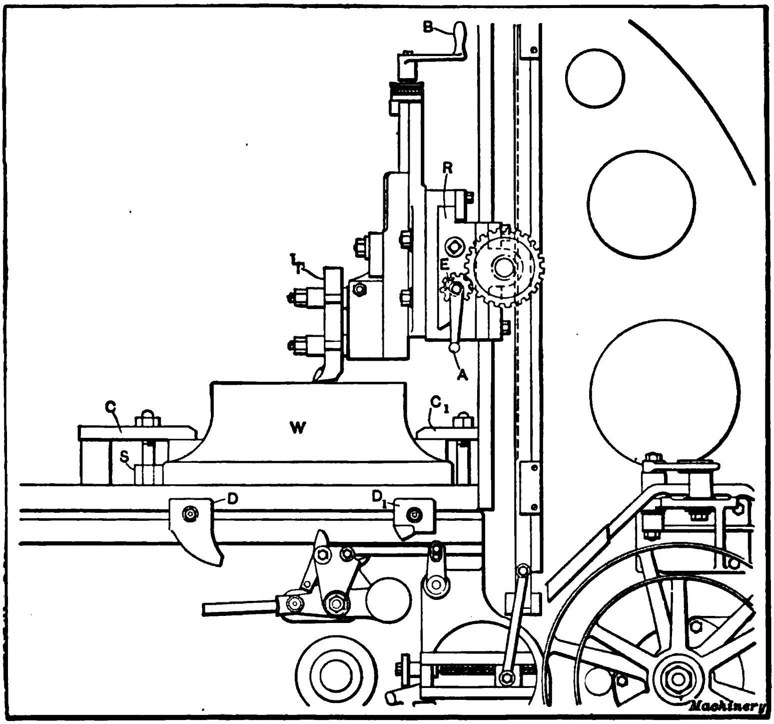

Fig. 6. Side View of Planer with Work in Position

reception of clamping bolts and stop-pins. When the casting is securely attached to the platen, a planing tool *T* is clamped in the toolpost, and cross-rail *R* is set a little above the top surface of the work. The dogs *D* and D_1 are then placed opposite the work and are set far enough apart to give the platen and work a stroke slightly greater than the length of the surface to be planed. The movement of the work during a stroke is illustrated in Fig. 7, the full lines showing its position with relation to the tool at the beginning of the cutting stroke, and the dotted lines the end of the stroke or the point of reversal. The dogs should be adjusted so that the distance x is not more than $1\frac{1}{2}$ to 2 inches and the tool should just clear the work at the other end. If the stroke is much longer than the length of the surface being planed, obviously more time is required for planing than when the stroke is properly adjusted.

Taking the Cut

The tool is moved over to the work by handle *A* and is fed down to the right depth for a cut by handle *B*. The planer is started by shifting an overhand belt (assuming that it is belt- and not motor-driven) and the power feed is engaged by throwing the feed pawl into mesh. On this particular planer, the feed pawl is inside the gear and it is engaged or disengaged by handle *E*. The tool planes the surface of the casting by feeding horizontally across it and removing a chip

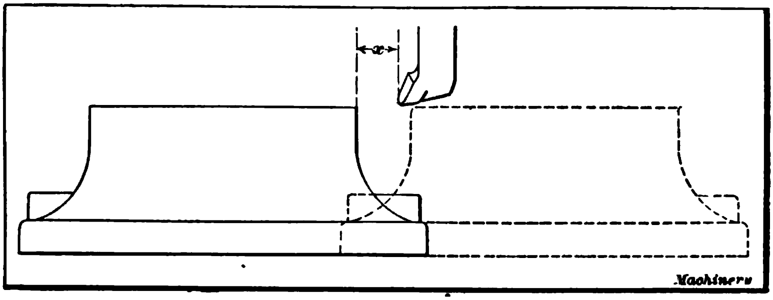

Fig. 7. Movement of Work with Relation to Planing Tool

during each forward stroke of the work. If there is not much metal to be planed off, one roughing and one finishing cut would probably be all that is necessary. For the finishing cut, a broad tool having a flat edge is often used, especially for cast iron, as it enables wide feeds to be taken, which reduces the time required for the finishing cut. The different types of tools ordinarily used on a planer, are illustrated in Chapter IV, which also explains how they are ground and gives typical examples of their use.

Planing Work held in a Chuck

Another planing operation is illustrated in Fig. 8. In this case, the sides of a cast-iron block *B* are to be planed parallel and square to each other. One method of holding the work would be to grip it in the planer chuck *A*. A cut can then be taken over the entire surface of one side, whereas if ordinary clamps *C*, Fig. 6, were used, they would interfere with the movement of the tool. This chuck, an end view of which is shown at *A* in Fig. 9, has one fixed jaw *J* and one movable jaw J_1 and the work is clamped between the jaws by the screws shown. The work is "bedded" by hammering it lightly, until the sound indicates that it rests solidly on the bottom of the chuck.

After a cut has been taken over the upper side *a* (Fig. 8), the casting is turned to bring its finished face against the stationary jaw *J* as shown at *A*, Fig. 9. A finished or planed surface should always be located against the fixed or stationary jaw of the vise, because the movable jaw is more liable to be out of alignment. If the fixed jaw is square with the planer table, and face *a* is held flat against it, evidently face *b*, when planed, will be at right angles to face *a*. Unless care is taken, however, the work may be tilted slightly as the movable jaw is set up, especially if the latter bears against a rough side of the casting. The way this occurs is indicated at *B*. Suppose, for example, that the rough side *c* is tapering (as shown somewhat exaggerated) and the jaw J_1 only touched the upper corner as shown. The

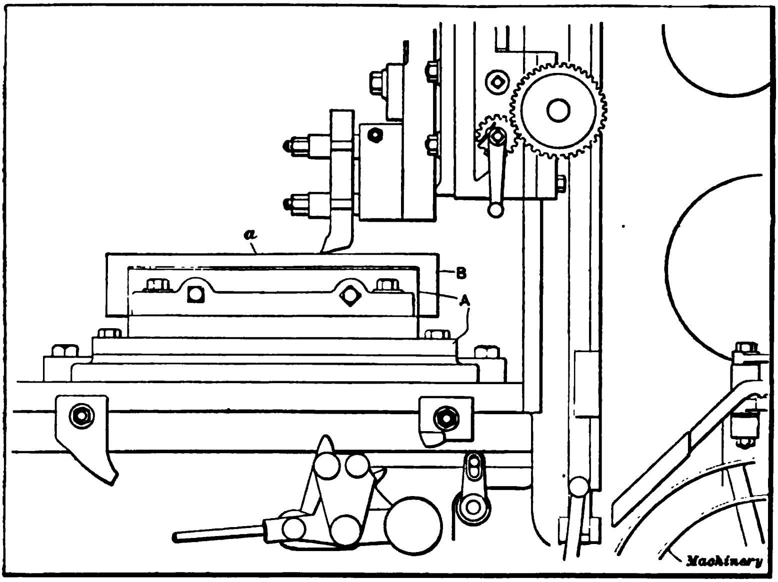

Fig. 8. Planing Work held in Chuck

finished face will then tend to move away at *x* (sketch *C*) as jaw J_1 is tightened, so that face *b*. when planed, would not be square with the side *a*. One method of overcoming this difficulty is to insert narrow strips of tin (or strips of paper when the irregularity is small) in the space *s* (sketch *B*) to give the clamping jaw a more even bearing. This tilting can also be prevented by placing a wire or cylindrical rod *w* along the center of the work as shown at *D*; the pressure of clamping is then concentrated at the center and the opposite side is held firmly against the fixed jaw. Sometimes a special packing strip *p*, having a rounded face, is inserted between the jaw and the work to prevent tilting, as at *E*. This strip acts on the same principle as the wire, and it is more convenient to use.

When the sides *a* and *b* are finished and the casting is being set for planing side *c*, it is necessary not only to have a good bearing against the fixed jaw, but as the sides are to be parallel, the lower side *a* must, at this setting, bear evenly on the bottom of the chuck. A simple method of determining when work is firmly bedded, is as follows: Place strips of thin paper beneath each end of the work, and after tightening the chuck and hammering the casting lightly to give it a good bearing, try to withdraw the paper strips. If both are held tightly, evidently the casting rests on the chuck and the upper side will be planed parallel, provided the chuck itself is true.

The foregoing method of planing a block square and parallel, by holding it in a chuck, is not given as one conducive to accuracy, but rather to illustrate some of the points which should be observed when

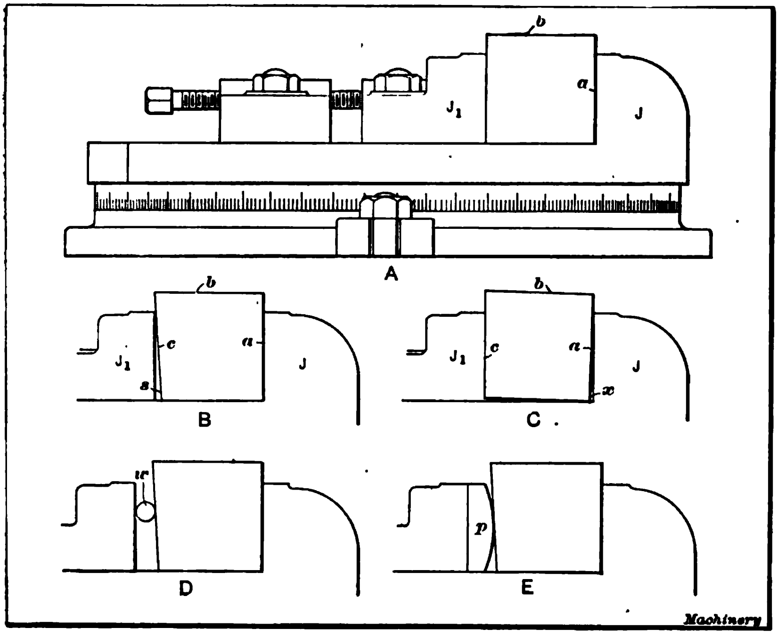

Fig. 9. Planer Chuck—Diagrams showing how Work is Tilted and Methods of Holding it Square

clamping work in a planer chuck. If considerable accuracy were required, the work could be held to better advantage by fastening it directly to the table with special clamps, as indicated in Fig. 10. The particular clamps illustrated have round ends which are inserted in holes drilled in the work. Of course, such clamps can only be used when the holes are not objectionable. As will be seen, these clamps are not in the way of the planing tool, and the block is held directly against the true surface of the platen.

This block could be planed accurately as follows: A roughing cut is first taken over all the sides to remove the hard outer surface, and then one side is finished. This finished surface is next clamped to the platen, thus permitting the opposite side to be planed. These two surfaces will then be parallel, provided the planer itself is in good condition. The finished sides are next set at right angles to the platen by using an accurate square, and the third side is planed. The fourth and last side is then finished with the third side clamped against the platen. By this method of holding the work, it would be easier to secure accurate results than by using a chuck; a chuck, however, is often very convenient for holding small parts.

Planing Vertical and Angular Surfaces

When vertical surfaces or those which are at right angles to the platen are to be planed, a tool having a bent end as shown at *A* in Fig. 11 is ordinarily used, unless the planer has side-heads, in which case a straight tool is used. The tool-block is also set at an angle, as shown, by loosening bolts *E*, which permit it to be swiveled to the right or left from its vertical position. The tool-block is set over in this way to prevent the tool from dragging over the planed surface on the return stroke. It should be explained that the tool-block of a planer is

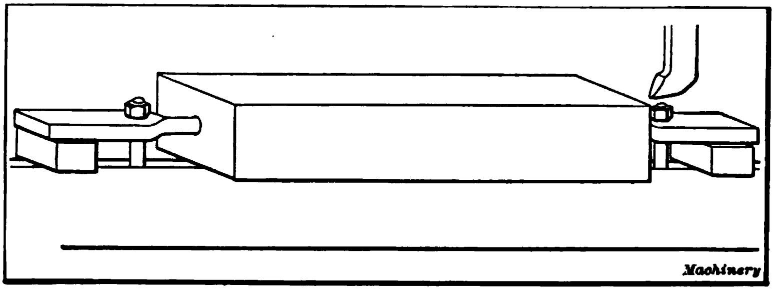

Fig. 10. Holding Block directly against Planer by Finger-clamps

free to swing forward so that the tool can lift slightly when returning for another cut. When a heavy cut is being taken, the tool is sprung sidewise to some extent, as well as backward, and if it were held rigidly on the return stroke, the cutting edge would drag heavily over the work and this would soon dull the edge. When a horizontal surface is being planed, the tool on its return tends to lift upward at right angles to the surface, because the tool-block is then set square with the platen. If, however, the tool-block were left in this position for vertical planing, the tool-point would swing upward in a plane *y–y*, and drag over the finished surface, but by setting the block in an angular position, as shown, the tool-point swings in a plane *x–x*, or at right angles to the axis *a–a* of the pin on which the block swivels. As plane *x–x* is at an angle with the surface of the work, the tool-point moves away from the finished surface as soon as it swings upward. The angular position of the tool-block does not, of course, affect the direction of the tool's movement, as this is governed by the position of slide *S* which is changed by swiveling the graduated base *D*.

A vertical surface is planed by adjusting the saddle *G*, horizontally along the cross-rail until the tool is in position for taking a cut. The tool is then fed down by hand, until the cut is started, after which the vertical feed is engaged, thus causing slide *S* and the tool to feed downward a certain amount for each stroke, while the saddle remains stationary on the cross-rail. The surface *y–y* will be planed square with the platen, provided the swiveling base *D* is set in the proper position. Before planing surfaces that are intended to be square with the platen, the position of the tool-slide *S* should be noted by referring to the graduation marks on the base *D*. When the zero marks on the stationary and swiveling parts of the base exactly coincide, the slide should be at right angles to the platen. Its position, however, can be determined more accurately by holding the blade of a square which

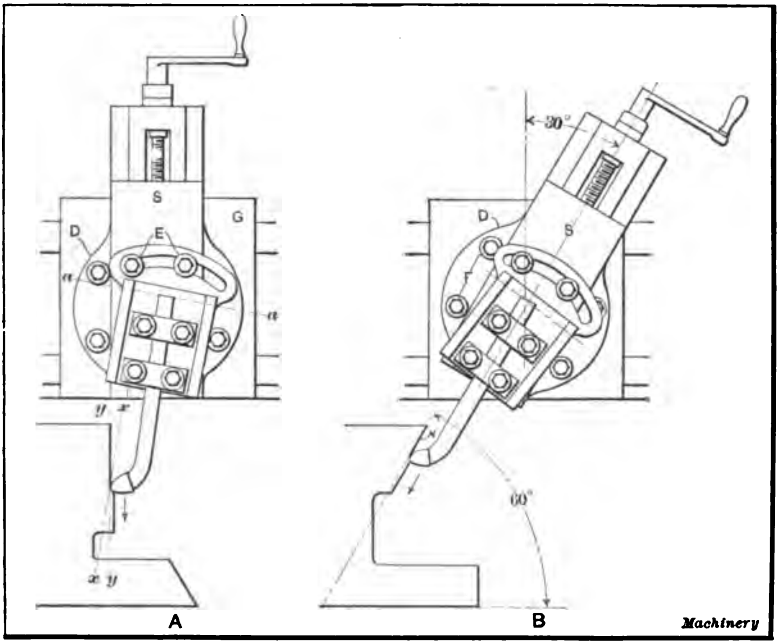

Fig. 11. Positions of Tool and Head for Planing Vertical and Angular Surfaces

rests on the platen, against one side of the tool-slide, as it is difficult to set graduation lines to exactly coincide, and even though they were in line, errors might result from other causes.

The planing of an angular surface is illustrated at *B*. The tool-head is first set to the proper angle by loosening bolts *F* and turning the base *D* until the graduations show that it is moved the required number of degrees. For example, if surface *s* were to be planed to an angle of 60 degrees with the base, as shown, the head should be set over 30 degrees from the vertical or the difference between 90 and 60 degrees. The tool would then be fed downward, as indicated by the arrow. The tool-block is also set at an angle with slide *S*, when planing angular surfaces, so that the tool will swing clear on the return stroke. The top of the block should always be turned *away from the surface to* *be planed*, which applies to the planing of either vertical or angular surfaces when using the cross-rail head.

An example of angular work is illustrated in Fig. 12, which shows a planer arranged for planing the V-shaped ways or guides on the bottom of a planer platen. Both tool slides are set to the required angle for planing one side of each vee. As there are two tool-heads, both vees can, of course, be planed simultaneously. The sides of the

Fig. 12. Double-head Planer set for Planing Angular Surfaces

platen are also planed at the same setting by tools held in the side-heads.

Position of the Tool and Cross-rail—Alignment of Cross-rail

The tool should be set about square with the work, as shown at *A*, Fig. 13, when planing horizontal surfaces. If it is clamped in the tool-block at an angle, as shown at *B*, and the lateral thrust or pressure of the cut is sufficient to move the tool sidewise, the cutting edge will sink deeper into the metal, as indicated by the dotted line, whereas a tool that is set square will swing upward. Of course, any shifting of the tool downward may result in planing below the level of the finished surface which would spoil the work. The tool should also be clamped with the cutting end quite close to the tool-block, so that it will be rigidly supported.

As previously mentioned, the cross-rail should be lowered until it is quite close to the top surface of the work. If it is set much higher than the work, the tool-slide has to be lowered considerably to bring the tool in position for planing; consequently, both the slide and the tool extend below the rail and they are not backed up and supported against the thrust of the cut as solidly as when the rail is more directly in the rear. The vertical adjustment of the cross-rail on the face of the housings is effected by two screws which are connected through bevel gearing with the horizontal shaft *U* (Fig. 1) at the top. On small planers this shaft is turned by hand, but on larger ones it is driven by a belt. Before making the adjustment, bolts at the rear which clamp the cross-rail to the housings must be loosened, and care should be taken to again tighten these bolts before using the planer. The ways on which the cross-rail slides, should be wiped clean before

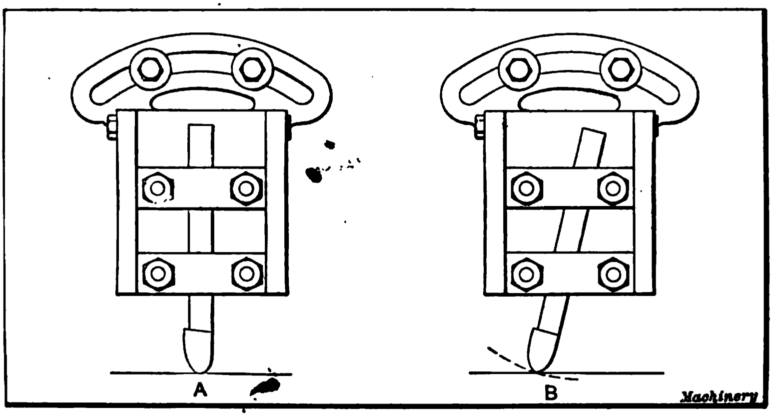

Fig. 18. Correct and Incorrect Positions for Planing Tool

making an adjustment, to prevent dirt from getting back of the rail as this would affect its alignment.

The cross-rail of a planer which is in good condition, is parallel with the upper surface of the platen, so that the planing tool, as it feeds horizontally, moves in a line parallel with the platen. Unfortunately this alignment is not always permanent and if accurate work is to be done, especially on a planer that has been in use a long time, it is well to test the cross-rail's position.

One method of making this test is as follows: An ordinary micrometer is fastened to the tool-head in a vertical position either by clamping it to the butt end of a tool, or in any convenient way, and the head is lowered until the end of the micrometer thimble is slightly above the platen. The thimble is then screwed down until the end just touches the surface to be tested, and its position is noted by referring to the regular graduations. The thimble is then screwed up slightly for clearance and, after the tool-head is moved to the opposite side, it is again brought into contact with the platen. The second reading will then show in thousandths of an inch any variations in the cross-rail's position.

Multiple or Gang Planing—Use of Planer with Double- and Side-heads

When a number of duplicate parts have to be planed, much time can often be saved by arranging the castings in a straight row along the platen so that they can all be planed at the same time. This method enables a number of parts to be finished more quickly than would be possible by machining them separately, and it also insures duplicate work. An example of multiple or gang planing is shown in

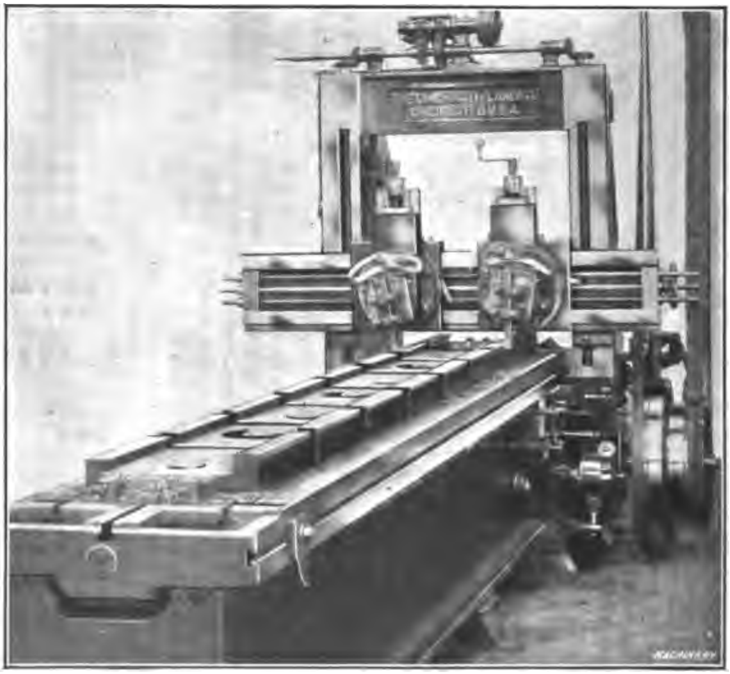

Fig. 14. Planing a Row of Duplicate Parts

Fig. 14. The particular castings illustrated are the "saddles" of planer tool-heads and eight castings are being planed at the same time. Both tool-heads are in use, and the tops and sides of the castings are finished at this setting.

This method of planing cannot always be employed to advantage as the shape of the work or location of the surfaces to be machined sometimes makes gang planing impracticable and even impossible. If the castings are so shaped that there will be considerable space between the surfaces to be planed, when they are placed in a row, so much time might be wasted while the tool was passing between the different surfaces that it would be better to plane each part separately. Some castings also have lugs or other projections which make it impossible for the tool to pass from one to the other without being raised to clear the obstruction. On the other hand, when castings are quite symmetrical in form and the surfaces are so located that the planing tool can pass from one to the other with a continuous stroke, as indicated in Fig. 14, the gang method of planing insures a uniform product and greatly reduces the time required for machining.

Two or more tools can often be used at the same time in connection with many planing operations. Fig. 15 shows a cross-section of an engine bed and illustrates how a double-head planer would be used on this particular job. The tool to the left is started first because it is the *leading* tool, as determined by the direction of the feed. This is

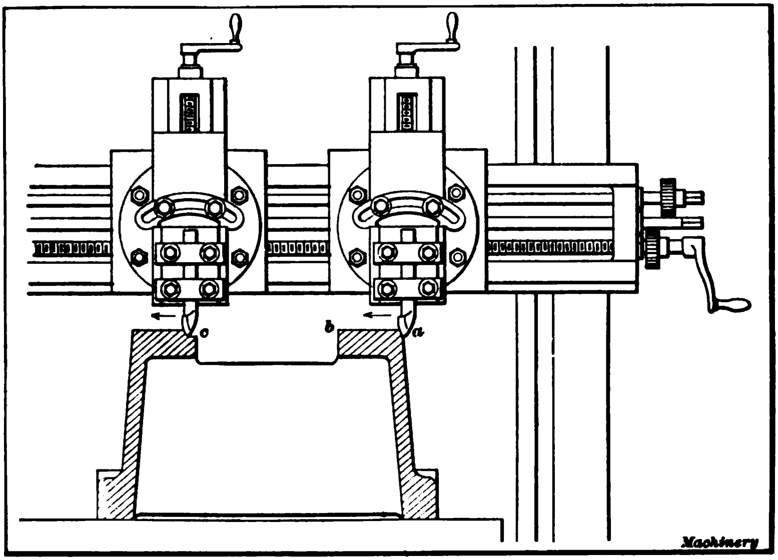

Fig. 15. Planing Two Surfaces Simultaneously with Two-head Planer

a good rule to follow especially when the tool-heads are quite close, as it prevents one head from feeding against the other, which might occur if the *following* tool were started first. The tools illustrated, cut principally on the side and are intended for deep roughing cuts in cast iron. The surfaces should be finished with a broad tool with a wide feed. If the planer were heavy and rigid, a feed of ½ or ¾ inch for each stroke, or even more, could be used for the finishing cut, but if the planer were rather light or in poor condition, it might be necessary to reduce the feed to ¼ inch or less, to avoid chatter. It is impossible to give any fixed rule for the amount of feed as this is governed not only by the planer itself, but also by the rigidity of the work when set up for planing, the hardness of the metal, etc. The final cut should be taken by a single tool to insure finishing both sides to the same height. This tool should be fed by power from *a* to *b*, and then rapidly by hand from *b* to *c* for finishing the opposite side.

The use of two tools for rough planing, greatly reduces the time required for machining work of this kind.

A typical example of the class of planer work on which a side-head can be used to advantage, is shown in Fig. 16. The operation is that of planing the edge and face of a large casting. The tool in the side-head is rough planing the vertical surface, while the other tool planes the edge. As the side-tool has the broadest surface to plane, it is started first. On some work two side-tools can be used simultaneously. The use of both cross-rail tool-heads at the same time is very common in

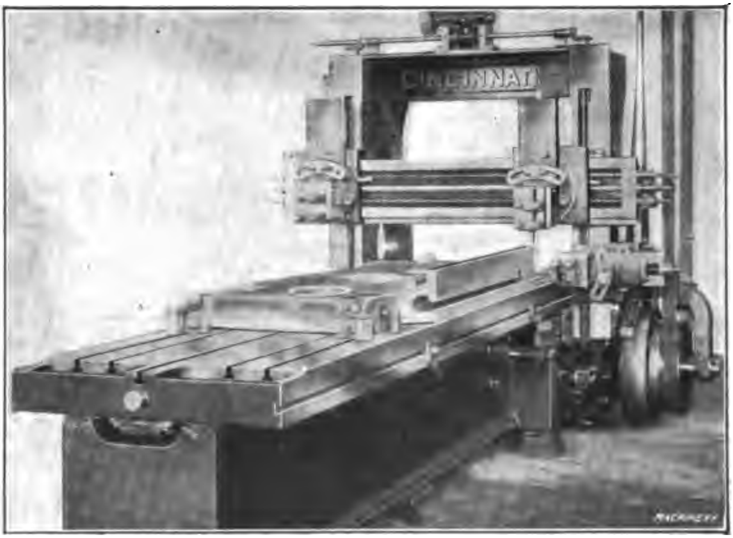

Fig. 16. Planing Top Edge and Side of Casting—Illustrating use of Side-head

connection with modern planer practice. Whether it is feasible to use one tool or four, simultaneously, depends altogether on the shape of the work and the location of the surfaces to be machined. Very often only one tool can be used and, occasionally, four tools can be operated at the same time, provided, of course, the planer is equipped with four heads. There are few fixed rules which can be applied generally to planer work, because the best way to set up and plane a certain part depends on its shape, the relative location of the surfaces to be finished, the degree of accuracy necessary, and other things which vary for different kinds of work. Before beginning to plane any part, it is well to consider carefully just what the requirements are and then keep them in mind as the work progresses.

CHAPTER III

HOLDING AND SETTING WORK ON THE PLANER

A great deal of the work done on a planer is very simple as far as the actual planing is concerned, but often considerable skill and ingenuity are required in setting the work on the planer and clamping it in the best manner. There are three things of importance that should be considered when doing work of this kind. First, the casting or forging must be held securely to prevent its being shifted by the thrust of the cut; second, the work should not be sprung out of shape by the clamps; and third, the work must be held in such a position

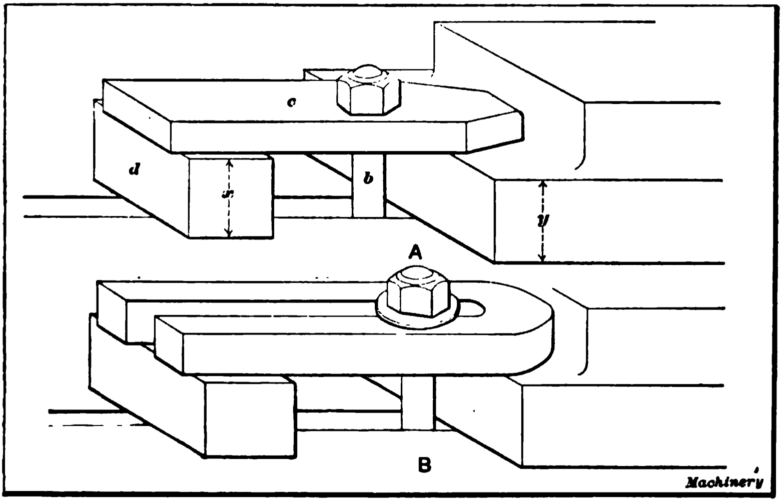

Fig. 17. Clamps for Attaching Work to Planer Platen

that it will be possible to finish all the surfaces that require planing, in the right relation with one another. Frequently a little planning before the "setting up" operation, will avoid considerable worry afterwards, to say nothing of spoiled work.

Different Forms of Planer Clamps and Bolts

Most of the work done on a planer is clamped directly to the platen. A form of clamp that is often used is shown at *A* in Fig. 17, *c* being the clamp proper, *b* the bolt, and *d* the packing block on which the outer end of the clamp rests. Obviously when the bolt is tightened, the clamp presses the work downward against the platen, and as this pressure is greatest when the bolt is close to the work, it should, if possible, be placed in that position. If the bolt were located near the packing block, the latter would be held tightly instead of the work. Another point to be observed is the height of the packing block. This height *x* should equal the height *y* of the part being clamped, provided a straight clamp is used. The end of the clamp will then have an even bearing on the work which will be held more securely than it would be if the clamp were inclined so that all the bearing was on the end or at the edge of the work. Packing blocks are made of either hard wood or cast iron.

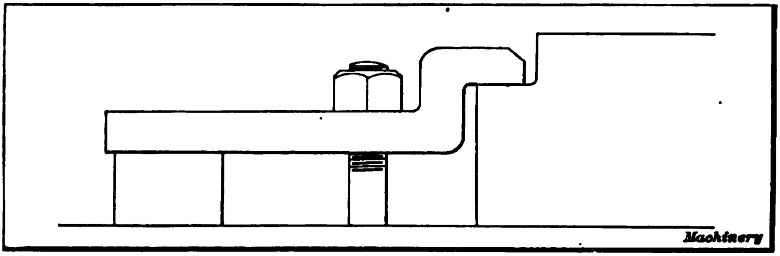

Fig. 18. Off-set Clamp

An excellent form of clamp, known as the U-clamp, is shown at *B*. This type is made by simply bending a square or rectangular bar of steel around, as shown, so as to form a slot in which the bolts can be placed. This continuous slot enables a bolt to be located in the best position, which is not always the case with clamps having holes.

Bent or off-set clamps are preferable to the straight type for holding certain kinds of work. Fig. 18 shows an off-set clamp applied to a casting which, we will assume, is to be planed on the top. If in this

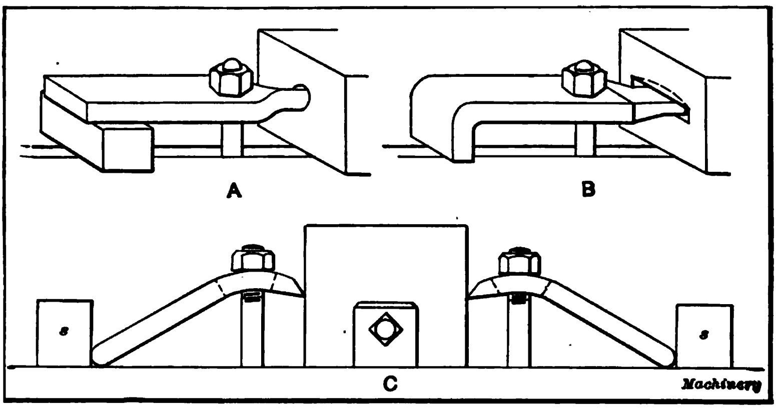

Fig. 19. Methods of Clamping Work which cannot be held by Ordinary Means

case a straight clamp were used, the clamping nut might be high enough to interfere with the planer tool, but the off-set clamp enables a shorter bolt to be used.

Frequently the "finger" clamps illustrated at *A* and *B* in Fig. 19 are convenient if not absolutely necessary. This type is used for holding work which cannot be held by ordinary means without interfering with the planer tool. The style to the left has a round end which enters a hole drilled in the work, whereas the clamp to the right has a flat end which engages a milled slot. An illustration of the use of finger clamps is given in connection with Fig. 10, Chapter II. As previously stated, they are only adapted to work in which holes or slots are not objectionable. Sometimes these clamps can be inserted in cored pockets or holes that are needed for other purposes. Sketch *C* illustrates a method that is sometimes resorted to when there are no projections for clamps and when holes or slots are not desirable. The clamps are placed in an angular position between the work and stop-pins *s* or strips clamped to the platen, and when the bolts are tightened, the work is forced downward. The bolt holes are elongated to permit the angular position of the clamps to be varied somewhat, and the nuts bear on the curved ends.

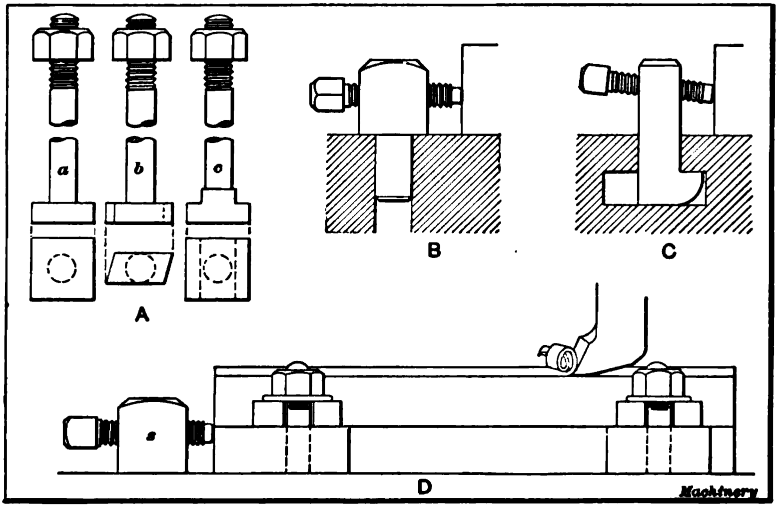

Fig. 20. Planer Clamping Bolts—Stop-pins—Use of Stop-pins

Three styles of bolts that are generally used for planer work are shown at *A*, Fig. 20. Bolt *a* has a square head so that it must be inserted at the end of a platen slot and then be moved to the required position. Occasionally it is desirable to place a bolt through some opening in a casting, in which case the bolt *b* can be used. The head is narrow enough to be inserted in the T-slot from above, and when the bolt is given a quarter turn, it is held the same as the square-headed type. Another style is shown at *c* which can be inserted from above. The lower end or head of this bolt is in the form of a nut planed to fit the T-slot. When the bolt is to be inserted from above, this nut is moved along the T-slot to the proper position and then the bolt is screwed into it after which the upper clamping nut is tightened.

Stop-pins and Braces

It would be very difficult to hold work securely by using only clamps and bolts, because the pressure of the clamp is in a vertical direction, whereas the thrust of the cut is in a horizontal direction, which tends to shift the work along the platen. To prevent such a movement, practically all work that is clamped to the platen is further secured by one or more stop-pins *s*, which are placed at one end of the part being planed as indicated at *D*, Fig. 20. These pins are generally made in two styles, one of which has a shank that fits the holes in the planer platen as shown at *B*, and the other an end which enters the T-slot as at *C*. By having one type for holes and another for T-slots, the stop-pins can be located in practically any position. After the pins are inserted in the platen, the screws shown are adjusted against the work. Stop-pins are ordinarily placed at one end of the work to take the thrust of the cut, and sometimes they are needed along the sides to prevent lateral movement. The screws of some stop-pins are inclined, as shown at *C*, in order to force the work down against the platen. These pins are also made without adjusting screws.

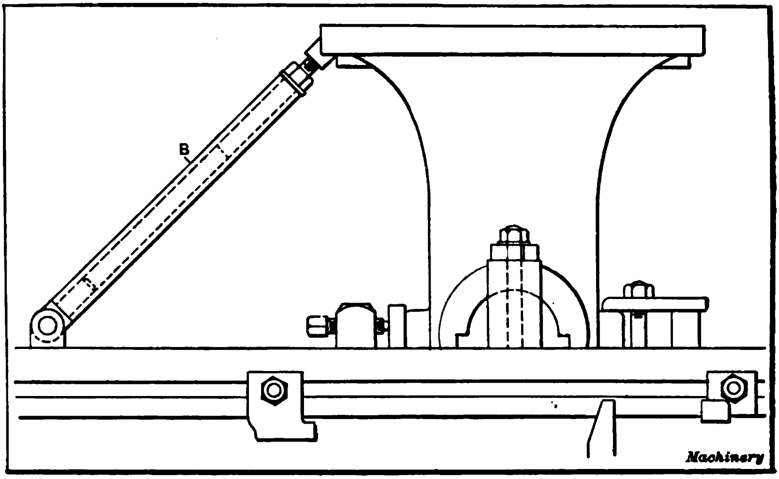

Fig. 21. High Work supported by Brace which takes Thrust of Cut

Some castings have surfaces to be planed that are a considerable distance above the platen, as shown in Fig. 21, which illustrates a large pillow-block set up for planing the base. As will be seen, the end resting on the platen is comparatively small, and if the casting were simply clamped at the lower end, it would tend to topple over when being planed, because the thrust of the tool is so far above the point of support. To prevent any such movement, braces *B* are used. These braces serve practically the same purpose as stop-pins. The style of brace shown has a hinged piece in its lower end, which enters a hole in the platen, and the body of the brace is a piece of heavy pipe. At the upper end there is an adjustable fork-shaped piece which engages the work, and the hinged joint at the lower end enables the brace to be placed at any angle. In some shops, wooden blocks are used as braces. The arrangement of these braces and the number employed for any given case, depends of course on the shape and size of the casting, and this also applies to the use of stop-pins and clamps. The location of all braces and clamping appliances should be determined by considering the strains to which the part will be subjected during the planing operation.

Use of Stop-pins and Planer Strip—Parallel Strips

An arrangement which can often be used to advantage in place of a chuck is shown in Fig. 22. The part to be planed is held between ordi-

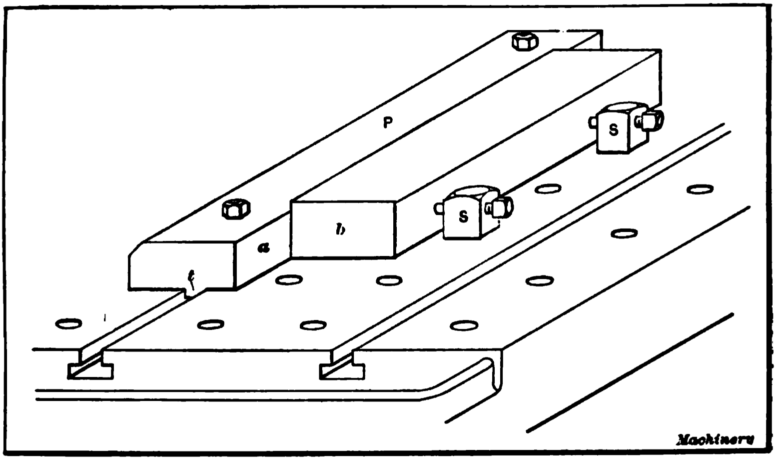

Fig. 22. Work held between Stop-pins and Strip Bolted to Platen

nary stop-pins *S* and a "planer strip" *P* that is bolted to the platen. This strip has a tongue piece *t*, which fits into the T-slot and locates the side *a* parallel to the travel of the platen. A stop-pin should be placed against the end *b* of the work to prevent longitudinal movement.

Parallel strips are placed beneath parts to be planed usually for the purpose of raising them to a suitable height, or to align a finished

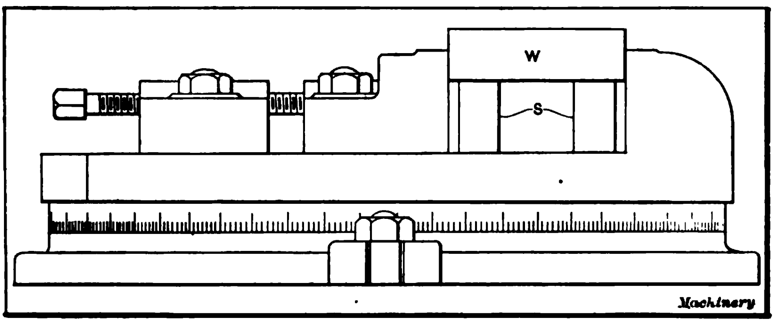

Fig. 23. Illustration showing use of Parallel Strips

surface on the under side with the platen, when such a surface cannot be placed in direct contact with the platen. These strips are made in pairs of different sizes and their sides are square and parallel to one another. An example showing the use of parallels in connection with chuck work, is illustrated in Fig. 23. If the part *W* were placed down on the bottom of the chuck, the top surface would be lower than the chuck jaws and the latter would interfere with the planing tool. By mounting the work on two parallel strips *S*, it is raised, and at the same time the under side is kept in line with the chuck, provided the parallels are accurate and the work is properly "bedded" on them.

Holding Castings of Irregular Shape—Holding Thin Work

The method of holding an odd-shaped casting on an angle-plate is illustrated in Fig. 24. The angle-plate *A* has two faces *a* and *b*

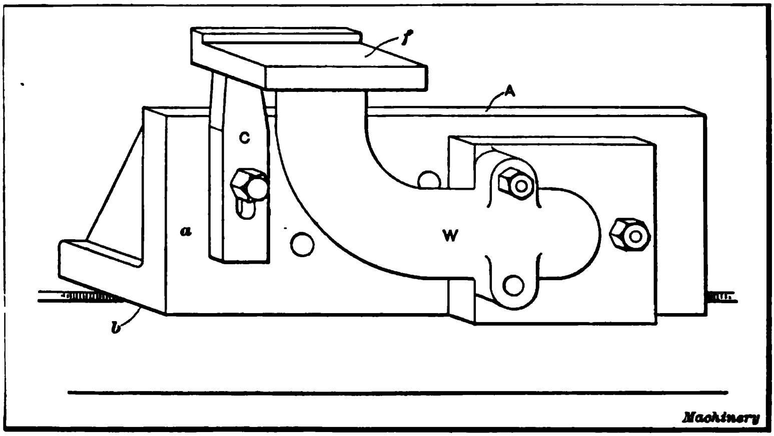

Fig. 24. Odd-shaped Casting attached to Angle-plate

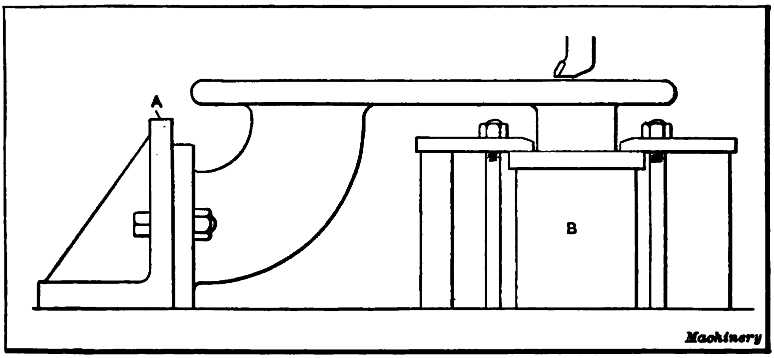

Fig. 25. Use of Angle-plate in Conjunction with Clamps for Holding Work

which are square with each other, and the work *W* is bolted or clamped to the vertical face, as shown. The arrangement of the clamps or bolts depends, of course, on the shape of the work. The particular part illustrated, which is to be planed at *f*, is held by bolts inserted through previously drilled holes, and the left end is supported by a clamp *C*, set against the under side to act as a brace and take the downward thrust of the cut. Angle-plates are generally used for holding pieces, which, because of their odd shape, cannot very well be clamped directly to the platen. Occasionally an angle-plate can be used in conjunction with clamps for holding castings, as illustrated in Fig. 25. In this example the angle-plate *A* is placed across the platen and serves as a stop for taking the thrust of the cut. The flange on the opposite end is supported by a block *B* against which the casting is clamped.

Some castings are so shaped that a great deal of time would be required for clamping them with ordinary means and for such work, special fixtures are often used. These fixtures are designed to support the casting in the right position for planing, and they often have clamps for holding it in place. Some work which could be clamped to the platen in the usual way, is held in a fixture because less time is required for setting it up. This is the practice where a large number of pieces have to be planed.

When it is necessary to plane thin plates or similar work which cannot be clamped in the usual way, either wedge-shaped or pointed pieces similar to those shown at *A* and *B*, Fig. 26, are used. These are known as "spuds" or "toe-dogs," and one way in which they are applied

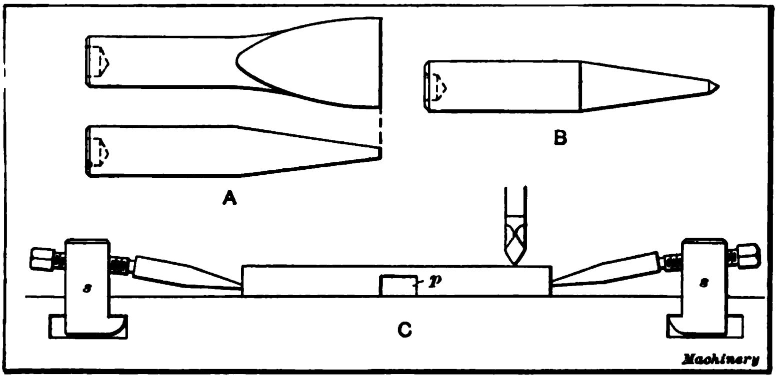

Fig. 26. Method of Holding Thin Flat Plates while Planing

is indicated at *C*. Stop-pins *s* are inserted in the platen on each side of the work, and the dogs are forced against the work by tightening the screws. Owing to the angular position of the dogs, the work is pressed down against the platen. The inclination should not be too great, as the outer end of the dog will move upward when the screws are tightened, without transmitting any pressure to the work. One or more stop-pins *p* should be placed in front of the part being planed to take the thrust, and at least two dogs will be required on each side unless the work is comparatively short.

Planing Round Work

The planer is sometimes used for cutting keyways or splines in shafts, and occasionally, other round work requires a planing operation. In order to hold and at the same time align round work with the platen, V-blocks (Fig. 27), are used. These blocks have a tongue piece *t* at the bottom which fits the T-slots in the platen, and the upper part of the block is V-shaped as shown in the end view. This angular groove is central with the tongue piece so that it holds a round shaft in alignment with the T-slot, which is parallel with the travel of the platen. The diameter of a shaft held in one of these blocks can vary considerably, as indicated by the two circles, without affecting the alignment. In other words, the centers c and c_1 of the large and small circles, respectively, coincide with the vertical center line.

Fig. 28 shows how a shaft is held while a keyseat is being planed in the end. Only one V-block is shown in the illustration, but ordinarily the opposite end of the shaft would be supported in a block

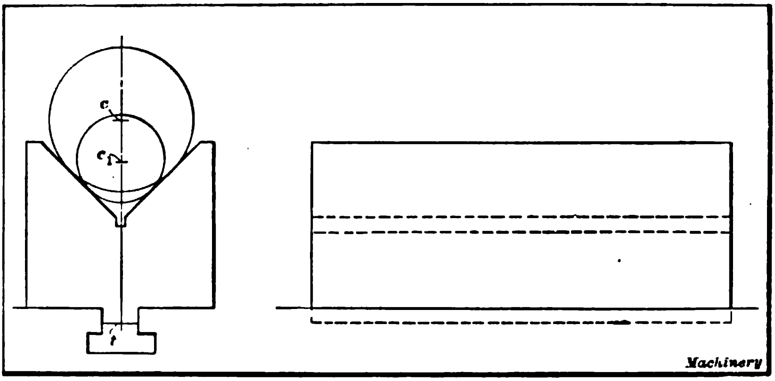

Fig. 27. V-block for Holding Cylindrical Parts

of corresponding size. Before the planing operation, a hole h is drilled to form a clearance space for the planing tool. The keyseat is then planed by using a square-nose tool, and if the V-blocks are accurately made, it will be in line with the axis of the shaft.

Fig. 29 illustrates how V-blocks are used in locomotive shops for holding a piston-rod while the cross-head, which is mounted on the

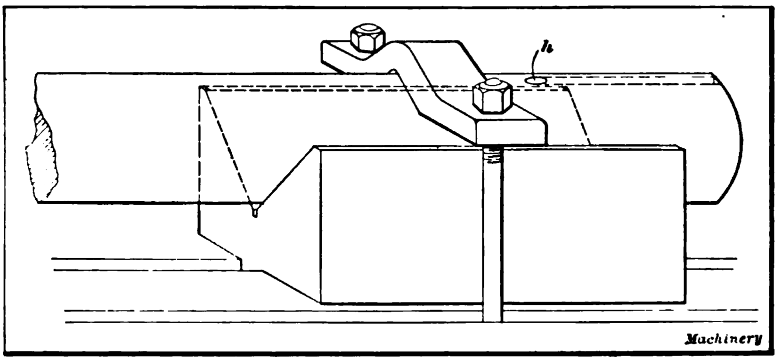

Fig. 28. End of Shaft Clamped in V-block

end, is being planed. The bearing surfaces of the cross-head must be in line with the rod which fits a tapering hole in one end. By assembling the cross-head and rod and then mounting the latter in V-blocks, the bearing surfaces are planed in alignment with the rod.

A good method of making a pair of accurate V-blocks is as follows: First plane the bottom of each block and form the tongue piece t, Fig. 27, to fit closely the platen T-slots. Then bolt both blocks in line on the platen and plane them at the same time so that they will be exact duplicates. A square slot or groove is first planed at the bottom of the vee, as shown, to form a clearance space for the tool. The head is then set to the required angle and one side of the vee is planed. The blocks are then reversed or turned "end for end" and the opposite side is finished without disturbing the angular setting of the head. This method of reversing the work, instead of setting the head to the opposite angle, insures equal angles for both sides and a vee that is exactly central with the tongue piece.

A special planer strip which is used in conjunction with screw-stops for holding round parts, is illustrated in Fig. 30. The strip has an angular face *f* so that pressure from the screws *s* tends to force the

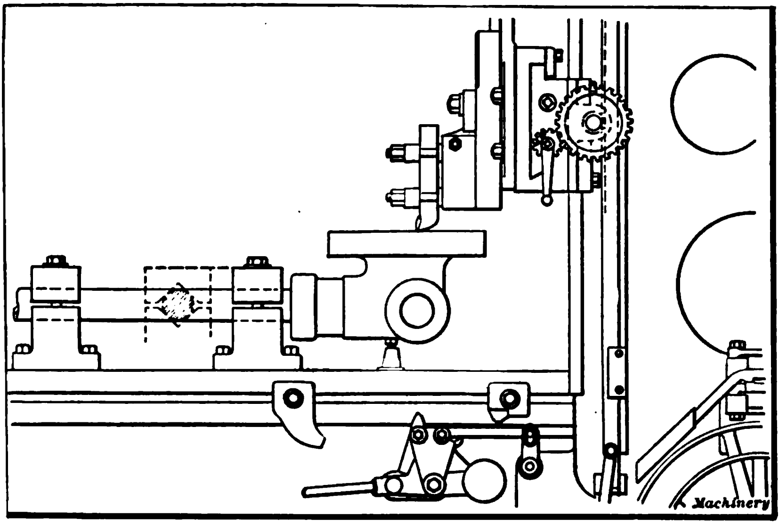

Fig. 29. Piston-rod and Attached Cross-head Mounted in V-blocks for Planing

shaft down against the platen as well as against the strip itself. This angular face is aligned with the platen by the tongue piece *t*.

Distortion of Work

When castings or forgings are set up on the planer for taking the first cut, usually the side that is clamped against the platen is rough and uneven, so that the work bears on a few high spots. This condition is shown illustrated on an exaggerated scale in Fig. 31, which shows a casting that bears at *a* and *b*, but does not touch the platen at the ends where the clamping is to be done. If the clamps were tightened without supporting the work at the end, the entire casting would probably be sprung out of shape more or less, depending on its rigidity, with the result that the planed surface would not be true after the clamps were released, because the casting would then resume its natural shape. To prevent inaccurate work from this cause, there should always be a good bearing just beneath the clamps, which can be obtained by inserting pieces of sheet metal, or even paper when the unevenness is slight. Thin copper or iron wedges are also used for "packing" under the clamps. It is good practice when accuracy is required and the work is not very rigid, to release the clamps slightly before taking the finishing cut. This allows the part to spring back to its normal shape and the finished surface remains true after the clamps are released.

Very long castings or those which are rather frail but quite large and

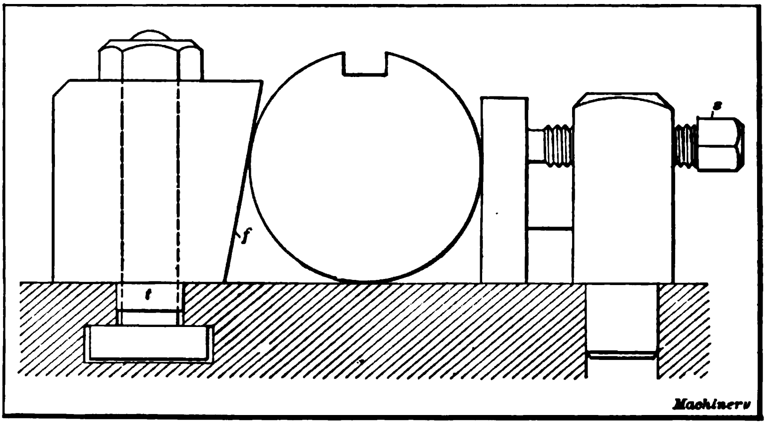

Fig. 30. Method of Holding Shaft for Splining or Keyseating

heavy, sometimes bend by their own weight or are sprung out of shape by the pressure of the planing tool, unless supported at the weak points. In such a case jacks, such as the one illustrated in Fig. 32, form a very convenient means of support. This particular jack has a ball joint at the top which allows the end to bear evenly on the work, and the screw can be locked after adjustment to prevent it from jarring loose. These jacks, which are made in different heights can also be used in various ways for supporting work being planed. Fig. 29 shows

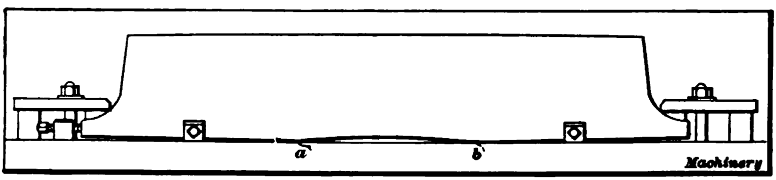

Fig. 31. Class of Work which is sometimes Distorted by Clamping

a practical application of planer jacks, two being inserted beneath the cross-head to prevent any downward spring. Hard-wood blocks cut to the right length are also used as supports.

Castings, even though properly clamped, are sometimes sprung out of shape by the internal stresses existing in the casting itself. These stresses are caused by the unequal cooling of the casting in the foundry. When a casting is made, the molten metal which comes in contact with the walls of the mold, naturally cools first and, in cooling, contracts and becomes solid while the interior is still more or less molten. The result is that when the interior cools and contracts, the tendency is to distort the part which solidified first, and internal stresses are left in the casting. These stresses often act in opposite directions and when a roughing cut is taken from one side of such a casting, thus relieving the stress on that side, a slight distortion takes place. This is illustrated on an exaggerated scale in Fig. 33. Suppose a casting is clamped as at *A*, so as to avoid all spring, and then a roughing cut is taken over side *a*, thus removing the hard outer surface. The chances are that the shape would change as shown (exaggerated) by the dotted lines, because the stresses which formerly counteracted those of the opposite side are now removed. Let us assume that the casting is next turned over and clamped as at *B* without springing it by the pressure of the clamps. If a roughing cut is then taken from the opposite side *b*, another change would probably occur because this would relieve the tension or stress of that side. The work would then assume what might be called its natural shape, and if both sides were then finished, they would tend to remain true, though slight changes might occur even then. Because of this tendency to distortion as the result of internal stresses, all work, especially if not rigid, should be rough-planed before any finishing cuts are taken. Of course, such a change of shape does not always occur, because the stresses may be comparatively slight and the planed surface so small in proportion to the size of the casting, that distortion is impossible.

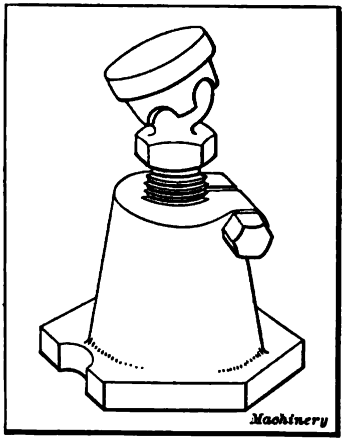

Fig. 32. Planer Jack

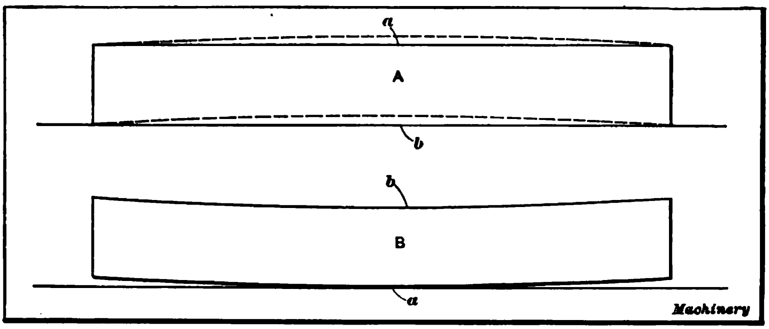

Fig. 33. Diagrams illustrating, on Exaggerated Scale, Distortion from Internal Stresses

Another important point in setting work is to locate it so that all surfaces to be planed can be finished to the required dimensions. On some work it is also desirable to have a planed part fairly true with a surface which remains rough, either to secure a neater finish or for more important reasons. Therefore, when either a casting or forging is being set up on the planer, it should be located according to the requirements for that particular part. As an illustration, suppose a flange *a*, the boss *b* and the surface *c* of a cast-iron cover plate, Fig. 34, is to be planed so that the distance between these surfaces corresponds to the dimensions given on the drawing. The first operation would be to plane the side *c*, the work being set up in the position indicated at *A*. The casting is first set about parallel with the platen, but it should be remembered that the surface which is set level or parallel is not necessarily the one to be planed. In this case the side *d* is to remain rough, and it is desirable to have a uniform thickness *x* when the cover is finished; therefore the casting is set by side *d* rather than by the upper surface *c*, or in other words, is located so that the *finished* surface will be true with the rough side of the casting.

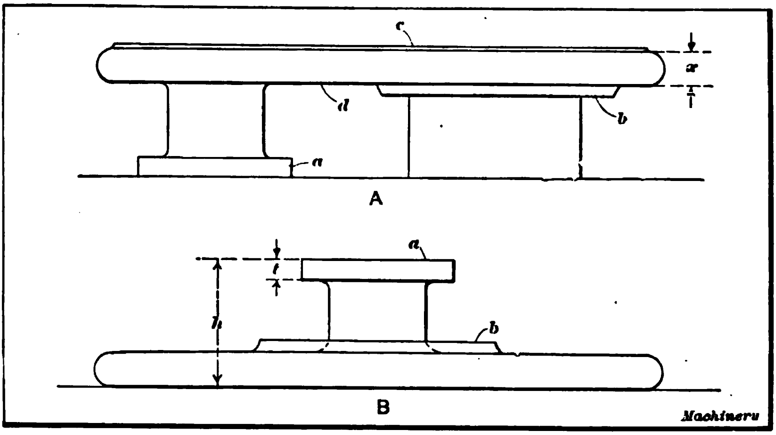

Fig. 34. Diagram illustrating Points relating to Position of Work

The amount of metal to remove when planing side *c* must be determined by considering the relation of this side to the other parts that are to be finished when the casting is turned over. For example, it should be possible to plane flange *a* to a height *h* (as given on the drawing) without removing too much or too little metal from the flange. Suppose a light cut were taken from side *c*, just deep enough to true it and then the casting were turned over, as indicated at *B*, for finishing the opposite side. When planing the flange it might be necessary to make the thickness *t* considerably less than it should be, in order to secure the proper height *h*. This, however, would not occur if when planing side *c*, the thickness of the flange as well as the height *h*, were considered. Therefore, the relation between the different surfaces should be kept in mind. Sometimes it is necessary to set a casting very carefully and to plane off just the right amount, in order to finish the other surfaces to the required dimensions.

The Surface Gage and its Use

The surface gage is used very extensively in connection with planer work for scribing lines that represent finished surfaces and also for setting parts parallel with the platen. This tool, which is shown in Fig. 35, has a rather heavy base on which is mounted a rod carrying a pointer or scriber *S*. The latter can be adjusted in or out and it also can be moved to any position along the rod. After the scriber or pointer has been set to about the right height, it can be set accurately to the position desired by turning screw *A* which gives a fine adjustment. There are two pins *B* in the base which can be pushed down when it is necessary to keep the gage in line with the edge of a plate or the side of a T-slot. The method of using a surface gage for setting a surface parallel to the platen is indicated in Fig. 36. The scriber *s* is first set to just touch the work at some point; the gage is then moved around to the opposite side, as shown by the dotted lines, and in this way the height at various points are compared.

Fig. 35. Surface Gage

The surface gage is also used extensively for laying out work. As a simple illustration, suppose the sides *b* and *c* (Fig. 36) were to be planed and it were necessary to have the thicknesses *x* and *y* of the flanges and the height *z* all conform to given dimensions. If lines *l* and l_1 representing the finished surfaces were first scribed on the flanges, these would serve as a guide when planing, and such lines could easily be drawn by using a surface gage, even though the sides did not lie in the same vertical plane. The surface gage is also used for setting lines which have been scribed on the work and represent the location of finished surfaces, parallel with the planer platen.

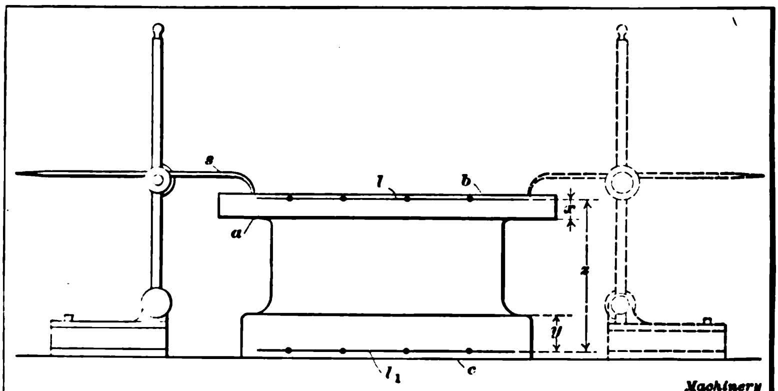

Fig. 36. Testing Alignment by using Surface Gage

CHAPTER IV

PLANER TOOLS—VARIOUS FORMS USED AND POINTS ON GRINDING

The number and variety of the tools used on a planer depend on the character of the work which is done on that particular machine. If the work varies considerably, especially in its form, quite a number of tools of different shapes will be needed, whereas, planers that are used principally for making certain parts, do not need a large tool equipment. In Figs. 37 and 38, two sets of tools intended for general work are shown. Occasionally, tools of special form are required, but the various types in the sets illustrated, will take care of practically all ordinary planing operations. Fig. 37 also shows some typical examples of the kind of planing for which the different tools are adapted.

The tool shown at *A* is a roughing tool. This form is particularly adapted for taking deep "roughing" cuts in cast iron, when it is necessary to remove considerable superfluous metal. This style of tool is also made to the opposite hand as at *B*, as it is sometimes desirable to feed the tool toward the operating side of the planer; ordinarily, however, horizontal surfaces are planed by feeding the tool *away* from the operator, the tool moving from right to left, as viewed from the front of the machine. This enables the workman to see just what depth of cut is being taken at the beginning of the cut. The tool *C* with a broad cutting edge is used for taking finishing cuts in cast iron. The cutting edge is set parallel with the planer platen, and the feed for each cutting stroke is a little less than the width of the edge. Notwithstanding the coarse feed, a smooth surface is left on the work, provided the tool is properly ground and set, and does not chatter when in use. Tools of this type are made in various widths, and when planing very large and rigid castings, wide cutting edges and coarse feeds are used. A plain round-nose tool is shown at *D*. This style is often used for rough planing steel or iron. It can also be made into a finishing tool for the same metals by grinding the nose or tip end flat. The width of the flat cutting edge is much less, however, than for cast-iron finishing tools, because if very broad edges and feeds were used when planing steel, there would be danger of the tool gouging into the work. Steel offers a greater resistance to cutting than cast iron and that is why broad tools tend to gouge in, especially if the tool is not held rigidly to prevent its springing downward. Tool *E*, which is known as a diamond point, is also used for rough-planing steel or iron. The bent tools *F* and *G* are used for planing either vertical surfaces or those which are at a considerable angle with the platen. These are right- and left-side roughing tools, and they are adapted to either cast iron or steel. They can also be used for finishing steel. Finishing tools for vertical or angular cast-iron surfaces are shown at *H* and *I*.

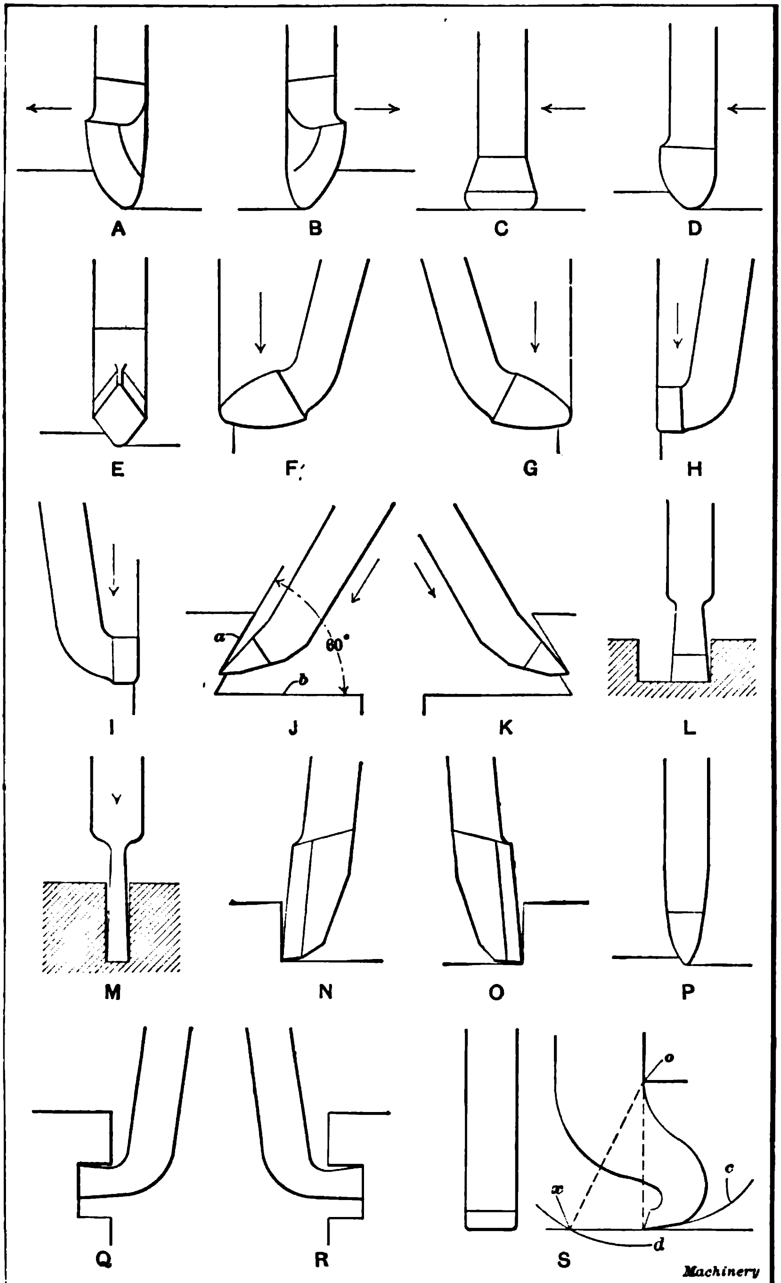

Fig. 37. Planer Tools of Different Form and Work to which they are Adapted

These have wide cutting edges to permit coarse finishing feeds. Vertical surfaces can often be planed to better advantage by using a straight tool in the side-head, when the planer is so equipped. Right and left angle tools are shown at *J* and *K*. This style of tool is for planing angular surfaces which, by reason of their relation to horizontal or other surfaces, can only be finished by a tool having a form similar to that illustrated. A typical example of the kind of angular planing requiring the use of an angle tool is indicated in the illustration. After finishing side *a*, the horizontal surface *b*, (from which a roughing cut should have been taken previously) could be planed by feeding the same tool horizontally. A square-nose tool is shown at *L*. This is used for cutting slots and squaring corners, and

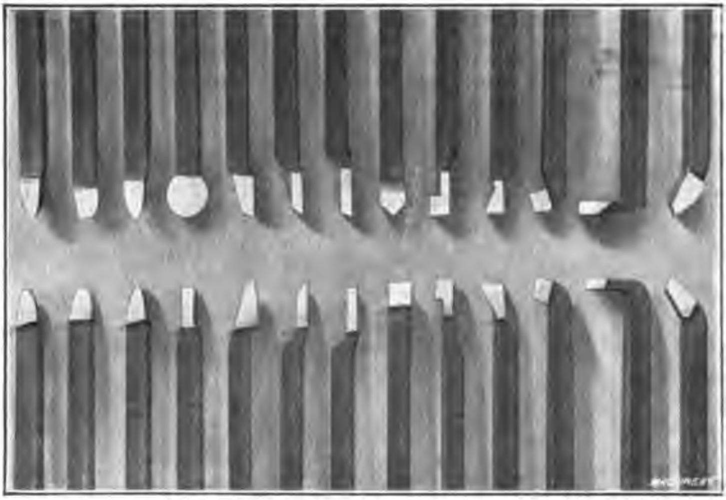

Fig. 38. Set of Planer Tools ground on Sellers Tool-grinding Machine

the same style of tool is made in different widths. A narrow square nose or "parting" tool is shown at *M*. It is adapted to cutting narrow grooves, and can also be used for cutting a part in two, provided the depth does not exceed the length of the narrow cutting end. Right and left side tools are shown at *N* and *O*. These can frequently be used to advantage on vertical or angular surfaces. A tool for planing brass is shown at *P*. It has a narrow rounded cutting edge and is very much like a brass turning tool. For finishing cuts in brass, tools having narrow flat ends are often used. Right and left bent square-nose tools are shown at *Q* and *R*. Such tools are used for cutting grooves or slots in vertical surfaces and for similar operations. The peculiarly-shaped tool shown by front and side views at *S*, is especially adapted to finishing cast-iron surfaces. This type is known as the "goose-neck" because of its shape, and it is intended to eliminate chattering and the tendency which a regular finishing tool has of gouging into the work. By referring to the side view it will be seen that the cutting edge is on a line with the back of the tool shank, so that any backward spring of the tool while taking a cut, would cause the cutting edge to move along an arc *c* or away from the work. When the cutting edge is in advance at some point *x*, as with a regular tool, it will move along an arc *d*, if the strain of the cut causes any springing action, and the cutting edge will "dig in" below the finished surface. Ordinarily the tool and the parts of the planer which support it, are rigid enough to prevent such a movement, so that the goose-neck tool is not always necessary.

All of the tools shown in Fig. 37 are forged from a solid bar of steel, the cutting end being forged to about the right shape, after

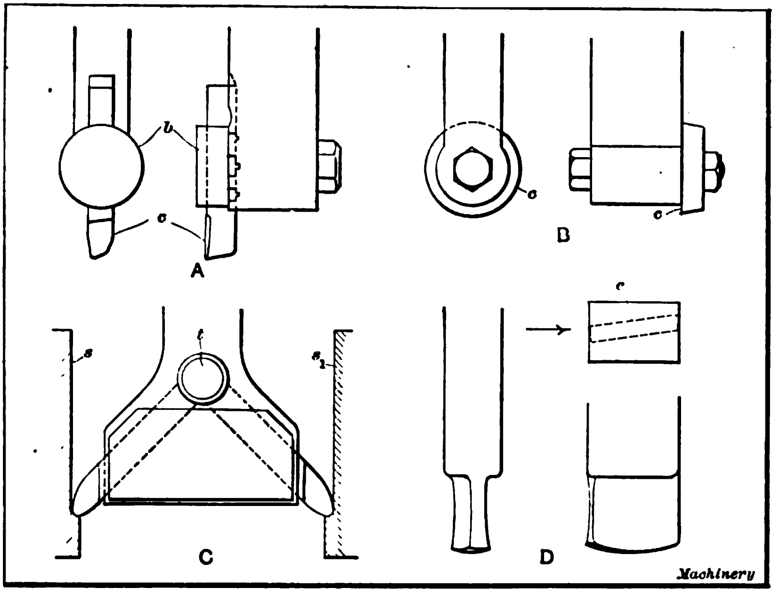

Fig. 39. (A) Planing Tool with Inserted Cutter. (B) Radius Tool (C) Tool having Two Cutters. (D) Finishing Tool

which the end is correctly formed by grinding. After the tool has been worn away considerably by repeated grindings, the end has to be re-forged or "dressed" to bring it back to the original form. To eliminate this work, and also to reduce the amount of steel required, tools are often used on the planer and other machines, having shanks into which small cutters can be inserted. These tools are made in many different designs, one of which is shown at *A* in Fig. 39. This particular style is so arranged that the cutter *c*, which is held against the shank by bolt *b*, can be set either vertically, horizontally, or at an angle of 45 degrees and the cutting edge can be placed on the right or left side of the shank, as required. This adjustment adapts the tool to the planing of horizontal, vertical or angular surfaces. It should be noted that the cutter is firmly seated in slots cut in the face of the shank. This tool can be used with the cutter in advance of the shank or to the rear; when in the latter position it has the advantages of the "goose-neck" tool.

What is known as a form tool is shown at *B*. The cutter *c* is circular and it is held to the shank by a bolt as shown. This particular tool is used for finishing round surfaces, the cutter being made to the required diameter. Form tools are also used for finishing surfaces of irregular form, the cutter being made to correspond in shape to the form required. A tool having two cutters is shown at *C*. This style is sometimes used for planing duplicate work, having two surfaces *s* and s_1, a given distance apart. By having two cutters, both sides are finished at the same time. As the cutters are ground away, they are moved out to the required width by drawing in the taper bolt *t* against which the inner ends of the cutters rest. This is an example of the special tools sometimes used in planer work. The

Fig. 40. Roughing and Finishing Tools

tool shown at *D* is a solid forged type, that is excellent for finishing steel. The way this tool operates is shown by the plan view. The cutting edge *e* is at an angle with the shank, and as the work moves in the direction shown by the arrow, the corner or edge *e* removes a light shaving and leaves a smooth surface. The edge is curved slightly, as shown by the side view, so that the cutting is done at the center. By using soda water, or even plain water, while planing, a bright surface is obtained. Only very light cuts are taken with this tool.

The action of a planer is quite different from that of a lathe, as it is used principally for producing flat surfaces, whereas the lathe produces cylindrical surfaces. In the forming or grinding of planing and turning tools, however, there are many underlying principles which are common to both classes of tools.

Front and side views of a planer roughing tool are shown at *A*, Fig. 40. As the cutting is done by the curved edge *e*, the front surface *b* is ground to slope backward from this edge, to give the tool keenness. The end or flank of the tool is also ground to slope inwards to provide clearance. The angle *c* of clearance is about 4 or 5 degrees for planer tools, which is much less than for lathe tools. This small clearance is allowable because a planer tool is held about square with the platen, whereas a lathe tool, the height of which may be varied, is not always clamped in the same position. A lathe tool also requires more clearance because it has a continuous feeding movement along a spiral path, whereas a planer tool is stationary during the cut, the feed taking place just before the cut begins. This point should be considered when grinding planer tools, because the clearance of any tool should not be greater than is necessary to permit the tool to cut freely, as excessive clearance weakens a tool. The slope of the top surface *b* depends on the hardness of the metal to be planed, the slope angle being less for hard material, to make the cutting edge more blunt and consequently stronger. When tools are ground by hand, the angles of slope and clearance are not ordinarily measured, the workman being guided by experience. As the cutting is done principally by side *e*, the slope of the top (or front when the tool is in position for planing) is back from this point, or away from the *working part* of the cutting edge. By grinding a flat spot on the nose or lower end, this same tool can be used for taking finishing cuts in steel. Finishing cuts are also taken with a round nose, by using a fine feed. The edge *c* of the cast-iron finishing tool (*B*) should be ground straight by testing it with a small straightedge or scale. The corners should also be rounded slightly, as shown, as a square corner on the leading side will dull quickly. The illustration shows clearly the tool's shape. The square-nose tool (Fig. 41) cuts along its lower edge *e*, and is given clearance on the end and sides as shown in the two views. The lower edge is the widest part of the cutting end, the sides sloping inward in both a vertical and horizontal direction, which prevents the tool from binding as it moves through a narrow slot. The side-tool in the lower part of Fig. 41 cuts along edge *e*, which, as the side view shows, slopes backward. Planer side-tools are not always made in this way, but it is a good form, as the sloping edge starts a cut gradually, whereas a vertical edge takes the full width of the cut suddenly, thus producing a shock.

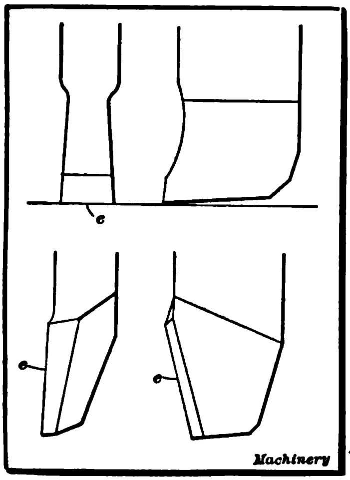

Fig 41. Square-nose Tool—Side-tool with Sloping Edge

Reference has been made to the grinding of these few types of tools, merely to point out some of the principles connected with the grinding of planing tools. When the principle of tool grinding is understood, the various tools required, whether regular or special in form, can be ground without difficulty. One thing that should be remembered when grinding a tool, is that it does not pay to force the tool too hard against the emery wheel or grindstone, as is often done in attempting to grind quickly. The tool should be ground with a moderate pressure, and it should be withdrawn frequently when forming a flat surface, to prevent excessive heating and burning of the tool. The grinding wheel should always be supplied with cooling water.

CHAPTER V

THE SHAPER

The shaper, like the planer, is used principally for producing flat surfaces, but it is intended for smaller work than is ordinarily done on a planer. The shaper is preferable to the planer for work within its capacity because it is less cumbersome to handle and quicker in its movement. The action of a standard shaper, when in use, is quite different from the planer; in fact, its operation is just the reverse, as

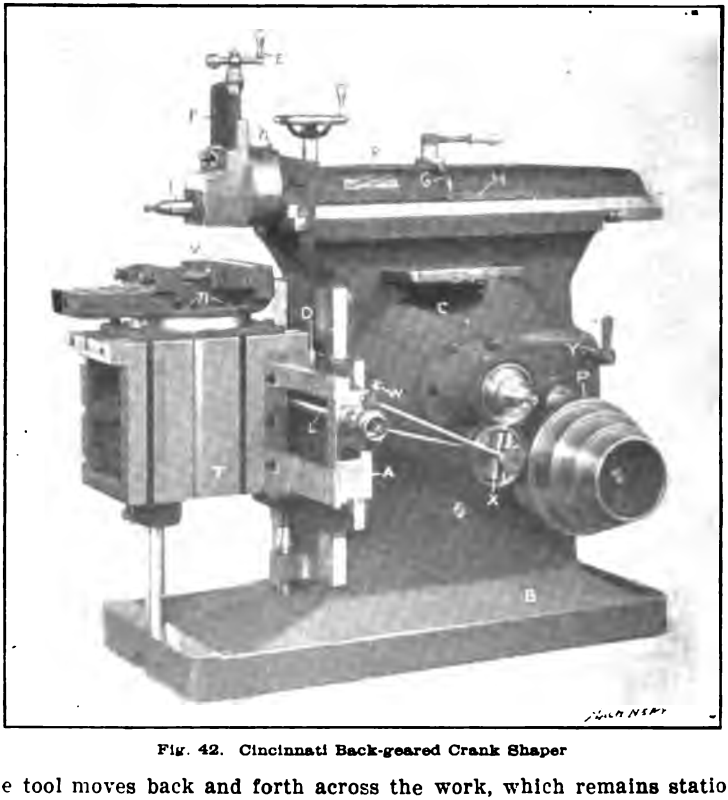

Fig. 42. Cincinnati Back-geared Crank Shaper

the tool moves back and forth across the work, which remains stationary, except for a slight feeding movement for each stroke. A shaper of typical design is shown in Fig. 42. The principal parts are the base and column *B* and *C*, the table *T* which has a vise *V* for holding work, and the ram *R* which carries a planing tool in tool-post *I*, and is given a reciprocating motion by a crank mechanism inside the column. The work-table is mounted on a saddle or cross-slide *D*. and it can be moved along the cross-rail *A* by turning the lead-screw *L* with a crank or by an automatic feeding mechanism. The cross-rail can be adjusted vertically on the face of the column to accommodate work of various heights, and the tool-slide *F* with the tool, can be fed downward by handle *E*.

The driving mechanism for the ram is shown in the sectional views Fig. 43. Shaft *S* on which the driving pulley is mounted, is connected through gearing with crank gear *C*. This gear carries a crank-pin or block *B* which engages a slot in the arm *N*, and this arm in turn, connects with the ram *R* and is pivoted at its lower end. As the crank gear rotates, a vibrating motion is given to arm *N* which imparts a reciprocating movement to the ram. The amount that the arm moves and, consequently, the stroke of the ram, is governed by the position of the crank-block *B* which can be adjusted toward or from the center of the gear by shaft *O*. This shaft connects through spur and bevel gears with a screw that engages the crank-block as shown in the cross-section to the left. The stroke can be changed while the shaper is in motion, and the pointer *G*, as it travels along the stationary scale *H*, shows the length of the stroke in inches (see also Fig. 42). The *position* of the stroke can also be varied (while the machine is in motion) by turning handwheel *J* which causes screw *K* to rotate and shifts the position of block *L* with relation to the ram. Before making this adjustment, block *L*, which is ordinarily clamped to the ram, is loosened by turning lever *M*. By means of this adjustment for the *position* of the stroke, the tool is made to move back and forth over that part of the work that requires planing, whereas the stroke adjustment serves to change the travel of the tool according to the length of the work.

The cross-rail *A* with the attached slide and table, is adjusted vertically on the face of the column by a telescopic screw *Q*, which is rotated through bevel gears, by a horizontal shaft operated by a crank on the left side of the machine. Before making this vertical adjustment, binder bolts at the rear of the slide, which clamp the cross-rail rigidly to the column, must be loosened, and the column ways should also be cleaned to prevent chips or dirt from getting back of the slide. The outer end of the table is prevented from springing downward when taking heavy cuts, by a shaft *U* which rests on the base and can be adjusted for any vertical position of the table.

The feeding movement of the work-table for each stroke of the ram, is derived from a slotted crank *X*, Fig. 42, which is rotated by gearing. This crank is connected by the rod shown, with a pawl *W*. As the crank rotates, this pawl engages a ratchet gear and turns lead-screw *L*, thus moving the work-table along the cross-rail. The amount of this feeding movement for each stroke of the ram, is varied by adjusting the sliding block of crank *X* toward or from the center. When the power feed is not required, it is disengaged on this shaper by turning a sleeve around beneath the pawl, thus preventing the latter from engaging the ratchet gear. To reverse the feed, the pawl is simply given a half turn, which causes it to rotate the ratchet when moving in the opposite direction.

On this particular shaper there are eight speed changes for the

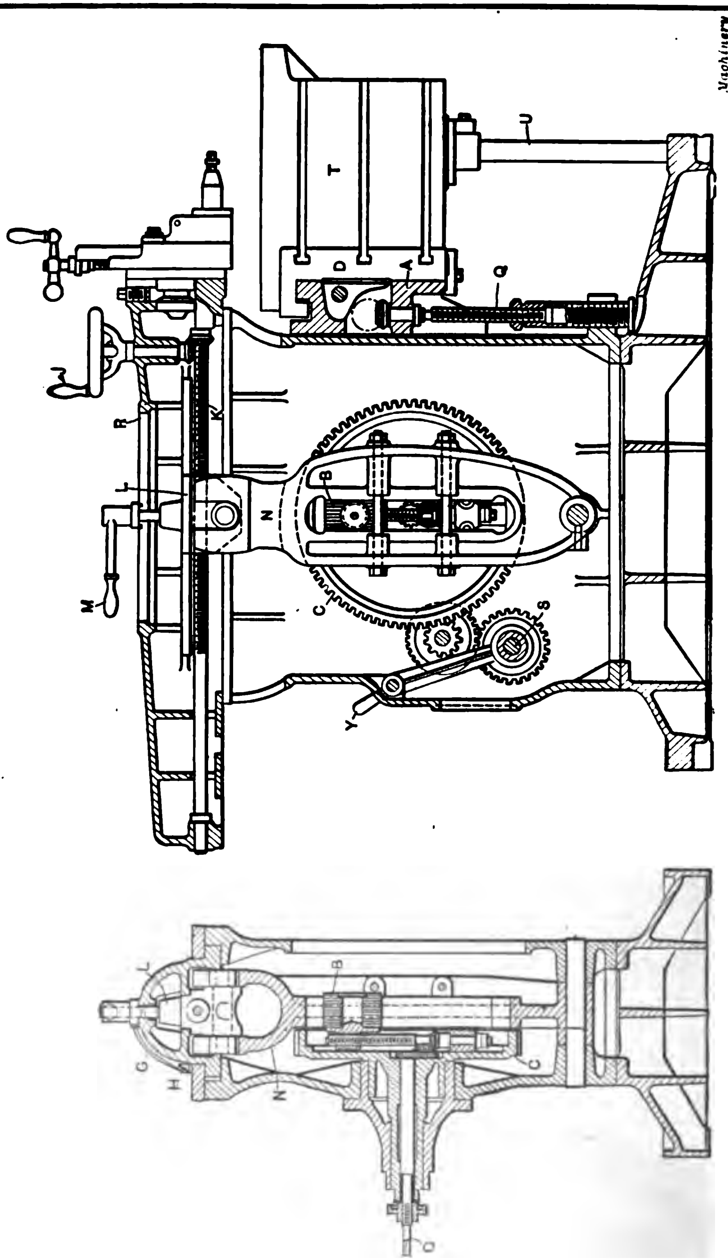

Fig. 43. Cross and Longitudinal Sections of Back-geared Crank Shaper

ram. Four of these are obtained by shifting the driving belt on different steps of the cone-pulley *P* (Fig. 42), and this number is doubled by back-gears inside the column which are engaged or disengaged by lever *Y*. Shapers are also made without back-gears, in which case the number of speed changes equals the number of steps on the driving cone pulley. The higher speeds are used when the tool travel or stroke is comparatively short and the slow speeds for long strokes. If there were no way of changing the speed and the shaper made the same number of strokes per minute regardless of the length, there would, of course, be a wide variation in the cutting speed of the tool. This change of speed, however, which accompanies a change of stroke, only occurs with a crank shaper, the cutting speed of a geared or rack shaper being constant for any length of stroke. The difference between these two types will be referred to later.

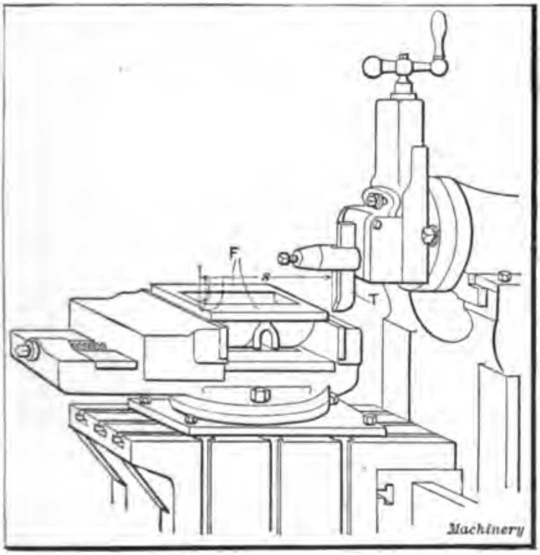

Fig. 44. An Example of Shaper Work

Examples of Shaper Work

Most of the work done in the shaper is either held in the vise *V* (Fig. 42) or is clamped to the table *T*, which is provided with slots for receiving the clamping bolts. The vise resembles a planer vise, and it can be removed readily when work is to be attached directly to the table. It can also be swiveled to any angular position by loosening nuts *n*, the position being shown by degree graduations. The table of this particular shaper is also removable, to permit clamping parts directly to the face of the saddle or cross-slide *D*, which also has bolt-slots in the front face.

Fig. 44 shows an example of the kind of work which is held in the vise. The part illustrated is a small engine slide valve, which is set up for planing the face *F*. After the casting is properly located in the vise and the tool *T* is clamped in place, the shaper is started and the stroke adjusted both for length and position, to give the tool a movement about as indicated by the arrow *s*. The tool is then fed downward to the work and the latter is moved crosswise, by hand, until a cut of the right depth is started; the automatic feed is then engaged by dropping the feed-pawl into mesh with the ratchet gear on lead-screw as previously explained.

The tools used in a shaper are similar in form to planer tools, though smaller. When taking finishing cuts in the shaper, broad tools and wide feeds cannot be used to the same extent as in planer work, because the shaper is less rigid and, consequently, there is a greater tendency for the tool to chatter.

Fig. 45 shows an odd-shaped casting bolted to the side of the table for planing the top surface. The table, in this case, serves the same

Fig. 45. Casting of Irregular Shape bolted to Side of Table

Fig. 46. Table removed and Casting Clamped to Cross-slide

purpose as an angle-plate on the planer, and the method of holding the casting to it is clearly shown in the illustration. Clamp *C* simply forms a stop for supporting the outer end of the casting, which would otherwise tend to sag down under the thrust of the cut. Work that is bolted directly to the table is held by practically the same kind of clamps that are used in connection with planer work.

In Fig. 46 the table is shown removed and a casting is clamped directly to the face of the cross-slide for planing the top bearing surface. This is an illustration of the class of work that can be held to advantage in this way. When setting work in the shaper, a surface gage can often be used effectively the same as in planer work. The tool itself can also be employed as a gage for setting the work level, by comparing the distance between the surface being tested and the tool point. When using the tool in this way, it is placed close to the work and the latter is shifted so that its height at various points can be determined.

When vertical or angular surfaces are planed in the shaper, the tool block is swiveled so that the top of the block inclines away from the surface being planed, to avoid any interference with the tool on the return stroke, as explained in connection with planer work. The entire tool head can also be set to any angle for planing angular surfaces, by loosening locking bolt *h* (Fig. 42), and its position is shown by degree graduations. Some shapers have an automatic verti-

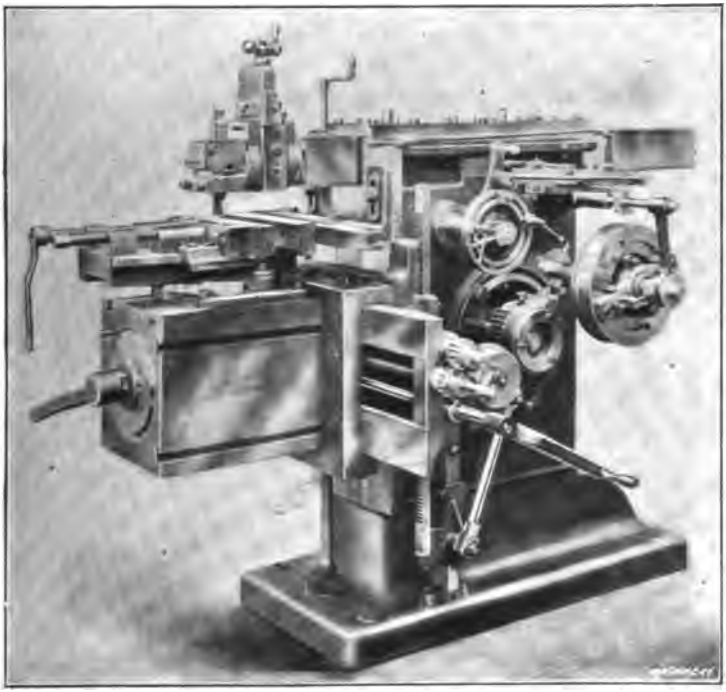

Fig. 47. Morton Draw-cut Shaper

cal feed for the tool as well as an automatic horizontal feed for the work, but most of the shapers now used are not so equipped, the tool being fed vertically by hand. Both the horizontal and vertical feed screws of the machine shown in Fig. 42, have graduated collars which are used when it is desired to feed the tool down or crosswise a definite amount. These collars have graduations representing a movement of 0.001 inch, and they can often be used to advantage for adjusting the tools.

Rack Shaper—Draw-cut Shaper—Special Types

A shaper of the type illustrated in Fig. 42, or one which is operated by a crank and slotted lever, is known as a crank shaper to distinguish it from the rack shaper which has an all-geared drive. The driving mechanism of a rack shaper is similar to that of a spur-gear type of planer. The ram has a rack on its under side and it is driven by a gear which meshes with this rack. The movement of the ram is reversed either by open- and cross-belts which are alternately shifted on tight and loose pulleys, or by friction clutches, which alternately engage the forward and return pulleys. The length of the stroke is controlled by adjustable tappets.

The shaper illustrated in Fig. 47 differs from the ordinary type in that the tool cuts when it is moving towards the column of the machine. In other words, the tool is pulled or drawn through the metal on the cutting stroke instead of being pushed. For this reason the name "draw-cut" is applied to a shaper of this type. The planing tool is, of course, set with the cutting edge reversed. The ram of this

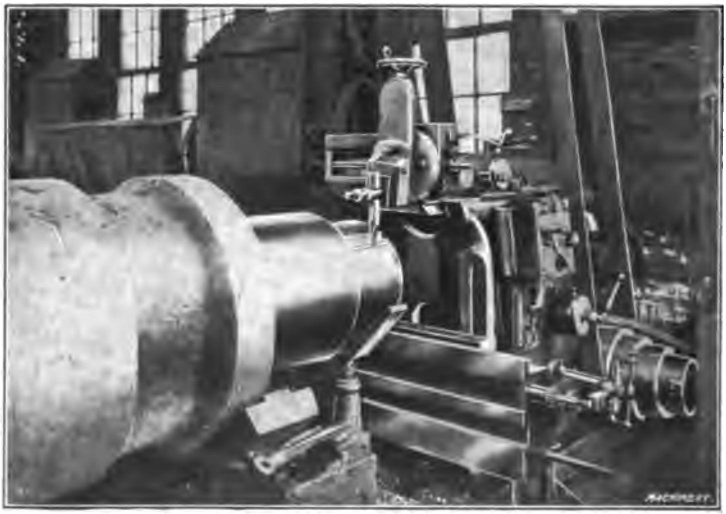

Fig. 48. Planing End of 20-ton Steel Roll, with Shaper having Side-traversing Tool-head

machine is driven by a rack and gearing, and the reciprocating motion is obtained by open- and cross-belts. The forward motion pulley is on one side of the column and the reverse pulley on the other. These pulleys are alternately engaged by friction clutches, and the length of the stroke is regulated by adjustable tappets mounted on the circular disk seen near the top of the column. There is also a hand lever for reversing the ram at any part of the stroke.

The object in designing a shaper to take a draw cut is to secure greater rigidity and, consequently, a higher degree of accuracy. The thrust of the cut is toward the column and this tends to relieve the cross-rail from excessive strains, especially when taking deep cuts.

Shapers of special types are also built in a number of different designs which are varied to suit certain classes of work. These differ from the standard types either in the motion of the ram relative to the work-table or in having a greater range of adjustment which adapts them to work which could not be handled in an ordinary shaper.

A shaper is shown in Fig. 48, which is provided with a cross traverse for the tool-head. The advantage of this feature, for certain classes of work, is indicated by the illustration. The regular table has been removed, and the end of a 20-ton steel roll is being planed. The traversing head enables horizontal cuts to be taken over the work which remains stationary. This shaper is a special design built by Gould & Eberhardt, and it can be used to advantage on large, unwieldy parts such as the one illustrated.

CHAPTER VI

THE SLOTTING MACHINE

The slotting machine or "slotter," as it is commonly called, is a vertical machine and is adapted to cutting keyways in the hubs of flywheels or pulleys and for finishing slots or other enclosed parts which could not be finished by the tool of a horizontal machine like the planer or shaper. The slotter is also used for various other classes of work, requiring flat or curved surfaces, which can be machined to better advantage by a tool which moves vertically. The ram *R* of the slotter, to which the planing or slotting tool is attached (see Fig. 49), has a vertical reciprocating movement at right angles to the work table. This vertical movement is obtained from a crank disk *D* which is connected to the slotter ram by a link and is driven by a cone pulley *P* and the large gearing seen at the rear. The tool is fastened to the end of the ram by the clamps shown, and the work is secured to the platen *T*. There are two sets of clamps on the ram so that the tool can be held in a vertical or horizontal position. The tools used for keyseating or finishing slots, are held in a vertical position, whereas larger surfaces which can readily be reached, are planed by a tool held horizontally against the end of the ram. The platen *T* can be moved crosswise along the saddle *S* and the latter can be traversed at right angles along the bed. In addition, the platen can be rotated about its center for slotting circular surfaces. These three movements can be effected by hand or power. The lengthwise adjustment on the bed is effected by turning squared shaft *A* with a crank; similarly, squared shaft *B* is used for moving the platen crosswise. The platen is rotated by turning shaft *C*. The automatic power feed for these three movements is derived from the cam *E* on the inner side of the large driving gear. This cam is engaged by a roller on the end of lever *F* and whenever the ram or tool is at the top of its stroke, an irregular place in the cam track causes lever *F* to oscillate. This movement is transmitted by connecting link and shaft *G* at the side of the bed, to the slotted crank *H*. This crank turns the large gear *I* slightly for each stroke of the ram, by means of a ratchet disk carrying a double-ended pawl *K* which engages the gear. Gear *I*, in turn, transmits the movement through the intermediate gears shown, to either of the three feed shafts. If a power feed along the bed is wanted, gear *J* is placed on the feed-shaft *A*, as shown in the illustration. On the other hand, if a cross feed is desired, gear *J* is inserted on shaft *B* and, similarly, the rotary feed is obtained by placing this same gear on shaft *C*. The amount of feed is varied by changing the position of the crankpin at *H*, and the direction of the feed is reversed by shifting the double-ended pawl *K*. The stroke of the ram is varied by adjusting the crankpin of disk *D*, to or from the center. The vertical position of the ram is changed so that the tool

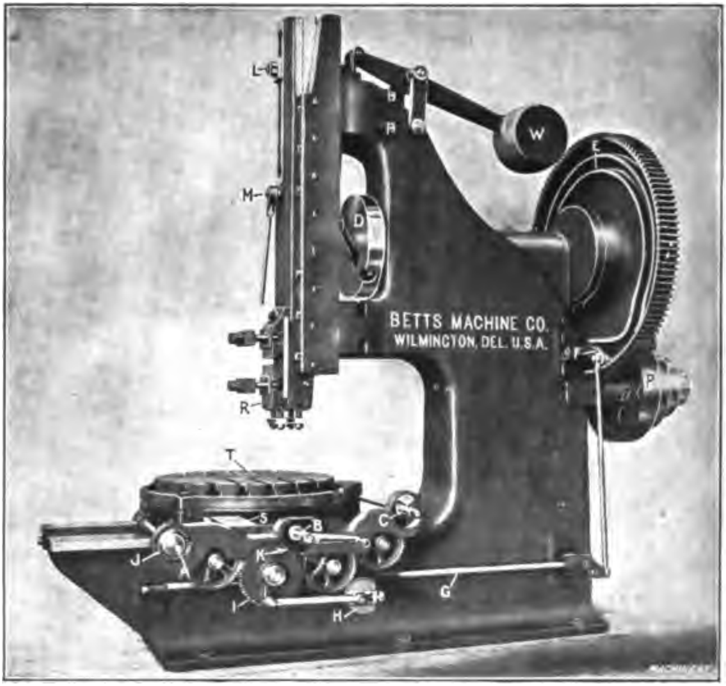

Fig. 49. Betts Slotting Machine

will operate in the right relation to the work, by loosening nut *L* and moving the ram up or down by turning shaft *M* with a hand ratchet. The ram is counterbalanced by a weight *W* and it has a quick return movement for the upward or idle stroke.

A typical example of the kind of work done on the slotter is shown in Fig. 50 which illustrates, diagrammatically, the slotting of a locomotive driving-wheel box. The side and top views at *A*, indicate how the inner sides of the box are finished. The work is set on parallel strips *s* to provide clearance for the tool at the lower end of the stroke, and it is secured to the platen by four clamps. The stroke of the ram *R* should be about one inch greater than the width of the surface to be slotted and most of the clearance between the tool and the work should be at the top of the stroke where the feeding movement takes place. When the stroke is adjusted, the ram is placed in its lowest position and it is lowered until the end is a little above the top of the work. The tool is extended below the end of the ram far enough to allow the cutter *c* to reach through the box when at the bottom of the stroke. The line previously scribed on the work to show the location of the finished surface, is next set parallel to the cross travel of the platen. This can be done by comparing the movement of the line with relation to the stationary tool-point while the work is fed

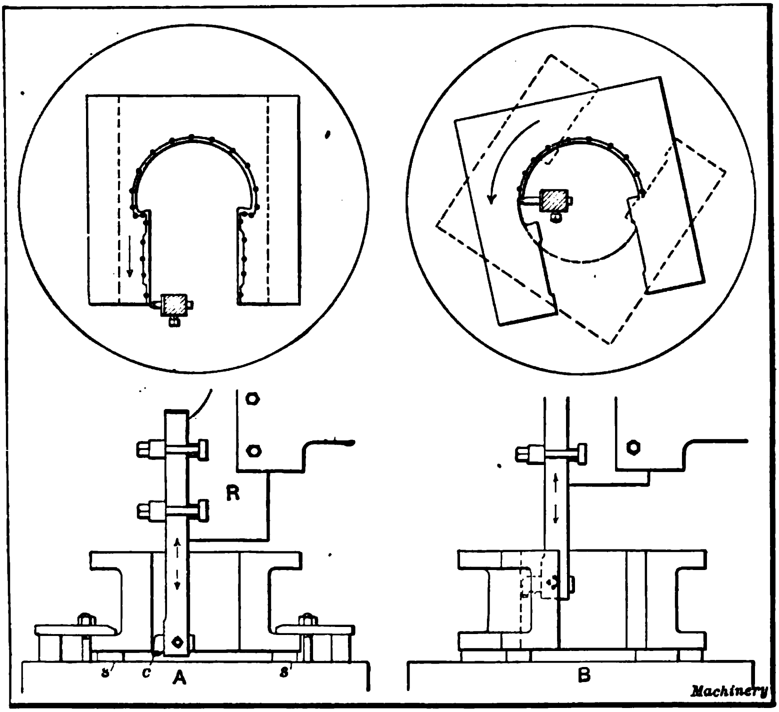

Fig. 50. Example of Straight and Circular Slotting

laterally by hand. If adjustments are necessary, these can be made by swiveling the platen one way or the other as required. When the work is set, the platen is locked to the saddle by clamps provided for that purpose. The cut is started at one end as shown in the plan view and the side is planed by the vertical movement of the tool combined with the lateral feeding movement of the platen and work. The opposite side is slotted without disturbing the position of the work by simply turning the tool half way around. The sketch at *B* indicates how the curved seat for the brass journal is finished. The radius of the seat is shown by a scribed line which must be set concentric with the center or axis about which the platen rotates. The platen must also be adjusted laterally and longitudinally, if necessary, until the tool will follow the finish line as the work feeds around. The position of the work soon after the cut is started is shown in the plan view by the full lines, and the dotted lines indicate how the box feeds around while a cut is being taken across the circular seat. After the slotter is set in motion, the cut is started by hand and then the power feed is engaged. The finish lines on work of this kind usually serve merely as a guide and the final measurements are determined by calipers or special gages.

A number of duplicate parts can sometimes be slotted simultaneously by clamping one piece above the other in a stack or pile. The tool then planes the entire lot to the same shape. This method only applies to work which can readily be stacked up.

Some of the tools used in the slotter are illustrated in Fig. 51. Those shown at *A*, *B* and *C* are forged from the solid bar and have

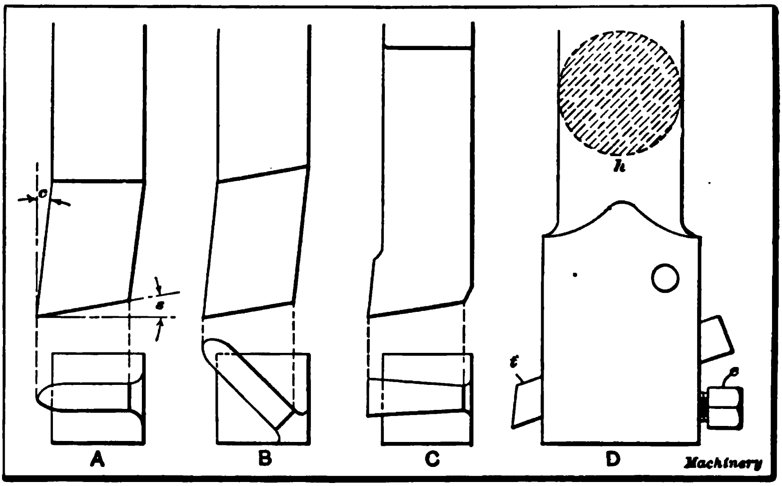

Fig. 51. Some of the Tools used for Slotting

cutting edges formed on the ends, whereas tool *D* consists of a heavy bar in which a small cutter *t* is inserted. Tools *A* and *B* are used principally for slotting interior surfaces, where there is little room for the tool to operate. For exterior slotting, or whenever there is plenty of room, tool *D* is preferable because it is more rigid. The cutting end of tool *B* is inclined to the right or left (as indicated by the end view) for working in corners, etc. The position of tool *D*, which has a round shank *h*, can be varied by turning it in clamps at the upper end which hold it to the slotter ram. The cutter *t* is held by setscrew *c* in a pivoted, spring-relief block which allows the tool point to swing away from the work on the upward stroke. The tool tends to spring away from the work on the downward or cutting stroke, and if there is no relief movement, it drags heavily over the planed surface on the upward stroke. Tool *C* is used for cutting keyways or narrow slots. These tools have a slope *s* at the end and the front side is ground to a clearance angle *c*. The direction of the slope at the end (which is the surface against which the chips bear while being severed) is away from the cutting edge, and this is a rule which applies generally to tools for turning or planing iron or steel.

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SECOND EDITION

DRILLING MACHINES

CONTENTS

CHAPTER I

UPRIGHT DRILLING MACHINES

In the construction of practically all machinery, a great many holes have to be drilled owing to the extensive use of bolts and studs for holding the various parts together. The drilling machines or "drill presses," as they are often called, which are used for drilling these holes, are made in many different types which are designed for handling different classes of work to the best advantage, and the various

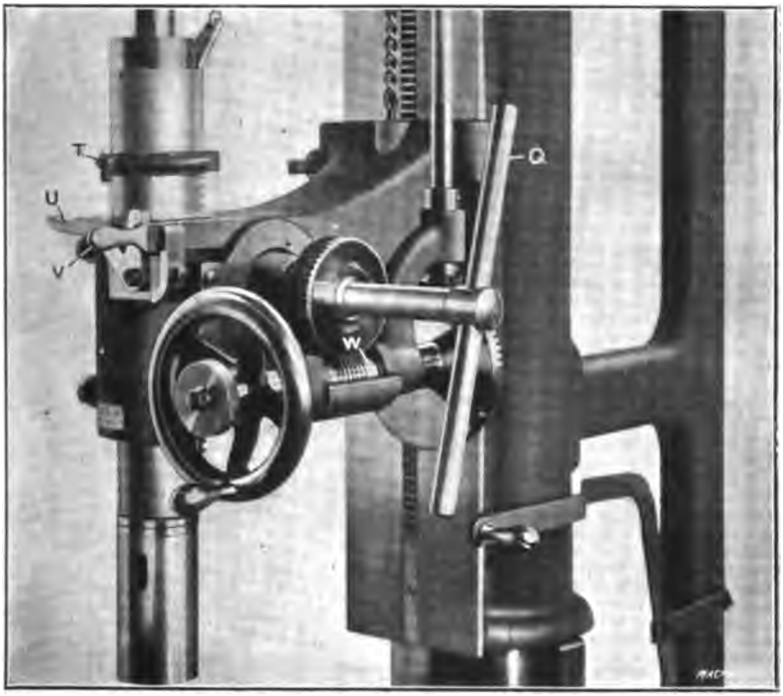

Fig. 1. Drill Spindle Feeding and Automatic Trip Mechanism

types are also built in a great variety of sizes, as the most efficient results can be obtained with a machine that is neither too small nor too large and unwieldly for the work which it performs.

An upright drill press of medium size is shown in Fig. 2. The drill itself is inserted in the end of spindle *S*, and when the machine is in use, this spindle is fed downward either by hand or power, thus causing the revolving drill to cut a hole into the work. The spindle is driven by a horizontal shaft *B* connecting with a cone pulley *P*, which is driven by belt from a lower cone pulley P_1. The shaft on which the lower cone pulley is mounted, is rotated by a belt from an overhead countershaft. The machine is started by shifting this driving belt

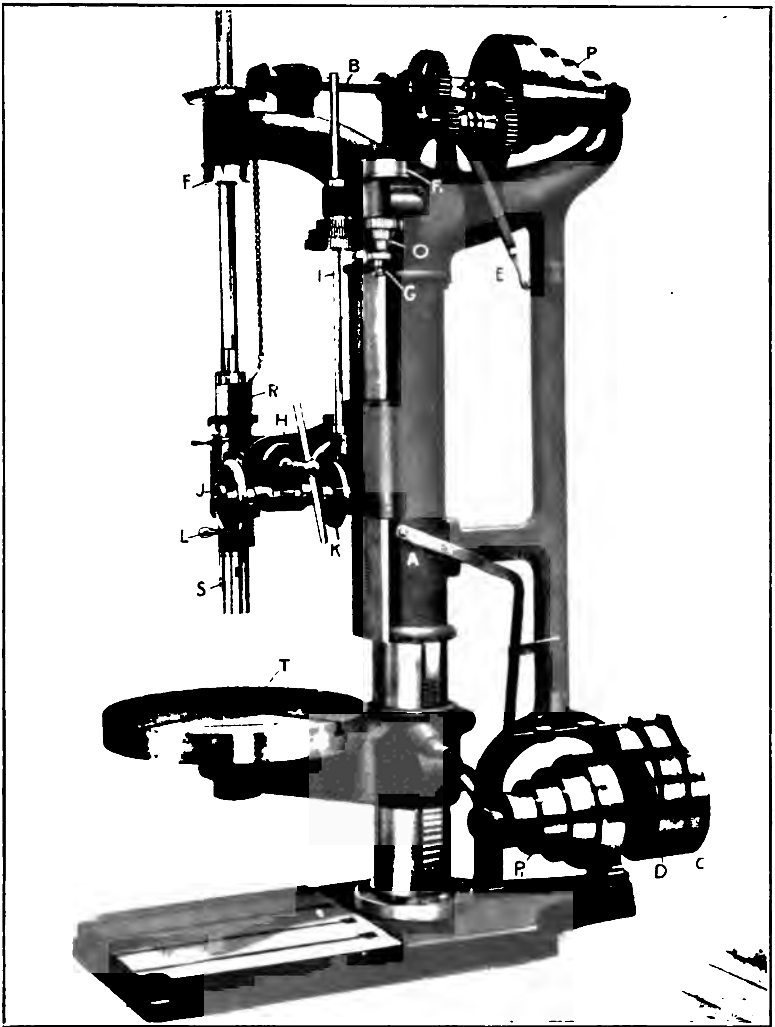

Fig. 2. Hamilton Upright Drilling Machine

from the loose pulley *C* to the "tight pulley" *D* which is keyed to the shaft, and the position of the belt is controlled by handle *A*. The speed of the spindle must be varied according to the diameter of the hole being drilled, the speed being increased as the diameter diminishes. To obtain these speed variations, the belt connecting pulleys *P* and P_1

is shifted to steps of different diameter. The range of speeds obtained in this way can be doubled, on this particular machine, by back-gears located just in front of the upper pulley. When these gears are not in use, shaft *B* is coupled direct to cone pulley *P* by means of a sliding clutch *N* (see the detail view Fig. 3), but when the back-gears are shifted into engagement by operating lever *E*, the clutch is disengaged and the cone pulley drives shaft *B* through train of gears *a*, *b*, *c* and *d*. The fastest speed obtained with the back-gears engaged, is slower than the slowest speed when driving direct, so that a gradually increasing range of eight speeds is available.

As the illustration shows, the connection between shaft *B* and the spindle is made by bevel gears. The spindle is free to move vertically

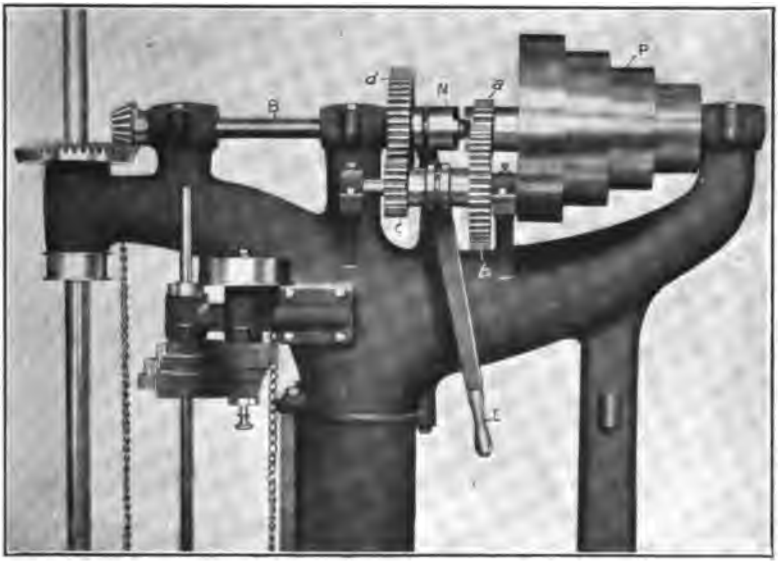

Fig. 3. Back-gearing and Feed Change-gears of Upright Drilling Machine

through the large bevel gear, and the lower end is steadied by the head *H*. (Fig. 2) which is clamped to the column and can be adjusted to different heights. The work-table *T* can also be adjusted vertically on the column to suit the height of the work, and it can be swung to one side when a large heavy part is to be supported directly on the base. After the work is clamped to the table, it can be adjusted for drilling at any point by swinging the table about the column and also by turning the table about its own center. When the table is properly adjusted, it can be clamped to the arm and the arm to the column by the bolts shown.

The power feed for the spindle is driven by a belt operating on pulleys *F* and F_1. Pulley F_1 is mounted on a shaft carrying a cone of gears *O* any one of which can be locked to the shaft by changing the position of "pull-pin" *G*. These gears are in mesh with corresponding gears on shaft *I*, which rotates, through bevel and worm-gearing, a pinion meshing with rack *R* attached to the quill in which the spindle revolves. As this pinion rotates, the quill and spindle are moved vertically and the amount of this movement for each revolution can be varied by shifting pull-pin *G*. For example, when a large gear in the cone *O* is locked and becomes the driving gear (by changing the position of the pull-pin), the feed or vertical movement of the spindle is more rapid than when the power is transmitted by one of the smaller gears. The driving gear is locked by a key attached to the pull-pin, and as this key can only engage one gear at a time, the others revolve idly on the shaft. The power feed is engaged or disengaged by tightening or loosening a knurled nut *J*, which controls a friction clutch that connects or disconnects bevel gear *K* with the worm-shaft. When the power feed is disengaged, the spindle can be moved up or down by turning hand-wheel *L*. On some drilling machines, the vertical feed shaft *I* is driven direct by a belt operating on cone pulleys and the feed changes are obtained by shifting this belt. The spindles of small drill presses usually have only the hand feed as the power feed is unnecessary when the holes to be drilled are small and not very deep; furthermore such holes can be drilled more rapidly when the spindle is fed by hand.

The machines equipped with power feed usually have some sort of trip mechanism which can be set to automatically disengage the feed when a hole has been drilled to the required depth. The automatic trip or stop on the machine illustrated in Fig. 2 is shown in detail in Fig. 1. This trip has an adjustable collar *T*, the position of which controls the depth of the hole drilled or the point at which the feed is disengaged. This disengagement is effected as follows: When collar *T* strikes the latch *U*, lever *V* is disengaged and worm *W* drops out of mesh with its wheel, thus stopping the feed. The spindle can then be raised quickly for drilling a new hole, by turning handle *Q* whicn is provided for that purpose. The automatic trip mechanism prevents drilling holes deeper than they should be, after it is properly set, and close attention on the part of the operator is not required.

These are the principal features of an upright drill press which, in many respects, is a typical design. Before referring to drilling machines of other types, some examples of drilling will be described.

CHAPTER II

DRILLING, REAMING, COUNTERBORING AND TAPPING

A simple example of drill-press work is shown in Fig. 5, which illustrates a steel link that is to have holes drilled in the ends. We shall assume that the location of these holes is indicated by circles previously drawn with dividers and dotted lightly to more clearly show their location. The centers of these circles should first be enlarged with a center-punch to form a starting point for the drill. When a part to be drilled is quite heavy and the holes are comparatively small, it is often unnecessary to clamp the work to the drill press table though, as a rule,

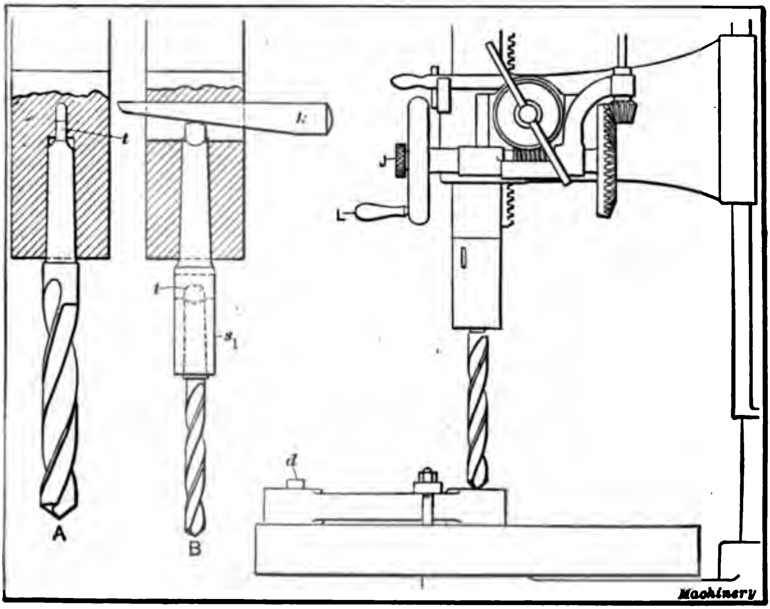

Fig. 4. Method of Holding and Driving Taper-shank Drills. Drilling-head of Upright Machine

it is better to use one or more clamps, depending on the shape and size of the work. A method of holding this particular part without using any special clamping appliances, is shown in Fig. 4. The end to be drilled is held by a clamp and a stop *d* is placed against one side of the work to prevent it from rotating with the drill.

The drill itself is inserted either directly in the spindle or in a socket, as will be explained later. The type of twist drill commonly used is shown at *A* in Fig. 6. It has two beveled cutting edges *e* at the end, formed by the two spiral grooves or flutes, and the part *s*. called the shank, is made to a standard taper. The size of the shank is the same on all drills up to a certain diameter, and then a larger shank is used for another range of sizes, and so on. In the Morse system of tapers, which is universally used for twist-drill shanks, the sizes are designated by numbers. For this particular operation, the drill would per-

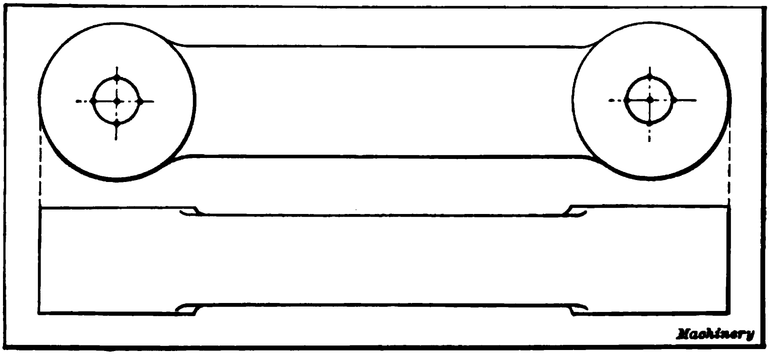

Fig. 5. Example of Drill-press Work

haps be large enough to permit inserting it directly in the spindle as shown at *A* in Fig. 4, though this would depend on the number or size of the taper hole in the spindle. On the other hand, if a comparatively small drill were to be used, it might be necessary to place a socket s_1 (see sketch *B*) in the spindle and insert the drill in the end of this

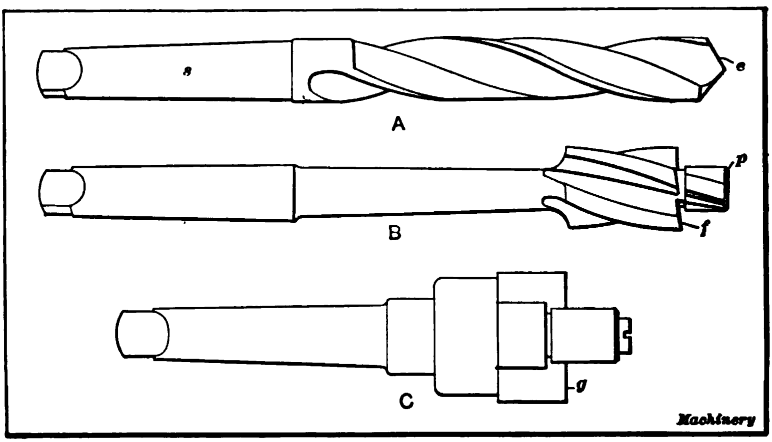

Fig. 6. (A) Twist Drill. (B) Solid Counterbore. (C) Counterbore with Inserted Blade

socket. The drill is caused to rotate with the spindle or socket, principally by a flat end or tang *t* on the shank, which engages a cross-slot at the end of the taper hole, as shown. As the taper of the shank corresponds with the taper of the hole in the spindle or socket, the drill is also driven partly by friction.

When the drill is in place, it is fed down by hand-wheel *L* for starting the hole. If the work is clamped in position, it is adjusted for drilling at the proper place, by turning the table about its own center and swinging the supporting arm about the column. When the drill begins to cut, the location of the hole with reference to the scribed circle should be noted. If the hole starts off center, as at *A*, Fig. 7, a groove should be cut down that side which is farthest from the circle (see sketch *B*) by using a gouge and hammer, the proper depth of this groove depending on the amount that the hole is off center. This operation is repeated, if necessary, so that the drill will be concentric with the circle (as at *C*) just before it begins to cut to the full diameter. The power feed is then engaged by tightening knob *J*. When the work rests directly on the table, as in this case, the end to be drilled should be set over a slot or hole, to prevent the drill from cutting the table when it comes through on the lower side. The table and arm should also be clamped after they are properly set. Drills or sockets are removed by a taper center-key or drift *k*, Fig. 4, which is

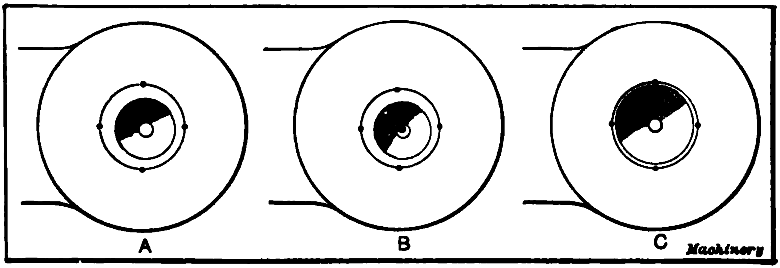

Fig. 7. Method of Starting Drill Concentric with Scribed Circle

driven in a cross-slot above the tang, as the illustration indicates. When drilling steel or wrought iron, the drill point should be kept lubricated. Sperm or lard oil may be used, and soda water, which is made by dissolving sal soda in water, is also extensively used for lubricating purposes. Cast iron and brass are drilled without a lubricant.

Finishing Holes by Reaming

Drilled holes are not always round or straight and the diameters vary to some extent, especially when the drill used is sharpened by hand, so that when accurate holes are required, the drilled hole is finished by reaming to secure smooth straight holes of uniform diameter. Holes for bolts that must fit accurately are often finished in this way, though on some classes of work, which does not need accurately fitting bolts, a drill slightly larger than the bolt body is used and the reaming operation is omitted.

Three different styles of reamers are shown in Fig. 8. The style of reamer shown at *A*, which is known as the fluted type, cuts along the edges *a–b* and it has a taper shank similar to a drill shank, which is inserted in the spindle. This reamer will produce a smooth accurate hole, but it is not adapted to removing much metal, and the diameter of the drilled hole should not be more than 0.010 or 0.015 inch under the finished size. The speed for reaming should be much slower than for drilling, and a fluted reamer should not be forced too hard, as both

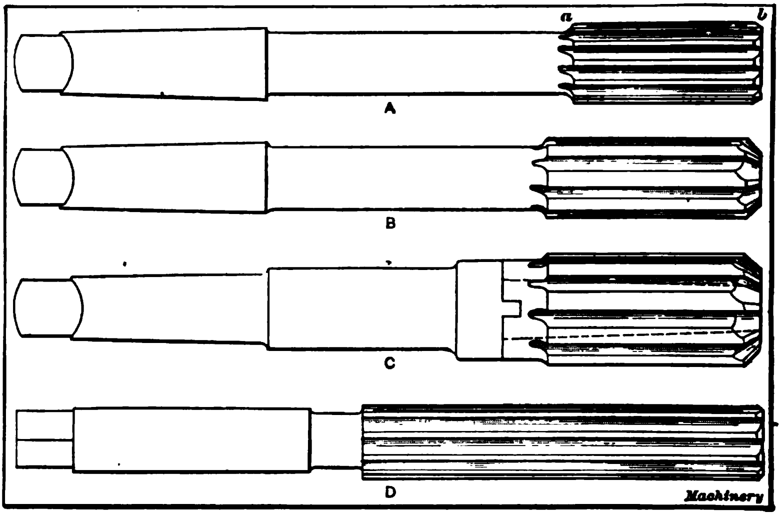

Fig. 8. Reamers of Different Styles

the tool and work may be injured. Another type of reamer is shown at *B*. This is called a rose reamer and it differs from the fluted type in that the cutting is all done by the beveled edges at the end. The fluted cylindrical body, back of the cutting edges, fits closely into the

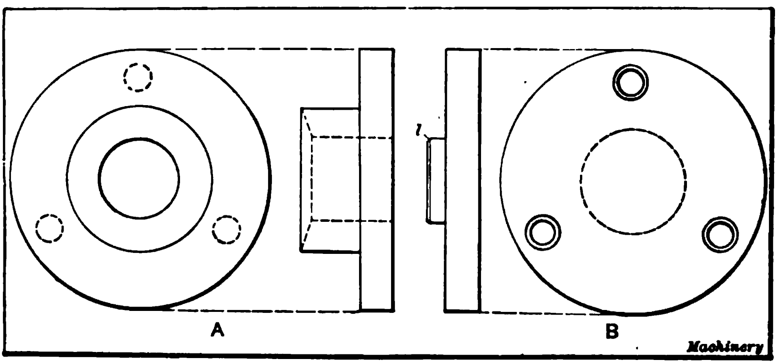

Fig. 9. (A) Packing Gland. (B) Drill Jig for Gland

reamed hole and guides the cutting end. This reamer will remove more metal than the fluted type and it is used for enlarging holes, as well as for truing drilled holes. When very accurate and smooth holes are necessary, the fluted reamer is ordinarily used, but for general purposes the rose reamer is preferable, especially for "machine reaming" when jigs are used. If a fluted reamer is guided by a hardened jig bushing, the cutting edges will be dulled more or less, depending on the alignment between the drilled hole and bushing and the resulting side thrust on the reamer. On the other hand, the rose reamer cannot be injured by the guide bushing as the cutting edges are on the end only. The shell type of rose reamer shown at *C* has an arbor on which the shell reamer is mounted. The advantage of this arrangement is that reamers of different sizes can be held on the same arbor.

When a very accurate hole is required, it is good practice to ream by hand. One method would be to first drill and rough ream the hole to within a few thousandths inch of the finished size, and then finish by using a hand reamer *D*. In order to keep the reamer in alignment with the hole, especially when starting, the upper end is sometimes supported by a conical center which is inserted in the spindle.

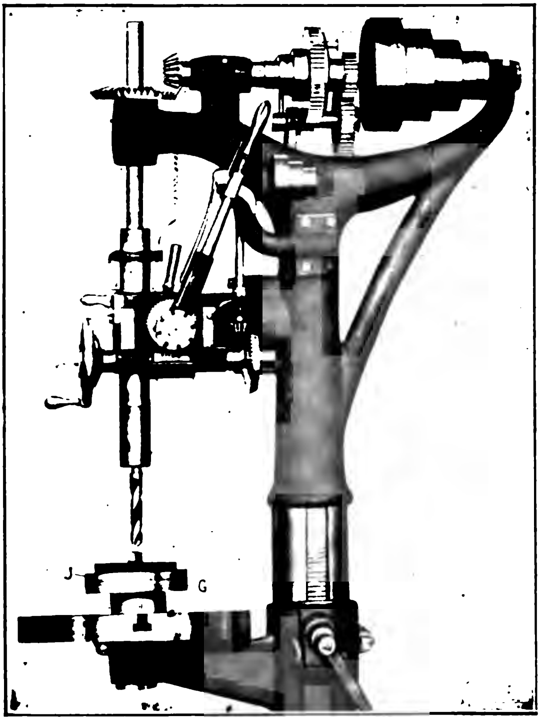

Fig. 10. Drill-press of the Wheel- and Lever-feed Type

Drilling by the Use of Jigs

Another example of drill-press work is shown at *A*, Fig. 9, which illustrates an engine packing gland that is to have three holes drilled through the flange as indicated by the dotted lines. This work could be done by laying out the three holes and proceeding as described in the foregoing in connection with the link illustrated in Fig. 5, but if a large number of these glands were to be drilled, it would be much better to use a jig for properly locating the drill with reference to the work, without any preliminary laying out operation. A simple form of jig for drilling this flange is shown at *B*. This jig has three holes for guiding the drill, and one side is provided with a round projection *l* which fits closely the hole in the gland, in order to locate the jig in a central position. The method of using the jig is shown in Fig. 10. The gland *G* with the jig *J* placed on it, is clamped to the table (in this particular instance) by a single clamp and bolt in the center, and the holes are drilled by feeding the drill, successively, through the three holes in the jig. It will be seen that the use of a jig not only saves time, but also insures accurate and uniform work, for naturally if a number of these glands were drilled without a jig and by simply laying out the holes, more time would be required and there would also be some variation in the location of the holes. As the result of the uniformity obtained by the use of jigs, corresponding parts are drilled so near alike that they will interchange, which is a great aid in assembling a machine and also makes it possible to easily replace a broken member.

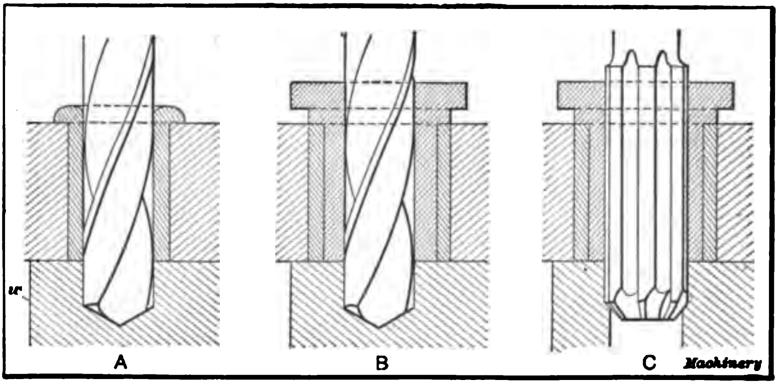

Fig. 11. Fixed and Removable Guide Bushings for Drill Jigs

The holes in jigs are ordinarily lined with hardened steel bushings to eliminate wear. These guide bushings fit the drill closely and keep it in the proper position. Some jigs have fixed guide bushings and others removable bushings. A fixed bushing is shown by the sectional view at *A*, Fig. 11, which also indicates how the drill is guided while it is drilling the work *w*. Jigs are equipped with removable bushings when drills of a different size are to be used, or when the drilled holes are to be finished by reaming. For example, if a hole is to be drilled and reamed, a removable bushing is used that fits the drill, as shown at *B*, and this is replaced by a bushing that fits the reamer, as shown at *C*. As previously intimated, a jig is only made when there are quite a number of parts to be drilled, as otherwise the saving effected by it would be more than offset by the expense of making it.

The ring-shaped jig shown at *A* in Fig. 12 is used for drilling the stud bolt holes in a cylinder flange and also for drilling the cylinder head, which is bolted to the cylinder. The position of the jig when the cylinder flange is being drilled, is shown at *B*. An annular projection on the jig fits closely in the cylinder counterbore, as the illustration shows, to locate the jig concentric with the bore. As the holes in the cylinder are to be tapped or threaded for studs, a "tap drill," which is smaller in diameter than the bolt body, is used and the drill is guided by a removable bushing *b* of the proper size. Jigs of this type are often held in position by inserting an acurately fitting plug through the jig and into the first hole drilled, which prevents the jig from turning with relation to the cylinder, when drilling the other holes. When the jig is used for drilling the head, the opposite side is placed next to the work as shown at *C*. This side has a circular recess or counterbore, which fits the projection on the head to properly locate the jig. As the holes in the head must be slightly larger in diameter than the studs, another size drill and a guide bushing of cor-

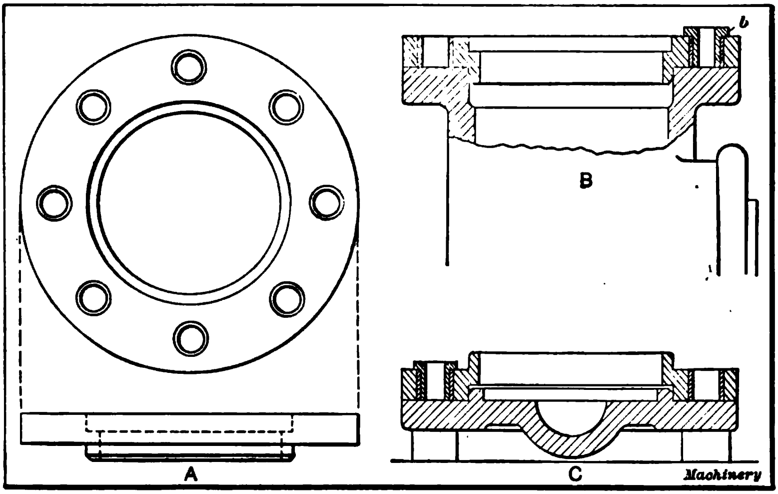

Fig. 12. Jig for Cylinder Flange and Head, and its Application

responding size is used. The cylinder is, of course, bored and the head turned before the drilling is done.

Jigs of the Box Type

As the use of drill jigs makes it possible to perform drilling operations quickly as well as accurately, jigs are used very extensively in all modern shops. Those shown in Figs. 9 and 12, represent a very simple type that is often used for drilling flanges, plates or similar parts. Jigs of this class, as well as those of other types, are made in a great variety of shapes, and, when in use, they are either applied to the work or the latter is placed in the jig. When the work is quite large, the jig is frequently placed on it, whereas small parts are more often held in the jig, which is so designed that the work can be clamped in the proper position. The form of any jig depends, to a great extent, on the shape of the work for which it is intended and also on the location of the holes to be drilled. As the number of differently shaped pieces which go to make up even a single machine, is often very great, and, as most parts require more or less drilling, jigs are made in an almost endless variety of sizes and forms. When all the holes to be drilled in a certain part are parallel, and especially if they are all in the same plane, a very simple form of jig can ordinarily be used; in fact, jigs for work of this class are often little more than flat plates having the necessary guide bushings and, perhaps, one or two clamps for holding the jig and work together. A great many parts, however, must be drilled on different sides and, frequently, the work is very irregular in shape, so that a jig which is made somewhat in the form of a box, and encloses the work, is very essential, as it enables the guide bushings to be placed on all sides and also makes it comparatively easy to locate and securely clamp the part in the proper position for drilling. This type of jig, which, because of its form, is known as a "box-jig," is used very extensively.

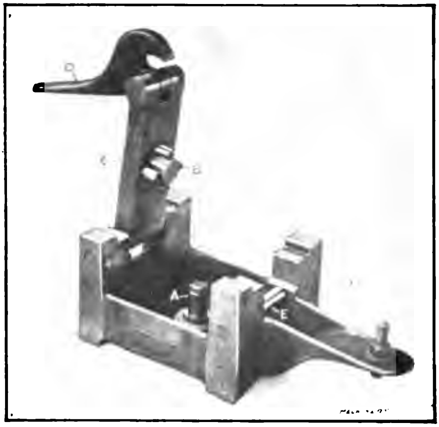

Fig. 13. Drill Jig of the Box Type

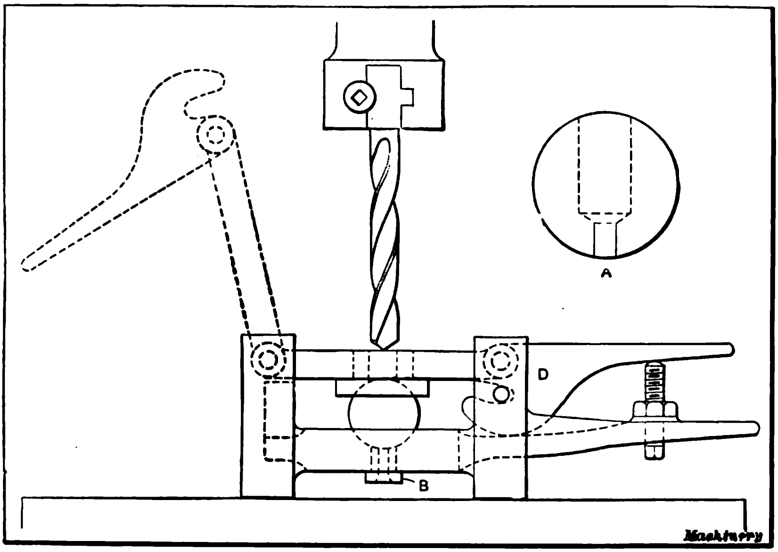

Fig. 14. Box Jig for Drilling Ball shown enlarged at A

A box jig of simple design is shown in Fig. 13. This particular jig is used for drilling four small holes in a part (not shown) which is located with reference to the guide bushings *B*, by a central pin *A* attached to the jig body. This pin enters a hole in the work, which is finished in another machine in connection with a previous operation. After the work is inserted in the jig, it is clamped by closing the cover *C*, which is hinged at one end and has a cam-shaped clamping latch *D* at the other, that engages a pin *E* in the jig body. The four holes are drilled by passing the drill through the guide bushings *B* in the cover.

Another jig of the same kind but designed for drilling a hole having two diameters, through the center of a steel ball, is shown in Fig. 14. The work, which is shown enlarged at *A*, is inserted while the cover

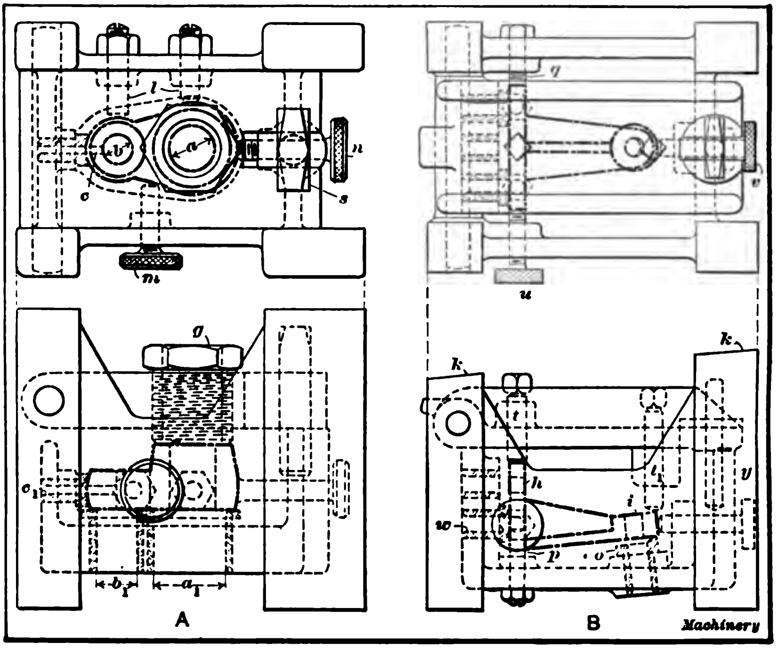

Fig. 15. Box Jigs for Drilling Parts shown by Heavy Dot-and-dash Lines

is thrown back as indicated by the dotted lines. The cover is then closed and tightened by the cam-latch *D*, and the large part of the hole is drilled with the jig in the position shown. The jig is then turned over and a smaller drill of the correct size is fed through guide bushing *B* on the opposite side. The depth of the large hole could be gaged for each ball drilled, by feeding the drill spindle down to a certain position as shown by graduation or other marks, but if the spindle has an adjustable stop, this should be used. The work is located in line with the two guide bushings by spherical seats formed in the jig body and in the upper bushing, as shown. As the work can be inserted and removed quickly, a large number of balls, which, practically speaking, are duplicates, can be drilled in a comparatively short time by using a jig of this type.

A box jig that differs somewhat in construction from the design just referred to, is illustrated at *A* in Fig. 15, which shows a side and top view. The work, in this case, is a small casting the form of which is indicated by the heavy dot-and-dash lines. This casting is drilled at *a*, *b* and *c*, and the two larger holes *a* and *b* are finished by reaming. The hinged cover of this jig is opened for inserting the work by unscrewing the T-shaped clamping screw *s* one-quarter of a turn, which brings the head in line with a slot in the cover. The casting is clamped by tightening this screw, which forces an adjustable screw bushing *G* down against the work. By having this bushing adjustable, it can be set to give the right pressure, and, if the height of the castings should vary, the position of the clamping bushing could easily be

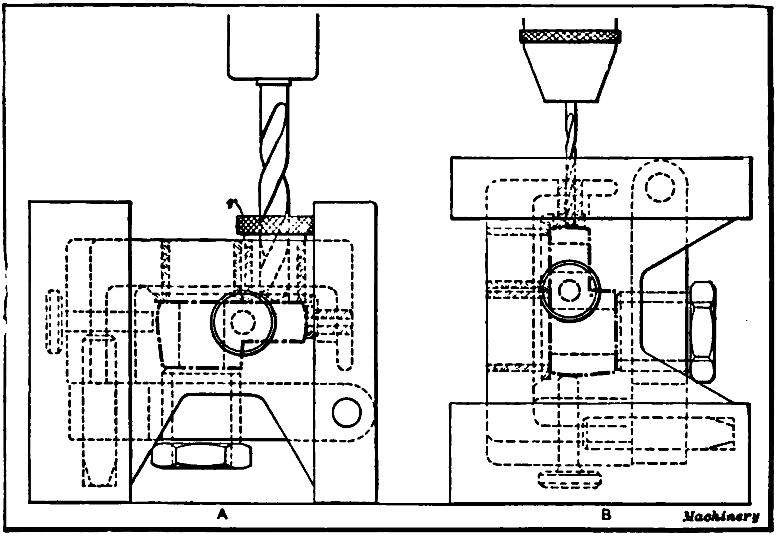

Fig. 16. Method of Using Jig

changed. The work is properly located by the inner ends of the three guide bushings a_1, b_1, and c_1, and also by the locating screws *l* against which the casting is held by knurled thumb-screws *m* and *n*. When the holes *a* and *b* are being drilled, the jig is placed with the cover side down as shown at *A* in Fig. 16, and the drill is guided by removable bushings, one of which is shown at *r*. When the drilling is completed, the drill bushings are replaced by reamer bushings and each hole is finished by reaming. The small hole *c* is drilled in the end of the casting by simply placing the jig on end as shown at *B*. Box jigs which have to be placed in more than one position for drilling the different holes, are usually provided with feet or extensions, as shown, which are accurately finished to properly align the guide bushings with the drill. These feet extend beyond any clamping screws, bolts, or bushings which may protrude from the sides of the jigs, and provide a solid support. When inserting work in a jig, care should be taken to remove all chips which might have fallen onto those surfaces against which the work is clamped and which determine its location.

Still another jig of the box type, which is quite similar to the one shown at *A*, Fig. 15, but is arranged differently owing to the shape of the work and location of the holes, is shown at *B* in the same illustration. The work has three holes in the base *h*, and a hole at *i* which is at an angle of 5 degrees with the base. The three holes are drilled with the jig standing on the opposite end *y*, and the angular hole is drilled while the jig rests on the four feet *k*, the ends of which are at such an angle with the jig body that the guide

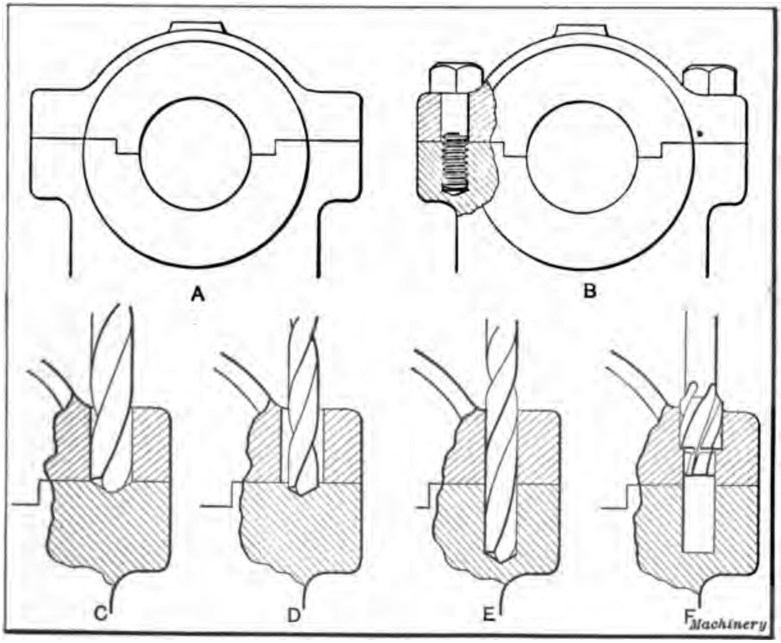

Fig. 17. Views indicating how Work can sometimes be used as a Jig

bushing for hole *i* is properly aligned with the drill. The casting is located in this jig by the inner ends of the two guide bushings *w* and the bushing *o* and also by two locating screws *p* and a side locating screw *q*. Adjustable screws *t* and t_1 in the cover, hold the casting down, and it is held laterally by the two knurled thumb-screws *u* and *v*. If an attempt were made to drill this particular part without a jig (as would be done if only a few castings were needed) it would have to be set with considerable care, provided the angle between hole *i* and those in the base had to be at all accurate, and it would be rather difficult to drill a number of these castings and have them all duplicates. By the use of a jig, however, designed for drilling this particular casting, the relative positions of the holes in any number of parts are practically the same and the work can be done much more quickly than would be possible if it were held to the drill-press table by ordinary clamping appliances.

These few jig designs have been referred to somewhat in detail to show, in a general way, how jigs are constructed and used. Those who would like to study other types of jigs and are interested in the principles of jig design, will find the subject fully covered in MACHINERY's Reference Books, Nos. 41 to 43, inclusive.

Using the Work as a Jig

When two separate parts must have holes drilled in line for bolts or studs, one part can often be used as a sort of jig. To illustrate, suppose a bearing cap and base (see sketch *A*, Fig. 17) are to be drilled for inserting bolts as shown in view *B* to the right. One

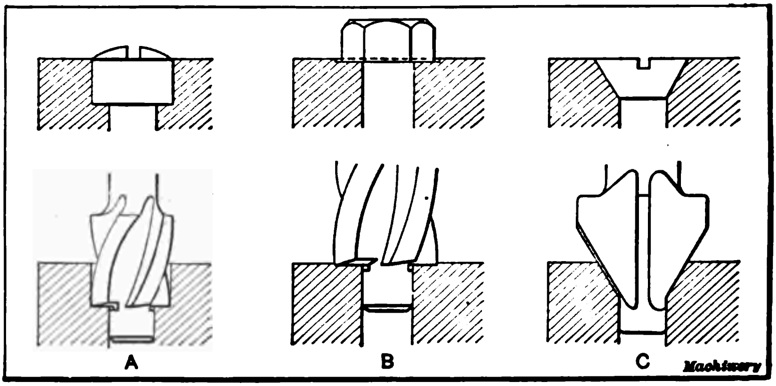

Fig. 18. Use of Counterbore and Countersink

method would be to first lay out and drill the bolt holes in the cap which we shall assume has been previously planed and fitted. The cap is then clamped in position and the same drill that was used for the bolt holes is fed down to cut a conical spot in the base as at *C*. This "spotting" operation forms a central starting point for the smaller "tap drill," which is then used as indicated at *D*. The drilling of holes which are to be tapped will be referred to later.

Another method of drilling this cap and base is shown at *E* and *F*. Both parts are clamped together and drilled with a tap drill as at *E*, after which the cap is removed and the holes are enlarged for the bolts by using a counterbore as indicated at *F*. This type of counterbore is shown in detail in Fig. 6. The cutting is done by the edges *f*, and the guide or pilot *p* fits closely into the hole which the counterbore is to follow, so that the enlarged part of the hole will be concentric. Another type of counterbore is shown at *C*. This style has a single blade or cutter, which cuts along the edges *g*. The blade can be removed by unscrewing the binding screw when it is desired to replace the blade with a different size. Guides and pilots of different diameters can also be attached to the end, as required.

Counterbores are also used frequently for enlarging holes to form seats for the heads of screws. A machine screw of the filister-head type, and a method of enlarging a hole which has been previously drilled for the body of the screw, is indicated at *A*, Fig. 18. The upper view shows the screw-head in position and the lower view the cutting end of a counterbore after it has been fed to the proper depth. Counterbores are often used for facing a spot around a hole, as indicated

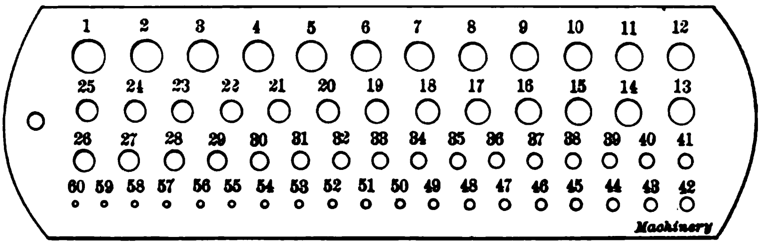

Fig. 19. Twist Drill and Steel Wire Gage

at *B*, to provide a true bearing surface for a bolt head. On some classes of work, screws having heads that are conical on the under side are used. Forming a conical seat for a head of this shape is known as countersinking. The operation is similar to counterboring except that a tool for forming a conical seat is used as indicated at *C*. The form of countersink shown is used after the hole for the screw-body has been drilled. Countersinks are also used which have a drill of

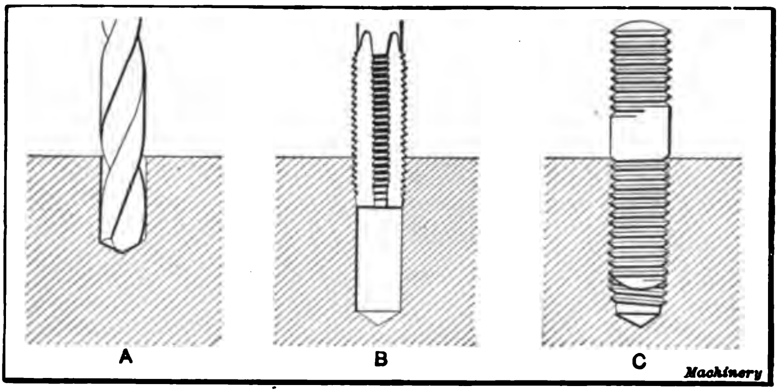

Fig. 20. (A) Tap Drill. (B) Tap for Threading Hole. (C) Stud inserted in Threaded Hole

the proper size at the end, instead of a pilot, so that the straight and conical parts of the hole are finished in one operation.

Drill Sizes

Regular taper shank drills may be obtained in a great variety of sizes. Many of the small drills used have straight shanks, and the sizes are designated by numbers or letters. A gage is shown in Fig. 19 for measuring drills with numbered sizes, the number of the drill being indicated by the number of the hole which it fits. The difference between the diameters of consecutive sizes represented by this gage only varies from 0.001 to 0.008 inch, so that almost any diameter between the smallest and largest size can be obtained. The decimal equivalents for each number are stamped on the back of the gage shown. Another common form of gage, known as the "jobbers' drill gage," has a series of holes which vary in diameter from 1/16 inch to 1/2 inch, the diameters increasing successively by sixty-fourths. The sizes of the different holes are expressed by common fractions which are stamped on the gage. The letter size drills are made in sets of twenty-six, or from

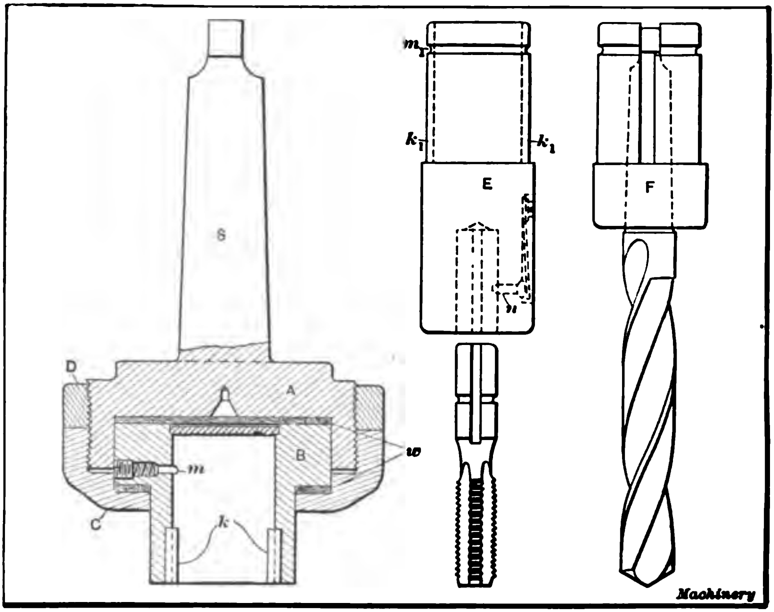

Fig. 21. Beaman & Smith Safety Drill- and Tap-holder

A to Z, and have a difference between consecutive sizes varying from 0.004 to 0.014 inch. Tables giving the corresponding sizes in decimals of an inch, for both lettered and numbered drills, are given in MACHINERY'S Reference Book, No. 35.

Drills having straight shanks are held, when in use, in chucks attached to the spindle. A common form of chuck is shown in Fig. 25. The drill is held between jaws in the chuck, which are tightened by turning the outer knurled sleeve by hand or with a spanner wrench.

Machine or Power Tapping

Holes which are drilled to receive studs or bolts are threaded by the use of taps. The hole is first drilled slightly larger than the "root diameter" of the thread, by using a "tap drill" as at *A*, Fig. 20. The hole is then threaded by screwing a tap into it, as indicated at *B*, after which a stud or bolt is inserted as at *C*. For example, if a hole were to be tapped for a ¾-inch stud having a U. S. standard thread, it would first be drilled to a diameter of ⅝ inch and a ¾-inch tap would then be used to cut the thread. The diameter of a tap drill—which is so called because it is followed by a tap—varies somewhat for U. S. standard and V-threads, and the proper size drill to use for any diameter of thread is usually determined by referring to a table. (Such tables are given in MACHINERY'S Data Sheet Book, No. 2.) It is important to use a tap drill of the proper size, for if a hole is drilled too small, an excessive amount of power will be required for tapping and, on the other hand, a tap drill that is too large is equally objectionable as the threads will not have sufficient depth.

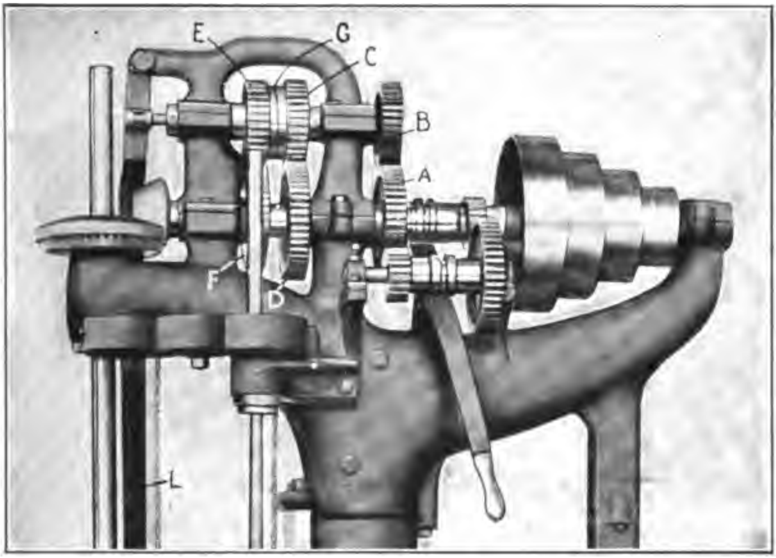

Fig. 22. Hamilton Tapping Attachment

When tapping a hole the tap can be turned with a hand wrench, but if tapping is done on an extensive scale, it is better to drive the tap by power. There are many appliances for machine or power tapping, which differ considerably in their construction, but most of them operate on practically the same principle. As most tapped holes do not extend clear through the work, but are "blind," provision should be made for allowing the tap to stop in case it should strike the bottom of the hole, as otherwise it might be broken. The tap's direction of rotation must also be reversed when it has been screwed down to the required depth, in order to back it out of the hole. One method of meeting the first requirement is to hold the tap in a friction chuck or holder, which will slip in case the tap strikes the bottom of the hole or meets with any other obstruction. A safety tap- and drill-holder which is extensively used, is shown in Fig. 21. This holder has a shank *S* which is inserted in the spindle of the drill press, and at the lower end of this shank there is an enlarged part *A*, which is recessed to receive the friction socket *B*. This socket is held in place by a cap *C* which is screwed onto the enlarged part. Fiber washers *w* are placed on each side of the friction socket flange, and the cap *C* is tightened until the friction between parts *A* and *B* is sufficient to drive the tap. The check-nut *D* is then screwed against cap *C*, which locks the parts securely. The tap itself is held in a socket *E*, which is inserted in the friction socket *B*. This tap socket is driven by the dove-tailed keys *k*, which engage the keyways k_1, and it is kept from dropping out of the friction socket when there is no upward pressure, by a small spring-pin *m* which enters the groove m_1. The tap, which has a special shank, is also driven by side keys and it is retained by a spring-pin *n* which engages the annular groove shown. The tap is not held rigidly but is allowed a slight "floating" movement to secure better alignment with the hole and a more perfect thread. If a tap which is held in a holder of this type, strikes the bottom of the hole, the friction socket *B* will slip (provided the friction is properly adjusted) and the tap will stop turning while the shank *S* continues to revolve. In this way the breaking of taps is avoided. This form of holder is also used for drilling, the drill being held in a socket *F* having a standard taper hole for receiving the drill shank. These sockets are also inserted in the friction socket *B* and they are made in sets to receive drill shanks of different sizes. The power required to overcome the friction between the parts *A* and *B* and cause a slipping movement, should be less than that represented by the breaking strength of the drill or tap. On some drilling machines an adjustable friction is introduced in the spindle-driving mechanism to prevent the breaking of taps.

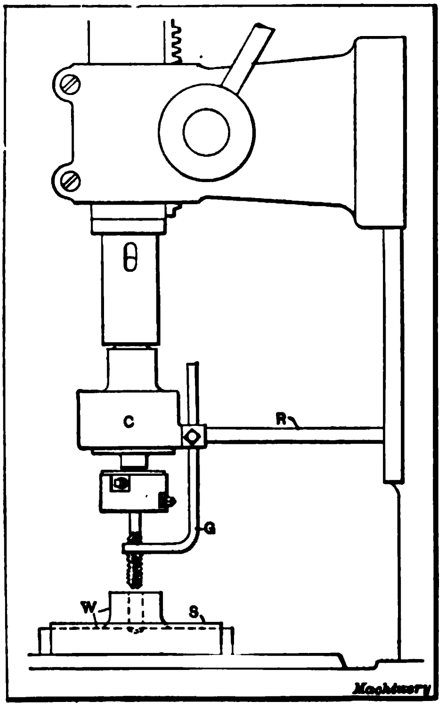

Fig. 28. Errington Automatic-reverse Tapping Chuck

The mechanism for reversing the spindle of a drill press, when the tap has reached the required depth, is known as a tapping attachment. One form of tapping attachment is illustrated in Fig. 22 which is a partial view of an upright drilling machine. When a hole is being tapped, power is transmitted to the spindle through gears *A*, *B*, *C* and *D*, until the tap has been fed to the required depth; the spindle rotation is then reversed by shifting lever *L* which, by means of a friction clutch at *G*, locks gear *E* with the upper shaft and releases gear *C*. The drive is then from gear *E* to *F* through an intermediate gear at the rear, which reverses the movement for backing the tap out of the hole. By placing lever *L* in a central or "neutral" position, the spindle can also be stopped, so that the machine is controlled by this single lever. Before beginning to tap, the feed-worm *W*, Fig. 1, is disengaged

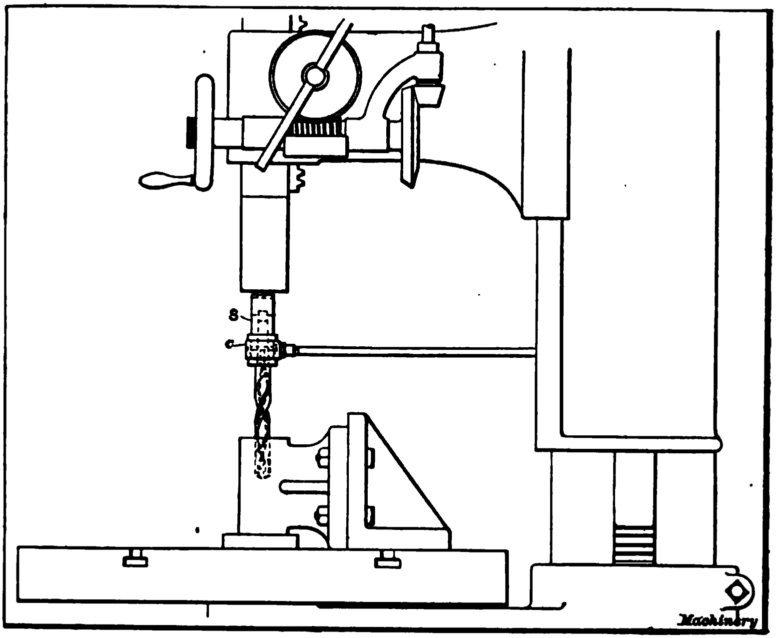

Fig. 24. Method of Applying Oil-tube Drill to Drill-press

and the tap is started in the hole by feeding it down with hand lever *Q*. As soon as a thread is started, the spindle, being free to move vertically, is fed down by the screwing action of the tap.

Errington Automatic-reverse Tapping Chuck

A tapping device is shown in Fig. 23, which is so arranged that the tap automatically stops when it strikes the bottom of the hole or when the adjustable depth gage *G* comes against the top of the work. The raising of the spindle then reverses the tap which backs out at an increased speed. This tapping chuck *C* is inserted in the spindle just like an ordinary drill chuck and as the tap is automatically reversed when the spindle is raised, no reversing gears or double belts are required to stop or change the rotation of the machine spindle. When this chuck is used in connection with light duplicate work which will center itself with the tap, very rapid production can be obtained by the following method: The work *W* to be tapped is prevented from rotating by passing it between two parallel pieces *S* clamped to the drill press table, just far enough apart to allow the work to be inserted easily. When a hole is being tapped, the spindle is raised and lowered

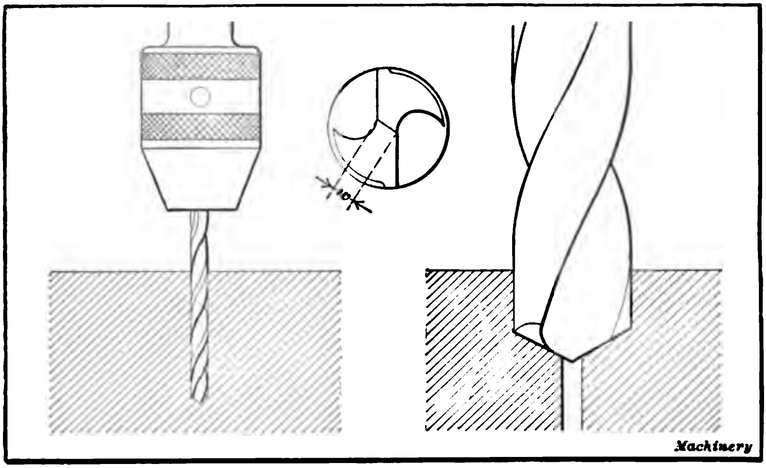

Fig. 25. Pressure for Feeding Large Drill can be reduced by Drilling Small "Lead Hole"

with the right hand while the work is inserted between the parallel pieces with the left hand, the operation being practically continuous. When this method is employed, the drilling is first completed and then the parts are re-handled for the tapping operation. Small round or irregularly shaped parts can often be held to advantage in a special holder which is passed between guides *S* attached to the table. This

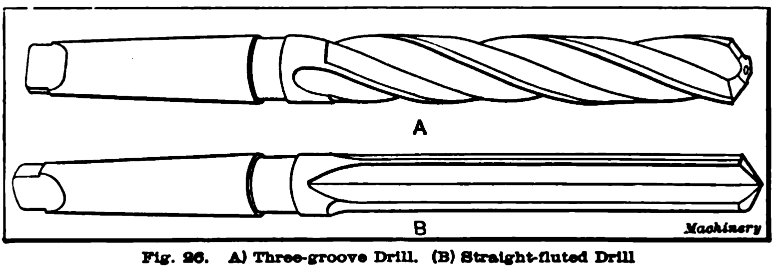

Fig. 26. A) Three-groove Drill. (B) Straight-fluted Drill

type of chuck is made with a positive drive or with an adjustable friction drive that prevents the breaking of taps. Part of the chuck and gage *G* are prevented from rotating by a rod *R* which, in this case, rests against the left side of the machine column. This rod slides freely up and down as the spindle and tap are raised and lowered.

Numerous other attachments are used for tapping and when this class of work is done in large quantities, special machines are often employed. A lubricant such as sperm or lard oil should be used when tapping.

Oil Drills—Drilling Large Holes—Special Drills

As previously stated, a lubricant, such as oil or soda water should be applied to the drill point when drilling iron and steel, in order to secure efficient results. Ordinarily the lubricant is inserted in the hole and runs down the drill flutes to the cutting end, but when a deep hole is being drilled, this method is unsatisfactory as the chips which are carried upward to the surface by the spiral grooves, tend to prevent the lubricant from reaching the drill point. To overcome this difficulty, twist drills are made having internal oil holes as shown by

TABLE OF DRILL SPEEDS—MORSE TWIST DRILL & MACHINE CO.

Diameter of Drills, Inches	Speed for Wrought Iron and Steel	Speed for Cast Iron	Speed for Brass	Diameter of Drills, Inches	Speed for Wrought Iron and Steel	Speed for Cast Iron	Speed for Brass
1/16	1712	2383	3544	1 1/16	72	108	180
1/8	855	1191	1772	1 1/8	68	102	170
3/16	571	794	1181	1 3/16	64	97	161
1/4	397	565	855	1 1/4	58	89	150
5/16	318	452	684	1 5/16	55	84	143
3/8	265	377	570	1 3/8	53	81	136
7/16	227	323	489	1 7/16	50	77	130
1/2	183	267	412	1 1/2	46	74	122
9/16	163	238	367	1 9/16	44	71	117
5/8	147	214	330	1 5/8	40	66	113
11/16	133	194	300	1 11/16	38	63	109
3/4	112	168	265	1 3/4	37	61	105
13/16	103	155	244	1 13/16	36	59	101
7/8	96	144	227	1 7/8	33	55	98
15/16	89	134	212	1 15/16	32	53	95
1	76	115	191	2	31	51	92

the dotted lines, Fig. 24, which lead the lubricant directly to the cutting end. A special socket *S* is used for an oil drill, having a stationary collar *c* which is connected with a pipe and hose leading to the source of supply. This collar has an annular groove located opposite holes in the revolving socket, which permits the lubricant to enter holes in the drill shank. The lubricant is either supplied by a pump or it is fed by gravity from a bucket suspended above the drill.

The pressure required for feeding a large drill is considerable, but it can be greatly reduced and the drill be made to cut faster, by first drilling a small "lead hole," as shown in the view to the left, Fig. 25. The diameter of this lead hole should be as large, or a little larger, than the width *w* of the drill point, because this point does not have the keenness of the cutting edges and merely scrapes the metal, so that the pressure necessary to force it downward is comparatively great. The lead hole relieves this excessive pressure and permits all the thrust to come directly on the cutting edges of the drill, as indicated by the sectional view to the right.

HENRY & WRIGHT MANUFACTURING CO.'S STANDARD CHART OF SPEEDS AND FEEDS FOR DRILLING

Carbon Steel Drills

Size of Drill	Feed per Rev.	Bronze, Brass, 150 Feet	C. Iron Ann'ld, 85 Feet	Hard C. Iron, 40 Feet	Mild Steel, 60 Feet	Drop Forg., 30 Feet	Mal. Iron, 45 Feet	Tool Steel, 30 Feet	Cast Steel, 20 Feet
Inches	Inches	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1/16	0.003	....	5185	2440	3660	1830	2745	1830	1220
1/8	0.004	4575	2598	1220	1840	915	1375	915	610
3/16	0.005	3050	1728	818	1220	610	915	610	407
1/4	0.006	2287	1296	610	915	458	686	458	305
5/16	0.007	1830	1037	488	732	366	569	366	245
3/8	0.008	1525	864	407	610	305	458	305	203
7/16	0.009	1307	741	349	523	261	392	261	174
1/2	0.010	1143	648	305	458	229	343	229	153
5/8	0.011	915	519	244	366	183	275	183	122
3/4	0.012	762	432	204	305	153	212	153	102
7/8	0.013	654	371	175	262	131	196	131	87
1	0.014	571	323	153	229	115	172	115	77
1 1/4	0.016	458	260	122	183	92	138	92	61
1 1/2	0.016	381	216	102	153	77	106	77	51
1 3/4	0.016	327	186	88	131	66	98	66	44
2	0.016	286	162	77	115	58	86	58	39

High-speed Steel Drills

Size of Drill	Feed per Rev.	Bronze, Brass, 300 Feet	C. Iron Ann'ld, 170 Feet	C. Iron Hard, 80 Feet	Mild Steel, 120 Feet	Drop Forg., 60 Feet	Mal. Iron, 90 Feet	Tool Steel, 60 Feet	Cast Steel, 40 Feet
Inches	Inches	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.	R.P.M.
1/16	0.003	....	....	4880	....	3660	....	3660	2440
1/8	0.004	....	5185	2440	3660	1830	2745	1830	1220
3/16	0.005	....	3456	1626	2440	1210	1830	1220	807
1/4	0.006	4575	2593	1220	1830	915	1375	915	610
5/16	0.007	3660	2074	976	1464	732	1188	732	490
3/8	0.008	3050	1728	818	1220	610	915	610	407
7/16	0.009	2614	1482	698	1046	522	784	522	348
1/2	0.010	2287	1296	610	915	458	636	458	305
5/8	0.011	1830	1037	488	732	366	569	366	245
3/4	0.012	1525	864	407	610	305	458	305	203
7/8	0.013	1307	741	349	523	261	392	261	174
1	0.014	1143	648	305	458	229	343	229	153
1 1/4	0.016	915	519	244	366	183	275	183	122
1 1/2	0.016	762	432	204	305	153	212	153	102
1 3/4	0.016	654	371	175	262	131	196	131	87
2	0.016	571	323	153	229	115	172	115	77

Large holes are sometimes drilled about one-half or two-thirds the required size by first using an ordinary two-groove drill, which is then followed by a three- or four-groove drill similar to the one shown at *A*,

Fig. 26. This type is only used for following smaller drills or for enlarging cored holes, and it is not adapted for drilling holes into solid stock.

A drill is shown at *B* in Fig. 26, having two straight flutes instead of the spiral form. This type is used to advantage for the drilling of brass or thin sheet metal. Ordinarily twist drills, owing to the acute angles of the cutting edges, tend to "dig in" or catch especially when coming through the lower side of a thin plate, but this is largely overcome by the straight-fluted type, as the cutting edges do not have the rake or slope common to twist drills. Sometimes the cutting edges of twist drills are ground flat at the front for drilling brass or thin sheet metal.

Speed of Drills

The proper speed for a drill depends on its diameter and the kind of material being drilled. The table on page 25 (which is recommended by the Morse Twist Drill & Machine Co.) gives the speeds in revolutions per minute, for drills ranging from 1/16 inch to 2 inches in diameter, when drilling wrought iron, steel, cast iron or brass. It may be necessary to vary these speeds somewhat in accordance with the hardness of the metal. Some castings, for example, are soft and others very hard, so that it is not possible to give speeds which will apply under all conditions. If the speed is too high, this will be shown by the action of the drill and the wear on the cutting edge. Oil drills can usually be run about 25 per cent faster than the speeds listed. Drills made from "high-speed" steel can also be run at much higher speeds than those made from ordinary carbon steel. An approximate idea of the feed to use for the various drill diameters can be obtained from the following figures: A ¼-inch drill should have a feed of about 0.005 inch, a ½-inch drill, 0.007 inch, and a ¾-inch size, 0.010 inch per evolution of the spindle.

The following suggestions regarding the use of high-speed steel drills, are given by the Cleveland Twist Drill Co. The drill should be started with a peripheral speed ranging between 50 and 60 feet per minute, and with a feed varying from 0.005 to 0.010 inch per revolution, for drills over ½ inch in diameter. The following points should also be carefully observed to obtain the best results. If the drill has a tendency to wear away on the outside, it is running too fast, and if it breaks or chips on the cutting edges, the feed is too coarse. When used in steel or wrought iron, the drill should be flooded with a good lubricant or cutting compound. Paraffine oil is recommended for brass and an air blast for cast iron.

The tables on page 26 give both speeds and feeds for various sizes of carbon and high-speed steel drills. These tables were compiled by a special committee and represent the results of tests covering a period of over two years, which were made to determine the most efficient feeds and speeds for drilling the different metals listed. The speeds given are comparatively high, and are only recommended for use with drilling machines of the high-speed type.

CHAPTER III

RADIAL, SENSITIVE, MULTIPLE-SPINDLE, AND HIGH-DUTY DRILLING MACHINES

What is known as a radial drilling machine is illustrated in Fig. 27. This type differs from the vertical machine illustrated in Fig. 2 in that the drilling head is so mounted that it can be moved to the required position for drilling, instead of adjusting the work or table each time a new hole is to be drilled. Because of this feature, the radial drill is

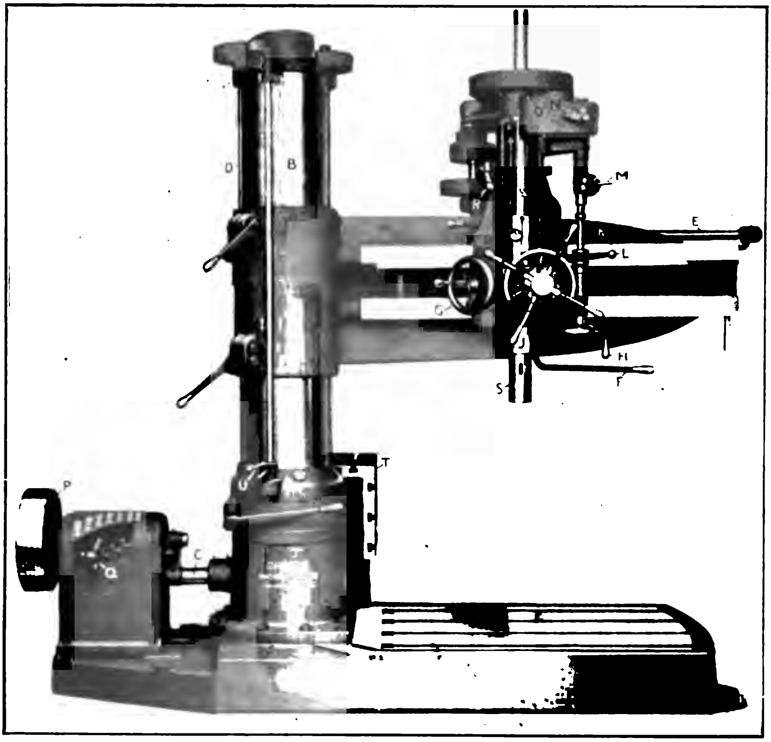

Fig. 27. Dresses Radial Drilling Machine

especially adapted to heavy work, as a number of holes can be drilled by simply adjusting the drill head to the proper position. This drill head, which contains the spindle *S*, is mounted on an arm *A* carried by an outer column *B*, which, with the arm, can be turned about a stationary inner column attached to the base. The head can also be traversed along the arm, and this radial adjustment, combined with the swinging movement of the arm about the column, makes it possible to set the drill spindle in any position within the range of the machine. The drill spindle is driven, indirectly, by a belt operating pulley *P*. The shaft carrying this pulley drives, through gearing, a lower shaft *C* which transmits the movement, by means of bevel gears, to a vertical internal shaft which extends to the top of the column. At this point connection is made by spur gears with an outer vertical shaft *D*, which drives shaft *E* mounted on the arm. Shaft *E*, in turn, rotates through bevel gears, a vertical shaft at the rear of the head which drives the drill spindle. The spindle can be started, stopped or reversed by lever *F*, which controls the connection between shaft *E* and the rear vertical shaft. The head is traversed along the arm by handwheel *G* and the spindle can be fed by handwheel *H* or by power. The spindle can also be traversed rapidly up or down by pilot wheel *J* after the feed has been disengaged.

The power feed is derived from the spindle through gears which drive shaft *K* which rotates, through worm-gearing, a pinion shaft meshing with a rack cut in the spindle quill. The feed is engaged or disengaged by handle *L*, and it can also be disengaged by an automatic stop mechanism, which is adjustable and can be set previously for tripping the feed when a hole has been drilled to the required depth. The amount of feed is varied by handles *M* and *N*, which change the combination of the feed gearing enclosed at *O*. The spindle speeds are changed by shifting lever *Q* of the geared speed-box, to different positions controlled by the notches shown, and the range of seven speeds obtained in this way can be tripled by back-gears in the spindle head, which are engaged or disengaged by handle *R*. The radial arm *A* can be adjusted vertically on column *B* by power, the adjustment being controlled by lever *U*. Both the arm and column can be clamped rigidly in any position by the levers shown. The work is placed either on table *T* or directly on the base, the position depending on its size.

The machine just described is known as a plain radial type and it can only be used for drilling holes at right angles to the base, whereas what is known as the universal type, is also adapted to drilling holes at an angle. The head and drill spindle of a "full universal" machine can be set at an angle with the radial arm, and the latter can also be rotated about its own center or axis, so that the drill spindle can be placed in almost any position. With the exception of the changes necessary to permit these adjustments, the construction of the universal radial is practically the same as that of the plain type. It should be remembered, however, that the construction of drilling machines, as well as of other types of machine tools, varies more or less with different makes.

Sensitive Drill-press

The type of machine illustrated in Fig. 28 is intended especially for drilling small holes in light work. The power is transmitted directly to the spindle by belts which operate on the pulleys shown. This particular design is driven direct by a motor *M* which is connected with the lower cone pulley. The speed changes are obtained by shifting the belt connecting the two cone pulleys to steps of different diameter, and the tension of the belts can be varied by the handwheels *W*. The spindle and drill have a hand-feeding movement only. This is effected by hand-lever *H*, which rotates a pinion meshing with a rack attached to the spindle quill. This simple method of feeding the drill has two distinct advantages when applied to the drilling of small holes: In the first place, it enables the workman to drill rapidly, because, ordinarily, little time is required for drilling small holes and the drill can be raised and lowered quickly when its movement is entirely controlled by hand. The hand-feed is also very sensitive, as the operator can tell by the sense of feeling about how much work the drill is doing, and by regulating the downward feeding pressure accordingly, the breaking of drills is largely avoided. For this reason, light machines of this class are called sensitive drills. The machine illustrated has two work-tables. The upper square table can be set at an angle with the spindle for angular drilling and for supporting work having an angular base. When this table is not in use it can be swung to one side. The round table beneath can be adjusted vertically on the column, and the position of the spindle head can also be varied as required. When necessary, the round table can be removed from its supporting bracket and be replaced with either the cone or crotch centers shown. These centers are used for supporting the ends of shafts, spherical and cylindrical parts, etc. This machine has a capacity for holes up to about 9/16 inch in diameter.

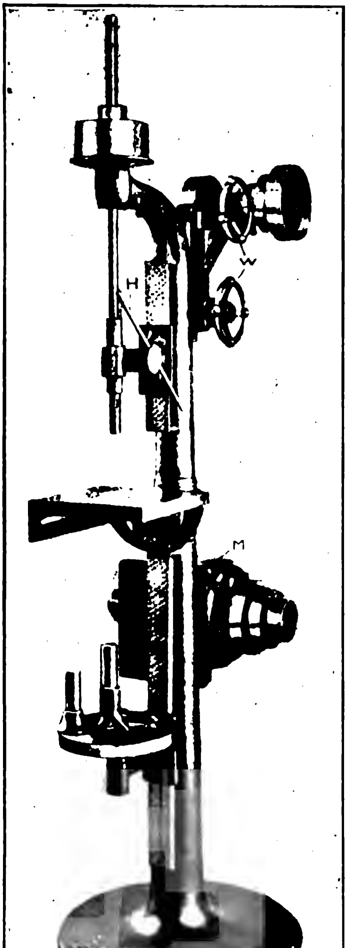

Fig. 28. Drill-press of the Sensitive Type

Multiple-spindle Drilling Machines

A great many parts that have to be drilled, require holes of different diameters, and other operations such as counterboring, reaming or countersinking are frequently necessary. When work of this class is done in a machine having one spindle, considerable time is wasted in removing one drill and replacing it with a different size or with some other kind of tool. For this reason, drilling machines having several

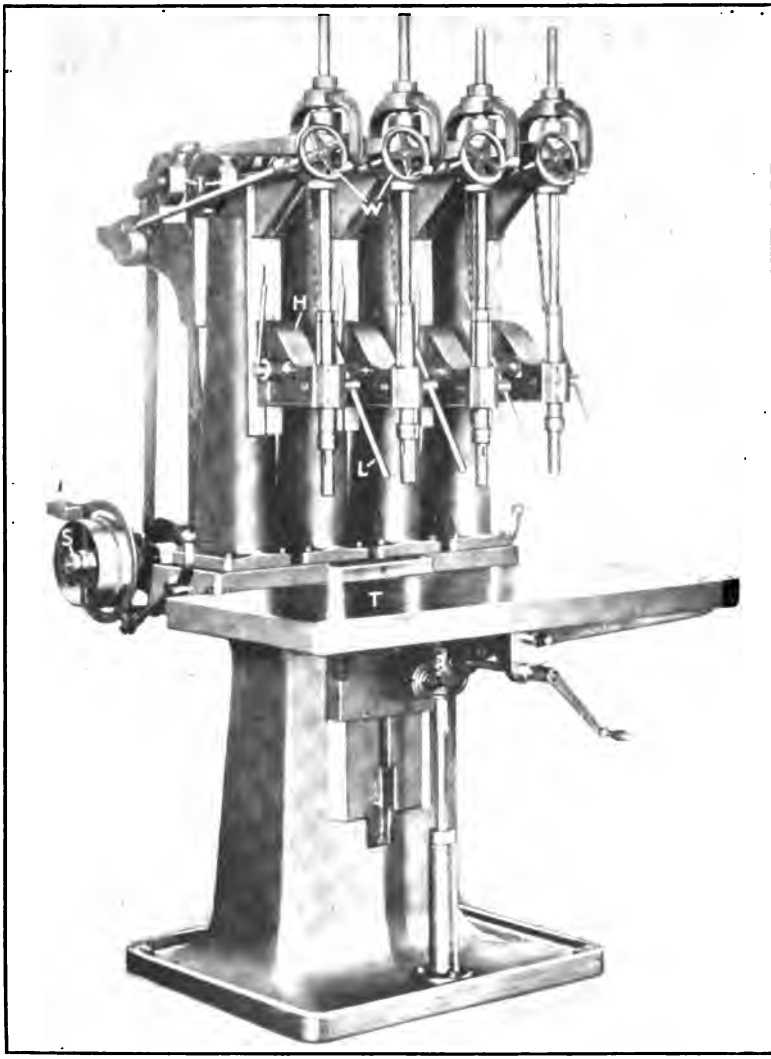

Fig. 29. Henry & Wright Multiple-spindle Drilling Machine

spindles are often used when the work requires a number of successive operations. The advantage of the multiple spindle or "gang" type is that all the different tools necessary can be inserted in the various spindles, and the drilling is done by passing the work from one spindle to the next. By this method, holes of different diameter can be drilled and counterboring or reaming operations be performed without changing any tools. Multiple-spindle machines can also be used to advantage for other purposes.

One type of multiple-spindle drilling machine is illustrated in Fig. 29. This particular design has four spindles, but the number of spindles in a machine of this type depends on the work for which it is intended. The spindles are all driven from a horizontal shaft *S* at the rear to which they are connected by belts as shown. The idler pulleys *I* over which the driving belts pass in making the quarter turn, can be ad-

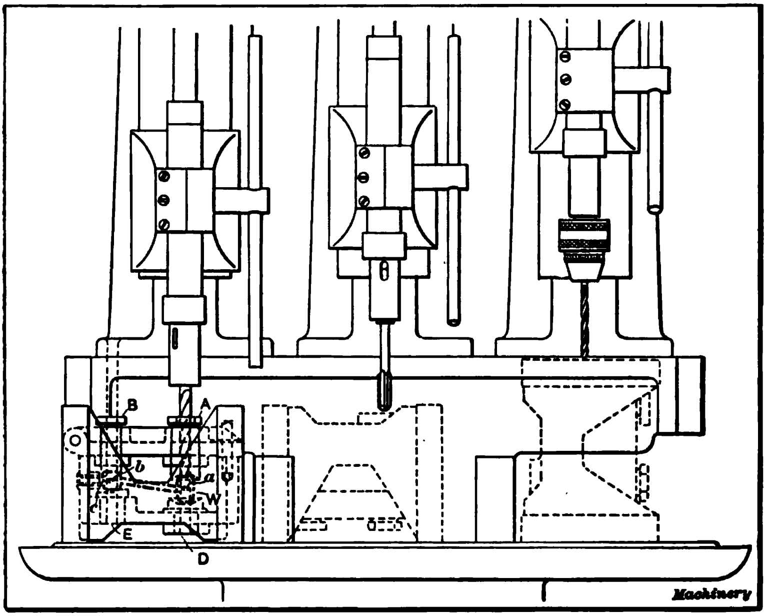

Fig. 30. Method of Using Multiple-spindle Machine for Successive Operations

justed for varying the tension of the belts by the handwheels *W*. The table *T* can be raised or lowered by the screw and crank shown, to suit the height of the work, and the spindle heads *H* also have vertical adjustment. The spindles are fed downward for drilling by the handlevers *L*.

The method of using a multiple-spindle machine for performing successive operations on the same part is illustrated in Fig. 30. The work *W*, which is held in a box jig, is drilled and reamed at *a* and *b* and a small hole *c* is drilled in the end. The holes *a* and *b* are first drilled with the left-hand spindle by feeding the drill through guide bushings *A* and *B*. The jig is then turned over (as shown by the dotted lines) and moved to the next spindle containing a reamer of the proper size, which is guided by bushings *D* and *E* in the bottom of the jig, as it is fed through the work. The third and last hole *c* is drilled by the right-hand spindle, while the jig is standing on end as shown. The advantage of having all the tools at hand so that the work can be completed by simply moving it from one spindle to the next, is obvious.

Drilling machines of the multiple-spindle type are also commonly

Fig. 31. Pratt & Whitney Adjustable Multiple-spindle Drilling Machine

used for drilling a number of holes simultaneously. The arrangement of these machines is varied considerably to suit different kinds of work, but they may be divided into two general classes, namely, those having spindles which remain in the same plane but can be adjusted for varying the center-to-center distance, and those having spindles which can be grouped in a circular, square or irregular formation. The first class referred to is used for drilling rows of bolt or rivet holes in steel plates, etc., and the second type is adapted to the drilling of cylinder flanges, valve flanges or similar work. A machine of the latter type is illustrated in Fig. 31. This machine has sixteen spindles, all or part of which can be used, as required. These spindles are driven from a single pulley *P* to which they are connected by shafts *S* and spur gears. The connecting-shafts have universal joints which permit the spindles to be arranged in accordance with the work. When the machine is in operation, the table and work are fed upward against the revolving drills. The feeding mechanism is located at *F* and the power feed is derived from pulleys *A* and *B*, which are connected by a belt as shown. The table can also be fed by hand lever *L*, which is connected with the feed pinion shaft. By simply loosening a nut, this lever can be set to the most convenient position for the operator. The power feed is engaged or disengaged by a downward or upward movement of lever *C*. It can also be disengaged automatically at any point by an adjustable stop *D*. As practically all work done on this type of machine is "jig drilled," the spindles are set by aligning them with the holes in the jig. The position of the spindles is changed by adjusting the spindle arms *E* which are clamped to the under side of the housing. The spindles have an independent vertical adjustment so that drills of different lengths can be used. This feature also permits setting the spindles for drilling holes that are not in the same horizontal plane. The machine illustrated is set up for drilling lathe carriages. The work *W* is mounted in a jig *J* and the various holes are all drilled at the same time. A number of castings which have been drilled are shown on the floor to the right.

Multiple-spindle machines of this type are also built in much larger sizes and in designs which are adapted to different classes of work.

High-duty Drilling Machine

Two views of a powerful and rigid drilling machine which is especially adapted to rapid drilling, are shown in Fig. 32. This type was developed for driving modern high-speed drills, which are capable of much higher speeds than drills made of carbon steel. The frame of the machine is designed to avoid any deflection when subjected to heavy feeding pressures. Where there is any springing action, either in the frame or work table, the drill will bind in the hole (especially if it be a long one) and this greatly increases the amount of power required. The increased friction also expands the drill, thus causing it to bind more tightly, which may result in breaking the drill, owing to excessive torsional strain.

This machine is driven by a belt operating on tight and loose pulleys at *A*. From here the motion is transmitted through enclosed back-gears, to an intermediate pulley *B* on the other side of the machine, where connection is made by belt with speed-box *C*. There are eight speed changes obtained by sliding gears in this speed-box. Connection is made with the spindle through the bevel gears *D*, vertical shaft *E* and the spur gears shown. The illustration to the right shows the machine equipped with a plain work table, and the left-hand view shows a "compound" table having longitudinal and cross adjustments. These tables have vertical adjustment on the face of the frame or column. This adjustment is effected by turning shaft *G*

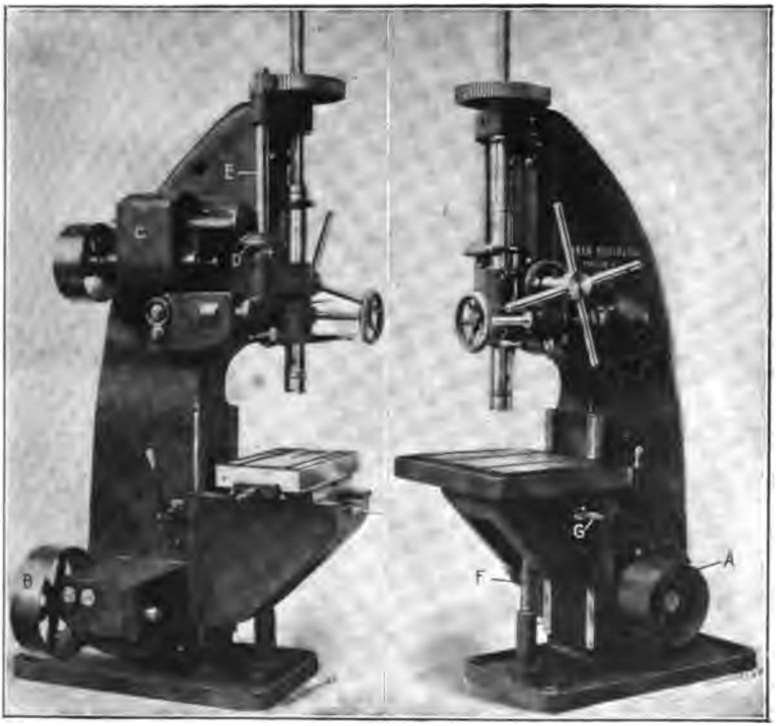

Fig. 32. Baker Bros. High-duty Type of Drilling Machine

which operates elevating screw *F*. The compound table permits work to be accurately centered under the drill, after it is clamped in place.

The following figures will give a general idea of this machine's capacity for rapid drilling. Several 1⅛-inch holes were drilled through 4 1/4-inch cast iron blocks at the rate of 8 2/3 seconds per hole, and a number of 15/16 inch holes were drilled through 3/4 inch machine steel plate at the rate of 3½ seconds per hole.

CHAPTER IV

GRINDING TWIST DRILLS

The point or cutting end of a drill should be carefully ground because a poorly formed drill effects the quality and quantity of the work produced. It is difficult to grind drills theoretically correct by hand, at least in a reasonable length of time, and special grinders are often used for this purpose. Many shops, however, do not have such grinders, but if the requirements of a correctly formed drill point are known, it is possible, with practice, to grind a drill satisfactorily by hand. The requirements briefly stated are as follows: The two cutting edges

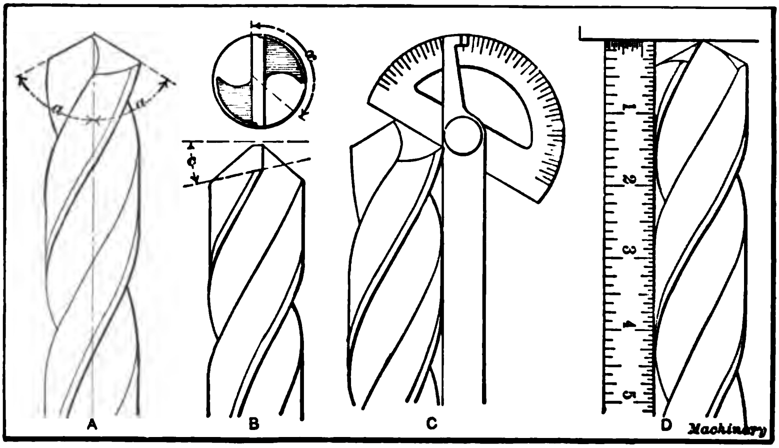

Fig. 33. Views showing Angles to be Considered when Grinding Drills, and Methods of Measuring Lip Angle and Clearance

should incline at the proper angle *a* with the axis, as shown at *A* in Fig. 33; each edge should have the same inclination and be of the same length; the angle of clearance *c* (see sketch *B*) should be sufficient to permit the drill to cut freely; the clearance should be the same on both sides, and increase toward the point of the drill.

At *A* in Fig. 34 is shown the relation between a drill point and a hole when the cutting edges are not at the same angle with the axis. When both cutting edges are ground to the same angle, one edge counteracts the tendency of the other to spring away from the cut (provided the clearance is also correct), but when these angles are different, as shown, one edge will do more work than the other, thus subjecting the drill to an unbalanced twisting or torsional strain. The drill will also be forced sidewise, which will result in an enlargement of the hole.

The effect produced when the lengths of the cutting edges are unequal, is illustrated at *B*. As the drill revolves about the center or point *p*, when it is fed into the metal, the horizontal distance *x* from this point to the side furthest away, will equal the radius of the hole which will, of course, be larger than the drill diameter if the point is not central; therefore, each cutting edge should have the same length, as otherwise the drill will cut a hole larger than its diameter. At *C* a drill point is shown having cutting edges inclined at different angles to the axis and of different lengths, thus combining the disadvantages mentioned in the foregoing.

Each cutting edge should be ground to an angle of about 59 degrees with the axis. When grinding, support the drill on the tool-rest of the grinder, and move it slowly back and forth, in order that any unevenness in the wheel-face will not affect the straightness of the cutting edge. Use preferably the face of the grinding wheel in order to derive benefit from the cooling water, and grind slowly so that the

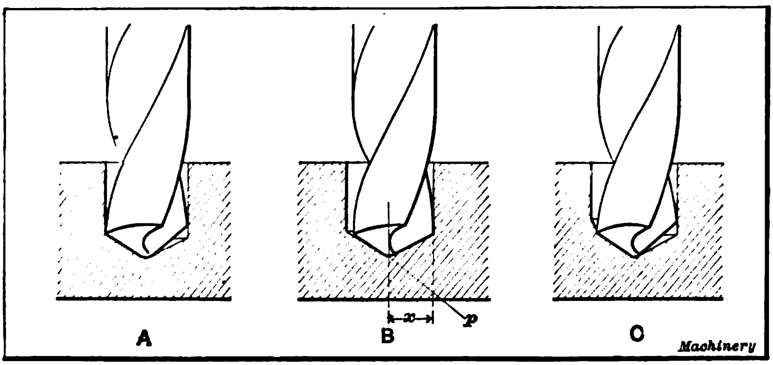

Fig. 34. Three Examples of Incorrect Drill Grinding

temper of the drill will not be affected. The position of the drill in relation to the face of the wheel, should be such that the angle *a* (Fig. 33) which the cutting edges make with the axis, and the angle of clearance *c*, will be ground as nearly correct as can be judged. The angle *a* can be tested by using a protractor as indicated at *C*. The length of each edge should also be measured with a scale and corrected by grinding if unequal, care being taken not to change the angle of the cutting edge, if this is found correct. It should be mentioned that there is a difference of opinion as to the best angle *a* for the cutting edges. As this angle is decreased, the pressure required for feeding a drill downward through the metal, becomes less, but the length of each cutting edge is increased, with the result that more power is required to turn the drill. An included angle of 118 degrees (59 degrees between the cutting edge and axis) is thought by some to equalize the thrust and torsion to the best advantage, while others advocate much more acute angles.

After each side or edge has been ground, the end of the drill will appear somewhat as shown in the upper view at *B*, the unshaded portion representing the ground surface. That part indicated by the shaded lines should then be ground away so that it will not interfere with the downward movement of the cutting edge when the drill is in use. When grinding this part, support the inner end of the drill on the tool-rest, and move the outer end so as to produce a surface which is approximately conical in form. The grinding should be continued until the conical surface is blended into the flat (unshaded) part, previously ground.

The clearance for each cutting edge may be tested by placing the drill point against a flat surface and then slowly revolving it close to a scale held in the position shown at *D*. If the clearances are not alike, this will be indicated by their relative positions to the graduation marks on the scale, as the drill is turned. The clearance is a very important feature in drill grinding, and the splitting of drills through the web is usually an indication either of incorrect clearance or excessive feed. If the end of a drill conforms exactly to the conical shape of the bottom of a hole, evidently it will not cut because the lack of clearance would make it impossible to sink the cutting edges into the metal; therefore, when there is insufficient clearance for a given feed, the drill binds back of the cutting edges, and is subjected to an excessive twisting strain. Theoretically, the clearance should be just enough to permit the drill to cut freely, because excessive clearance weakens the cutting edges. The Cleveland Twist Drill Co. advocates a clearance angle *c* of 12 degrees at the periphery of the drill, with a gradual increase towards the center, until the line joining the two cutting edges makes an angle x somewhere between 125 and 135 degrees, as shown in the plan view at *B*. When soft metal is to be drilled and heavier feeds are possible the angle of clearance may be increased to 15 degrees, whereas for hard material such as tool steel, for example, the amount of clearance is diminished, as a fine feed must necessarily be used and a strong cutting edge is required.

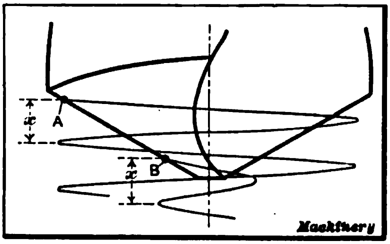

Fig. 35. The Angles of the Helical Paths described by Points A and B show why Angle of Clearance should increase toward Drill Point.

As previously stated, clearance should gradually increase toward the drill point. The reason for this will be apparent by considering the movement of two points *A* and *B* (Fig. 35) on the cutting edge, as the drill is fed downward, one point being much nearer the center than the other. Assuming that the feed is constant, the path described by each of these points will correspond to that indicated by the helical lines shown. As the vertical distance x, that each point moves per revolution of the drill, will be the same, the angle of the smaller helix or spiral will be greater than that of the larger one. The angle in each case indicates the minimum clearance necessary at that particular point for a feed per revolution equivalent to the distance x. The amount of feed indicated has been greatly exaggerated in order to make the comparison clear.

Worcester Drill-grinding Machine

As the correct grinding of drills by hand requires considerable time, even by an experienced workman, special grinders are often employed for this purpose. A type which has been used extensively is illustrated in Fig. 36. This grinder so controls the movement of the drill with relation to the grinding wheel, that the end is given the correct

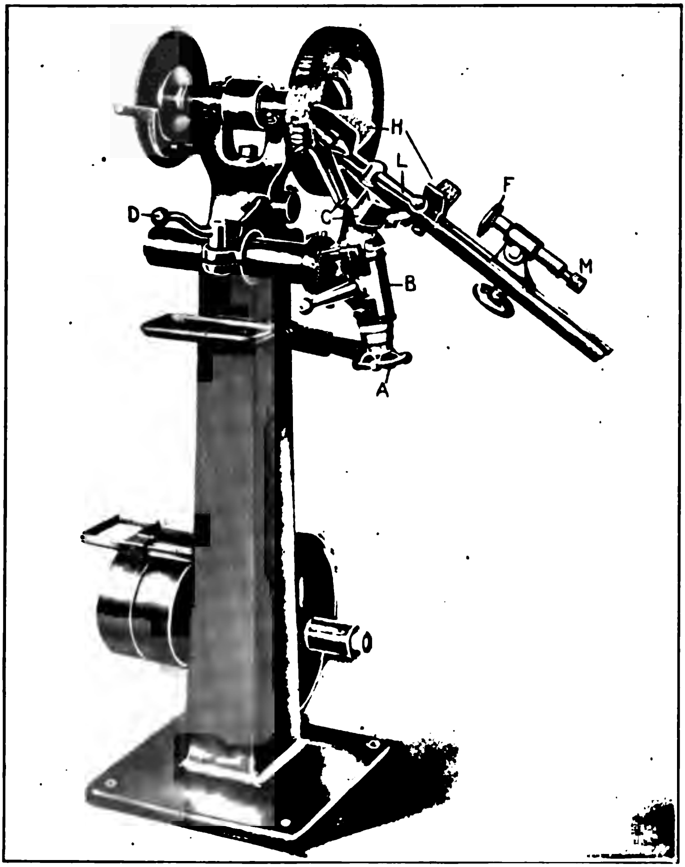

Fig. 36. Grinder for Sharpening Drills

form. The drill to be ground is first placed between the caliper jaws *C* which are adjusted to the diameter of the drill. This adjustment is effected by loosening lever *L* and shifting the sliding jaw the required amount. The drill is then placed in V-shaped holders *H* and it is turned to bring the lower lip against a hardened stop at the grinding end. In this way the drill is properly centered and located with reference to the face of the wheel. The point of the drill should project about 1/16 inch beyond the lip-rest, and the shank end is placed against an adjustable foot-stop *F*. The entire drill-holding device should be clamped in such a position that the drill will nearly touch the grinding wheel when the holder is swung at right angles to the wheel face. The grinding is done by oscillating the drill-holder in bearing *B* which is inclined to the face of the grinding wheel, as shown. After one lip is ground, the drill is turned over for grinding the opposite side. As the grinding proceeds, the drill is gradually fed against the wheel by turning micrometer screw *M* which pushes the foot-stop *F* forward. This screw should be turned to the same graduation for grinding each side of the drill, in order to secure cutting edges of equal length. When reversing or removing the drill, the holder should be swung to the extreme left.

The adjustment of the caliper jaws *C*, previously referred to, is done to give drills of different diameter a standard clearance. As these jaws are opened to fit a drill of given size, the lip rest and end of the drill is advanced with relation to the axis of bearing *B*, about which the holder rotates. If the opening between the jaws is made greater than the diameter of the drill, the clearance will be less than the standard, and, inversely, a smaller opening will increase the clearance. The proper way, however, to vary the angle of clearance, is by loosening hand wheel *A* and turning an eccentric bushing in which the holder rotates, thus moving the axis of rotation toward or away from the grinding wheel. This adjustment is indicated by suitable graduations, and it is not changed unless it is desired to vary the standard clearance. The entire holder can be adjusted in or out by loosening clamping lever *D*, in case this is necessary to compensate for the wear of the wheel face or to set the holder in correct relation to a new wheel.

When a drill has been shortened considerably by repeated grinding, the point or web becomes thicker because the grooves of twist drills gradually decrease in depth toward the shank. (The grooves are milled in this way in order to strengthen the drill). As the width of the point increases, more pressure is required for feeding the drill, and to overcome this, the point should be made thinner by grinding. The grinder shown in Fig. 36 has a thin elastic emery wheel on the left end of the spindle, which is provided for the thinning of drill points. Care should be taken to grind away an equal amount of stock on each side of the point in order to keep it central.

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NUMBER 95

OPERATION OF MACHINE TOOLS

By FRANKLIN D. JONES

VERTICAL AND HORIZONTAL BORING MACHINES

CONTENTS

CHAPTER I

THE VERTICAL BORING MILL

All the different types of turning machines now in use originated from the lathe. Many of these tools, however, do not resemble the lathe because, in the process of evolution, there have been many changes made in order to develop turning machines for handling certain classes of work to the best advantage. The machine illustrated in Fig. 1 belongs to the lathe family and is known as a vertical boring and turning mill. This type, as the name implies, is used for boring and turning operations, and it is very efficient for work within its range. The part to be machined is held to the table *B* either by clamps or in chuck jaws attached to the table. When the machine is in operation, the table revolves and the turning or boring tools (which are held in tool-blocks *T*) remain stationary, except for the feeding movement. Very often more than one tool is used at a time, as will be shown later by examples of vertical boring mill work. The tool-blocks *T* are inserted in tool-bars T_1 carried by saddles *S* which are mounted on cross-rail *C*. Each tool-head (consisting of a saddle and tool-bar) can be moved horizontally along cross-rail *C*, and the tool-bars T_1 have a vertical movement. These movements can be effected either by hand or power.

When a surface is being turned parallel to the work table, the entire tool-head moves horizontally along the cross-rail, but when a cylindrical surface is being turned, the tool-bar moves vertically. The tool-heads are moved horizontally by the screws *H* and H_1, and the vertical feed for the tool-bars is obtained from the splined shafts *V* and V_1, there being a separate screw and shaft for each head so that the feeding movements are independent. These feed shafts are rotated for the power feed by vertical shafts *A* and A_1 on each side of the machine. These vertical shafts connect with the feed shafts through bevel and spur gears located at the ends of the cross-rail. On most boring mills, connection is made with one of the splined shafts *V* or screw *H*, by a removable gear, which is placed on whichever shaft will give the desired direction of feed. The particular machine illustrated is so arranged that either the right or left screw or feed shaft can be engaged by simply shifting levers D_1 or *D*.

The amount of feed per revolution of the table is varied for each tool-head by feed-changing mechanisms located at *F* on each side of the machine. These feed boxes contain gears of different sizes, and by changing the combinations of these gears, the amount of feed is varied. Five feed changes are obtained on this machine by shifting lever *E*, and this number is doubled by shifting lever *G*. By having two feed boxes, the feeding movement of each head can be varied independently. The direction of either the horizontal or vertical feed can be reversed by lever *R*, which is also used for engaging or disengaging the feeds. This machine is equipped with the dials *I* and I_1 which can be set to automatically disengage the feed at any predetermined point. There are also micrometer dials graduated to thousandths of an inch and used for adjusting the tools without the use of measuring instruments.

The work table *B* is driven indirectly from a belt pulley at the rear, which transmits the power through gearing. The speed of the table can be varied for turning large or small parts, by levers *J* and *K*, and the table can be started, stopped or rotated part of a revolution by lever *L* which connects with a friction clutch. There are corresponding feed

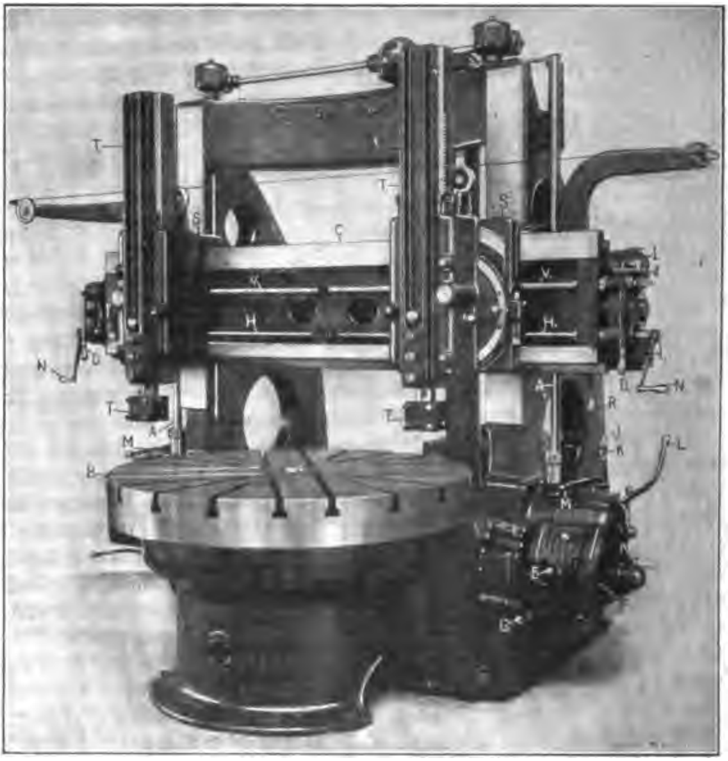

Fig. 1. Gisholt Vertical Boring and Turning Mill

and speed levers on the opposite side, so that the machine can be controlled from either position.

The heads can be adjusted along the cross-rail for setting the tools by hand-cranks *N*, and the tool slides can be moved vertically by turning shafts *V* with the same cranks. With this machine, however, these adjustments do not have to be made by hand, ordinarily, as there are rapid power movements controlled by levers *M*. These levers automatically disengage the feeds and enable the tool-heads to be rapidly shifted to the required position, the direction of the movement depending upon the position of the feed reverse lever *R* and lever *D*. This rapid traverse, which is a feature applied to modern boring mills of medium and large size, saves time and the labor connected with hand adjustments. The cross-rail *C* has a vertical adjustment on the faces of the right and left housings which support it, in order to locate the tool-heads at the right height for the work. This adjustment is effected by power and is controlled by levers at the sides of the housings. Normally, the cross-rail is bolted to the housings, and these bolts must be loosened before making the adjustment, and must always be tightened afterwards.

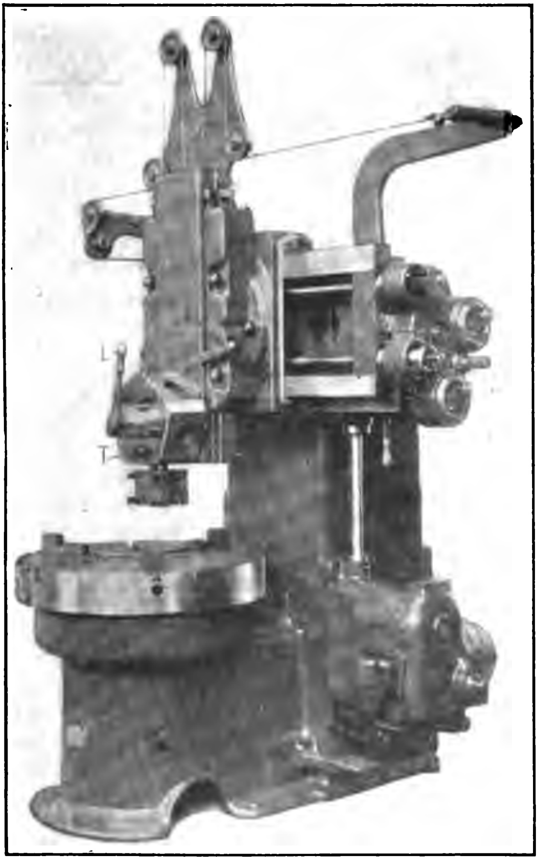

Fig. 2. Small Boring and Turning Mill with Single Turret-head

The function of these different levers has been explained to show, in a general way, how a vertical boring machine is operated. It should be understood, however, that the arrangement differs considerably on machines of different makes. The construction also varies considerably on machines of the same make but of different size. All modern vertical boring mills of medium and large sizes are equipped with two tool-heads, as shown in Fig. 1, because a great deal of work done on a machine of this type can have two surfaces machined simultaneously. On the other hand, small mills of the type illustrated in Fig. 2 have a single head. The tool-slide, instead of having a single tool-block, carries a five-sided turret *T* in which different tools can be mounted. These tools are shifted to the working position as they are needed, by loosening binder lever *L* and turning or "indexing" the turret. The turret is located and locked in any of its five positions by lever *I*, which controls a plunger that engages notches at the rear. Frequently, all the tools for machining a part can be held in the turret, so that little time is required for changing from one tool to the next. Some large machines having two tool-heads are also equipped with a turret on one head.

CHAPTER II

BORING AND TURNING IN A VERTICAL BORING MILL

The vertical boring mill is, in many respects, like a lathe placed in a vertical position, the table of the mill corresponding to the faceplate or chuck of the lathe and the tool-head to the lathe carriage. Much of the work done by a vertical mill could also be machined in a lathe, but the former is much more efficient for work within its range. To begin with, it is more convenient to clamp work to a horizontal table than to the vertical surface of a lathe faceplate, or, as someone has aptly said, "It is easier to lay a piece down than to hang it up." This is especially true of the heavy parts for which the boring mill is principally used. Very deep roughing cuts can also be taken with a vertical mill. The vertical mill is designed for turning and boring work which, generally speaking, is quite large in diameter in proportion to the width or height. The work varies greatly, especially in regard to its diameter, so that boring mills are built in a large range of sizes. The small and medium sizes will swing work varying from about 30 inches to 6 or 7 feet in diameter, whereas large machines, such as are used for turning very large flywheels, sheaves, etc., have a swing of 16 or 20 feet and larger sizes are used in some shops. The size of a vertical mill, like any other machine tool, should be somewhat in proportion to the size of the work for which it is intended, as a very large machine is unwieldy, and, therefore, inefficient for machining comparatively small parts.

Chucking and Setting Work on the Boring Mill Table

There are three general methods of holding work to the table of a boring mill; namely, by the use of chucks, by ordinary bolts and clamps, or in special fixtures. Chucks which are built into the table (as illustrated in Fig. 2) and have either universal or independent adjustments for the jaws, can be used to advantage for holding castings that are either round or irregular in shape. The universal adjustment is used for cylindrical parts, such as disks, flywheels, gear blanks, etc., and the independent adjustment, for castings of irregular shape. Chucks which have either an independent or universal movement for the jaws are known as a "combination" type and usually have three jaws. There is also a four-jaw type which has the independent adjustment only. This style is preferable for work that is not cylindrical and which must be held very securely. Chuck jaws that do not form a part of the machine table but are bolted to it in the required position, are also employed extensively, especially on comparatively large machines. Independent chuck jaws of this type are shown in Fig. 9.

Most of the work done in a vertical mill is held in a chuck. Occasionally, however, it is preferable to clamp a part directly to the table.

This may be desirable because of the shape and size of the work, or because it is necessary to hold a previously machined surface directly against the table in order to secure greater accuracy. Sometimes a casting is held in the chuck for turning one side, and then the finished side is clamped against the table for turning the opposite side. Parts which are to be machined in large quantities are often held in special fixtures. This method is employed when it enables the work to be set up more quickly than would be possible if regular clamps or chuck jaws were used.

Work that is to be turned or bored should first be set so that the part to be machined is about central with the table. For example, the rim of a flywheel should be set to run true so that it can be finished by removing about the same amount of metal around the entire rim; in other words, the rim should be set concentric with the table, as shown in Fig. 3, and the sides of the rim should also be parallel to the table. A simple tool that is very useful for testing the position of any cylindrical casting consists of a wooden shank into which is inserted a piece of wire, having one end bent. This tool is clamped in the toolpost and as the work revolves, the wire is adjusted close to the cylinderical surface being tested. The movement of the work with relation to the stationary wire point will, of course, show whether or not the part runs true. The advantage of using a piece of wire for testing, instead of a rigid tool, is that the wire, owing to its flexibility, will simply be bent backward if it is moved too close to a surface which is considerably out of true. The upper surface of a casting can be tested for parallelism with the table by using this same wire gage, or by comparing it with a tool held in the tool-post. An ordinary surface gage is also used for this purpose. The proper surface to set true, in any case, depends upon the requirements. A plain cylindrical disk would be set so that the outside ran true and the top surface was parallel with the table. When setting a flywheel, if the inside is to remain rough, the casting should be set by this surface rather than by the outside, so that the rim, when finished, will be uniform in thickness.

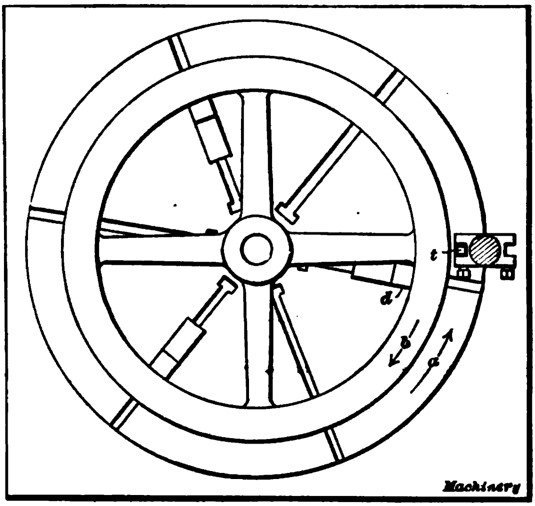

Fig. 3. Plan View showing Flywheel Casting Chucked for Turning

As far as possible, chucks should be used for holding cylindrical parts, owing to their convenience. The jaws should be set against an interior cylindrical surface whenever this is feasible. To illustrate, the flywheel in Fig. 3 is gripped by the inside of the rim which permits the outside to be turned at this setting of the work. The flywheel casting should also be set in the chuck so that a spoke rests against one of the jaws as at *d*. This jaw will then act as a driver and prevent the casting from slipping or turning in the chuck jaws, owing to the tangential pressure of the turning tool. When a cut is being taken, the table and work rotates as shown by arrow *a*, and the thrust of the cut (taken by tool *t*) tends to move the wheel backward against the direction of rotation as shown by arrow *b*. If one of the chuck jaws bears against one of the spokes, this movement is prevented. It is not always feasible to use a

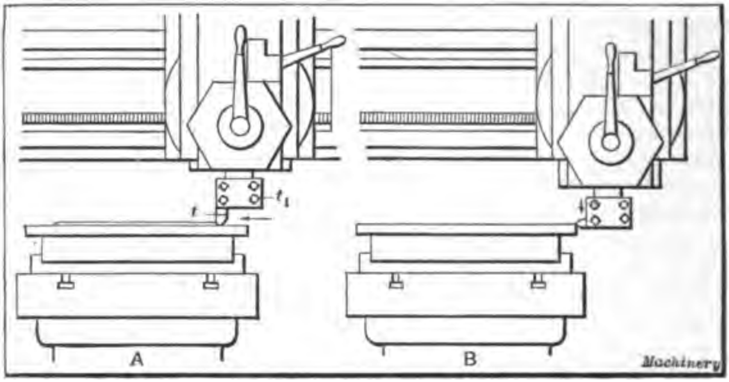

Fig. 4. (A) Turning a Flat Surface. (B) Turning a Cylindrical Surface

chuck jaw as a driver and then a special driver having the form of a small angle-plate, is sometimes bolted directly to the table. Another method of driving is to set a brace between a spoke or projection on the work and a chuck jaw or strip attached to the table. Drivers are not only used for flywheels, but in connection with any large casting, especially when heavy cuts have to be taken. Of course, some castings are so shaped that drivers cannot be employed.

Turning in a Boring Mill

The vertical type of boring mill is used more for turning cylindrical surfaces than for actual boring, although a large part of the work requires both turning and boring. We shall first consider, in a general way, how surfaces are turned and then refer to some boring operations. The diagram *A*, Fig. 4, illustrates how a horizontal surface would be turned. The tool *t* is clamped in tool-block t_1, in a vertical position, and it is fed horizontally as the table and work rotates. The tool is first adjusted by hand for the proper depth of cut and the automatic horizontal feed is then engaged. When a cylindrical surface is to be turned, the tool (provided a straight tool is used) is clamped in a horizontal position and is fed downward as indicated at *B*. The amount that the tool should feed per revolution of the work depends upon the kind of material being turned, the diameter of the turned part and the depth of the cut.

Most of the work machined in a vertical boring mill is made of cast iron and, ordinarily, at least one roughing and one finishing cut is taken. The number of roughing cuts required in any case depends, of

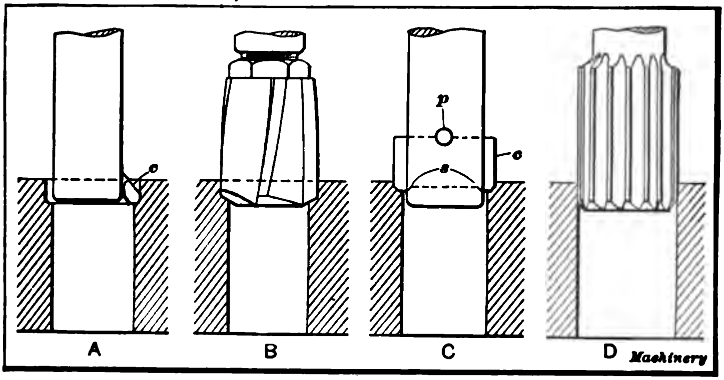

Fig. 5. Methods of Boring and Reaming Holes

course, upon the amount of metal to be removed. An ordinary roughing cut in soft cast iron might vary in depth from 1/8 to 3/8 inch and the tool would probably have a feed per revolution of from 1/16 to 1/8 inch, although deeper cuts and coarser feeds are sometimes taken. These figures are merely given to show, in a general way, what cuts and feeds are practicable. The tool used for roughing usually has a rounded end which leaves a ridged or rough surface. To obtain a smooth finish,

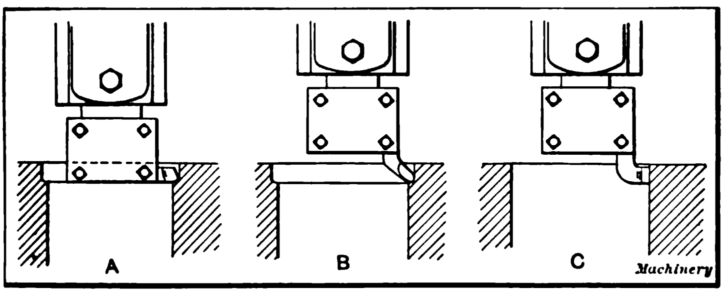

Fig. 6. Boring with Regular Turning Tools

broad flat tools are used. The flat cutting edge is set parallel to the tool's travel and a coarse feed is used in order to reduce the time required for taking the cut. The finishing feeds for cast iron vary from 1/4 to 3/4 inch on ordinary work. The different tools used on the vertical mill will be referred to more in detail later.

All medium and large sized vertical boring mills are equipped with two tool-heads and two tools are frequently used at the same time, especially on large work. Fig. 9 illustrates the use of two tools simultaneously. The casting shown is a flywheel, and the tool on the right side turns the upper side of the rim, while the tool on the left side turns the outside or periphery. As a boring mill table rotates in a counter-clockwise direction, the left-hand tool is reversed to bring the cutting edge at the rear. By turning two surfaces at once, the total time for machining the casting is, of course, greatly reduced. The turning of fly-

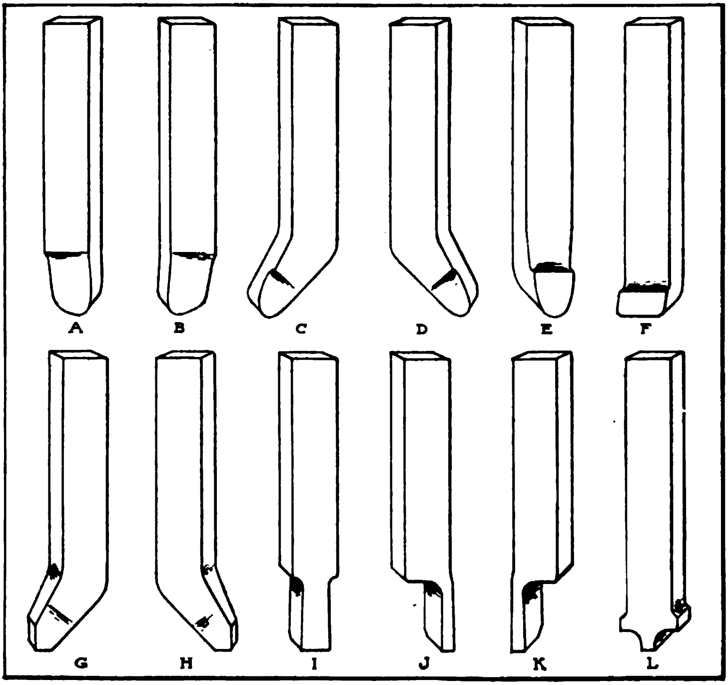

Fig. 7. Set of Boring Mill Tools

wheels is a very common vertical boring mill operation, and this work will be referred to in detail later on.

Boring Operations

There are several methods of machining holes in the vertical boring mill. Ordinarily, small holes are cored in castings and it is simply necessary to finish the rough surface to the required diameter. Some of the tools used for boring and finishing holes are shown in Fig. 5. Sketch *A* shows a boring tool consisting of a cutter *c* inserted in a shank, which, in turn, is held in the tool slide, or in a turret attached to the tool slide. With a tool of this type, a hole is bored by taking one or more cuts down through it. The tool shown at *B* is a four-lipped drill which is used for drilling cored holes preparatory to finishing by a cutter or reamer. This drill would probably finish a hole to within about 1/32 inch of the finish diameter, thus leaving a small amount of metal for the reamer to remove. The tool illustrated at *C* has a double-ended flat cutter *c*, which cuts on both sides. These cutters are often made in sets for boring duplicate parts. Ordinarily, there are two cutters in a set, one being used for roughing and the other for finishing. The cutter passes through a rectangular slot in the bar and this particular style is centrally located by shoulders *s*, and is held by a taper pin *p*. Some cutter bars have an extension end which passes through a close-fitting bushing in the table to steady the bar. Sketch *D* shows a finishing reamer. This tool takes a very light cut and is intended to finish holes that have been previously bored close to the required size.

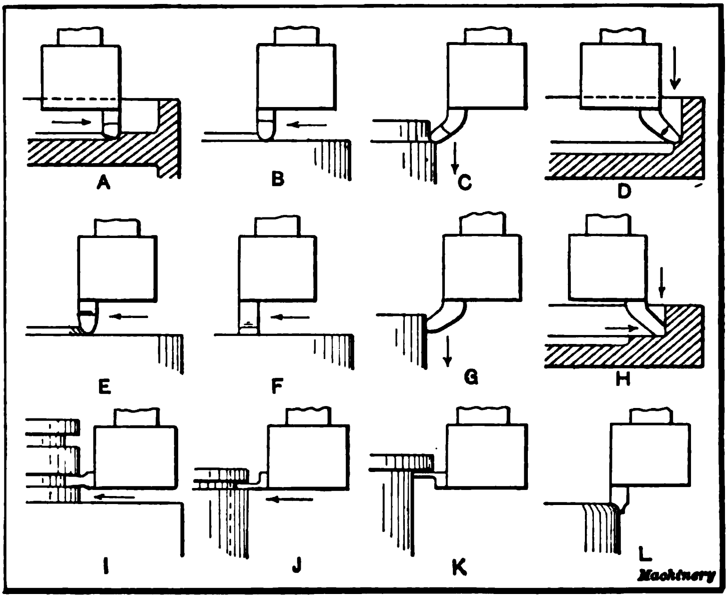

Fig. 8. Diagrams Illustrating Use of Different Forms of Tools

Sometimes a flat cutter *C* is used for roughing and a reamer for finishing. The reamer is especially desirable for interchangeable work, when all holes must have a smooth finish and be of the same size. When a reamer is held rigidly to a turret or tool-slide, it is liable to produce a hole that is either tapering or larger than the reamer diameter. To prevent this, the reamer should be held in a "floating" holder which, by means of a slight adjustment, allows the reamer to align itself with the hole. There are several methods of securing this "floating" movement.

Large holes or interior cylindrical surfaces are bored by tools held in the regular tool-head. The tool is sometimes clamped in a horizontal position as shown at *A*, Fig. 6, or a bent type is used as at *B*. Cast iron is usually finished by a broad flat tool as at *C*, the same as when turning exterior surfaces. Obviously a hole that is bored in this way must be large enough to admit the tool-block.

Turning Tools for the Vertical Boring Mill

A set of turning tools for the vertical boring mill is shown in Fig. 7. These tools can be used for a wide variety of ordinary turning operations. When a great many duplicate parts are to be machined, special tool equipment can often be used to advantage, but as the form of this equipment depends upon the character of the work, only standard tools have been illustrated herewith. The tool shown at *A* is a right-hand, "hog-nose" roughing tool, and a left-hand tool of the same type is shown at *B*. Tool *C* is an offset or bent, left-hand round nose for roughing, and *D* is a right-hand offset tool. A straight round nose is shown at *E*. Tool *F* has a flat, broad cutting edge and is used for finishing. Left- and right-hand

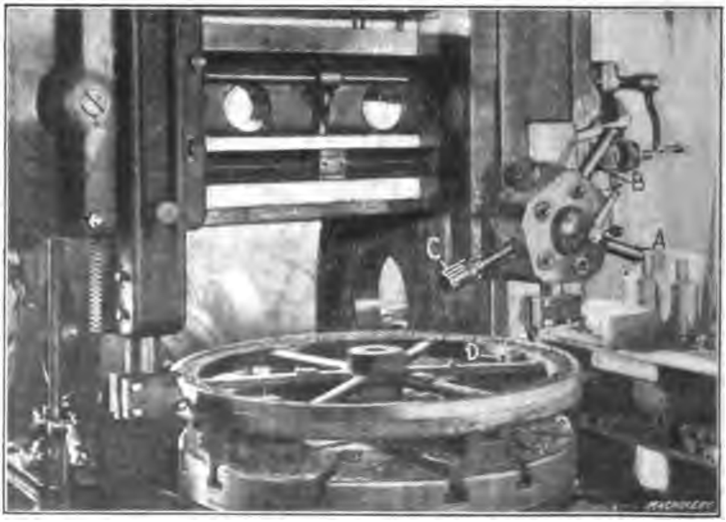

Fig. 9. Turning the Rim of a Flywheel

finishing tools of the offset type are shown at *G* and *H*, respectively. Tool *I* has a square end and is used for cutting grooves. Right- and left-hand parting tools are shown at *J* and *K*, and tool *L* is a form frequently used for rounding corners.

The diagrams in Fig. 8 show, in a general way, how each of the tools illustrated in Fig. 7 are used, and corresponding tools are marked by the same reference letters in both of these illustrations. The right- and left-hand roughing tools *A* and *B* are especially adapted for taking deep roughing cuts. One feeds away from the center of the table, or to the right (when held in the right-hand tool-block) and the other tool is ground to feed in the opposite direction. Ordinarily, when turning plain flat surfaces, the cut is started at the outside and the tool feeds toward the center, as at *B*, although it is sometimes more convenient to feed in the opposite direction, as at *A*. The tool shown at *A* could also be used for turning cylindrical surfaces, by clamping it in a horizontal position across the bottom of the tool-block. The feeding movement would then be downward or at right-angles to the work table. The offset round-nose tools *C* and *D* are for turning exterior or interior cylinder surfaces. As this form of tool extends below the tool-block, it can be fed down close to a shoulder. The straight type shown at *E* is adapted for steel or iron, and when the point is drawn out narrower, it is also used for brass, although the front is then ground without slope. Tool *F* is for light finishing cuts and broad feeds. The amount of feed per revolution of the work should always be less than the width of the cutting edge. The offset tools *G* and *H* are for finishing exterior and interior cylindrical surfaces. These tools also have horizontal cutting edges and are sometimes used for first finishing a cylindrical and then a horizontal surface, or *vice versa*. Tool *I* is adapted to such work as cutting packing-ring grooves in engine pistons, forming square or rectangular grooves, and

Fig. 10. Tool B set for Boring the Hub

similar work. The parting tools *J* and *K* can also be used for forming narrow grooves or for cutting off rings, etc. The sketch *K* (Fig. 8) indicates how the left-hand tool might be used for squaring a corner under a shoulder. Tool *L* is frequently used on boring mills for rounding the corners of flywheel rims, in order to give them a more finished appearance. It has two cutting edges so that either side can be used.

The turning tools of a vertical boring mill are similar, in many respects, to those used on a lathe, although the shanks of the former are shorter and more stocky than those of lathe tools. The cutting edges of some of the tools also differ somewhat, but the principles which govern the grinding of lathe and boring mill tools are identical, and those who are not familiar with tool grinding are referred to MACHINERY'S Reference Book No. 92 on lathe work, in which this subject is treated.

Turning a Flywheel on a Vertical Mill

The turning of a flywheel is a good example of the kind of work for which a vertical boring mill is adapted. A flywheel should preferably

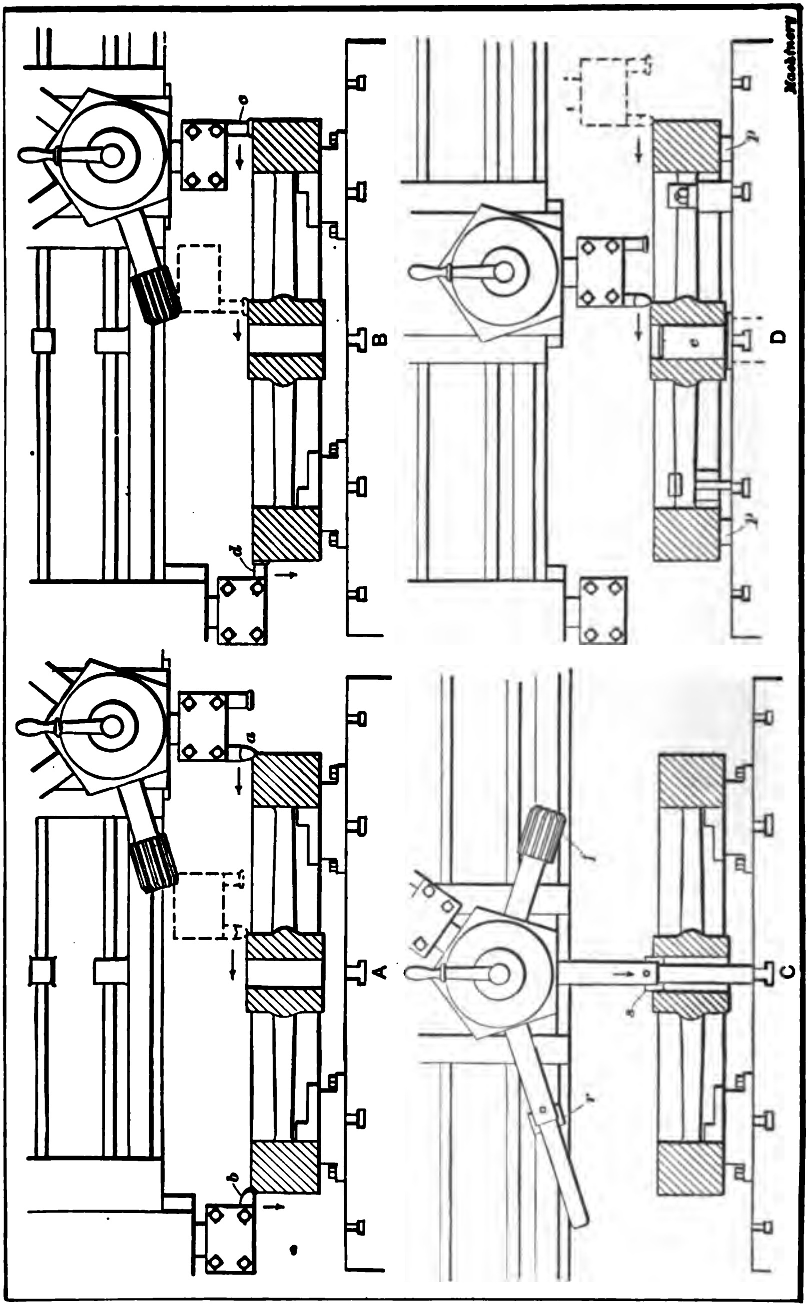

Fig. 11. Diagrams showing Method of Turning and Boring a Flywheel on a Double-head Mill having One Turret Head

be machined on a double-head mill so that one side and the periphery of the rim can be turned at the same time. A common method of holding a flywheel is shown in Fig. 9. The rim is gripped by four chuck jaws *D* which, if practicable, should be on the inside where they will not interfere with the movement of the tool. Two of the jaws, in this case, are set against the spokes on opposite sides of the wheel, to act as drivers and prevent any backward shifting of work when a heavy cut is being taken. The illustration shows the tool to the right rough turning the side of the rim, while the left-hand tool turns the periphery. Finishing cuts are also taken over the rim, at this setting, and the hub is turned on the outside, faced on top, and the hole bored. The three tools *A*, *B*

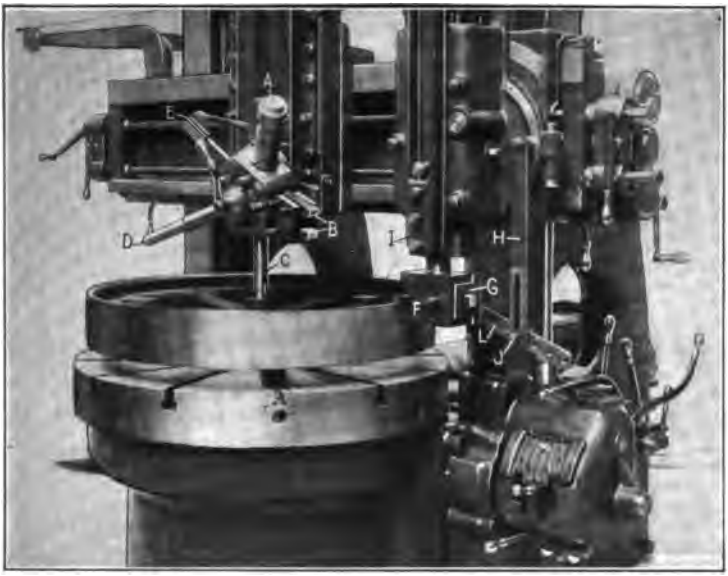

Fig. 12. Gisholt Mill equipped with Convex Turning Attachment

and *C*, for finishing the hole, are mounted in the turret. Bar *A*, which carries a cutter at its end, first rough bores the hole. The sizing cutter *B* is then used to straighten it before inserting the finishing reamer *C*. Fig. 10 shows the turret moved over to a central position and the sizing cutter *B* set for boring. The head is centrally located (on this particular machine) by a positive center-stop. The turret is indexed for bringing the different tools into the working position, by loosening the clamping lever *L* and pulling down lever *I* which disengages the turret lock-pin. When all the flywheels in a lot have been machined as described, the opposite side is finished.

In order to show more clearly the method of handling work of this class, the machining of a flywheel will be explained more in detail in connection with Fig. 11, which illustrates practically the same equipment as is shown in Figs. 9 and 10. The successive order in which the various operations are performed is as follows: Tool *a* (see sketch *A*) rough turns the side of the rim, while tool *b*, which is set with its cutting edge toward the rear, rough turns the outside. The direction in which each tool moves is indicated by the arrows. When tool *a* has crossed the rim, it is moved over for facing the hub, as shown by the dotted lines. The side and periphery of the rim is next finished by the broad-nose finishing tools *c* and *d* (see sketch *B*). The feed should be increased for finishing, so that each tool will have a movement of say 1/4 or 3/8 inch per revolution of the work, and the cuts should be deep enough to remove the marks made by the roughing tools. Tool *c* is also used for finishing the hub as indicated by the dotted lines. After these cuts are taken, the outside of the hub and inner surface of rim are

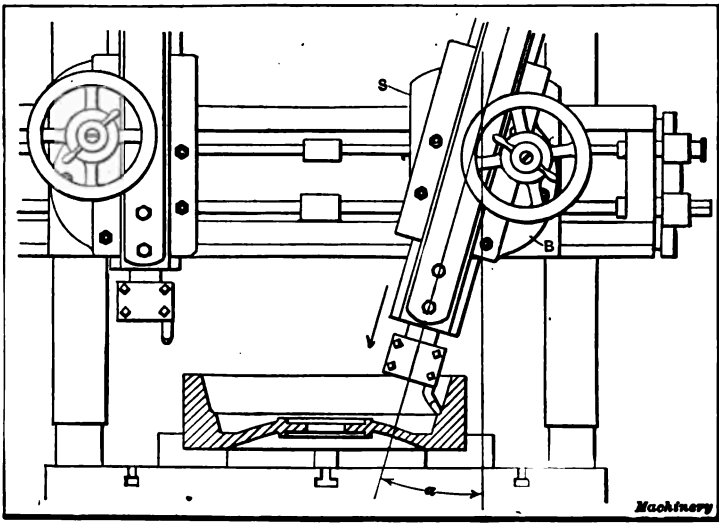

Fig. 13. Turning a Taper or Conical Surface

usually turned down as far as the spokes, by using offset tools similar to the ones shown at *C* and *D* in Fig. 7. The corners of the rim and hub are also rounded to give the work a more finished appearance, by using a tool *L*.

The next operation is that of finishing the hole through the hub. The hard scale is first removed by a roughing cutter *r* (sketch *C*), which is followed by a "sizing" cutter *s*. The hole is then finished smooth and to the right diameter by reamer *f*. The bars carrying cutters *r* and *s* have extensions or "pilots" which enter a close-fitting bushing in the table, in order to steady the bar and hold it in alignment.

When the hole is finished, the wheel is turned over, so that the lower side of the rim and hub can be faced. The method of holding the work for the final operation is shown at *D*. The chuck jaws are removed, and the finished side of the rim is clamped against parallels *p* resting on the table. The wheel is centrally located for turning this side by a plug *c* which is inserted in a hole in the table and fits the bore of the hub.

The work is held by clamps which bear against the spokes. Roughing and finishing cuts are next taken over the rim and hub and the corners are rounded, which completes the machining operations. If the rim needs to be a certain width, about the same amount of metal should be removed from each side, unless sandy spots or "blow-holes" in the casting make it necessary to take more from one side than the other. That side of the rim which was up when the casting was made, should be

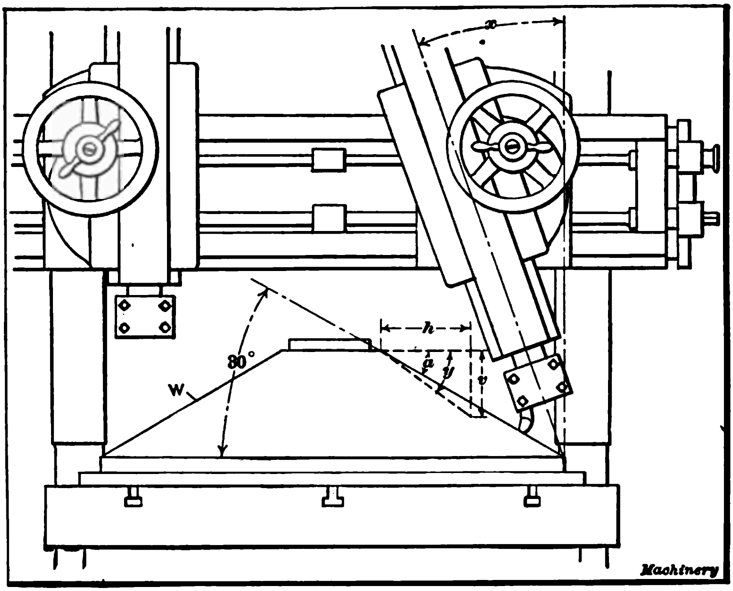

Fig. 14. Turning a Conical Surface by using the Combined Vertical and Horizontal Feeds

turned first, because the porous, spongy spots usually form on the "cope" or top side of a casting.

Convex Turning Attachment for Boring Mills

Fig. 12 shows a vertical boring mill arranged for turning pulleys having convex rims; that is, the rim, instead of being cylindrical, is rounded somewhat so that it slopes from the center toward either side. The reason for turning a pulley rim convex is to prevent the belt from running off at one side, as it sometimes tends to do when a cylindrical pulley is used. The convex surface is produced by a special attachment which causes the turning tool to gradually move outward as it feeds down, until the center of the rim is reached, after which the movement is inward.

This attachment consists of a special box-shaped tool-head *F* containing a sliding holder *G*, in which the tool is clamped by set-screws passing through elongated slots in the front of the tool-head. In addition, there is a radius link *L* which swivels on a stud at the rear of the tool-head and is attached to vertical link *H*. Link *L* is so connected to the sliding tool-block that any downward movement of the tool-bar *I* causes the tool to move outward until the link is in a horizontal position, after which the movement is reversed. When the attachment is first set up, the turning tool is placed at the center of the rim and then link *L* is clamped to the vertical link while in a horizontal position. The cut is started at the top edge of the rim, and the tool is fed downward by power, the same as when turning a cylindrical surface. The amount of curvature or convexity of a rim can be varied by inserting the clamp bolt *J* in different holes in link *L*.

The tools for machining the hub and sides of the rim are held in a turret mounted on the left-hand head, as shown. The special tool-holder *A* contains two bent tools for turning the upper and lower edges of the pulley rim at the same time. Roughing and finishing tools *B* are for

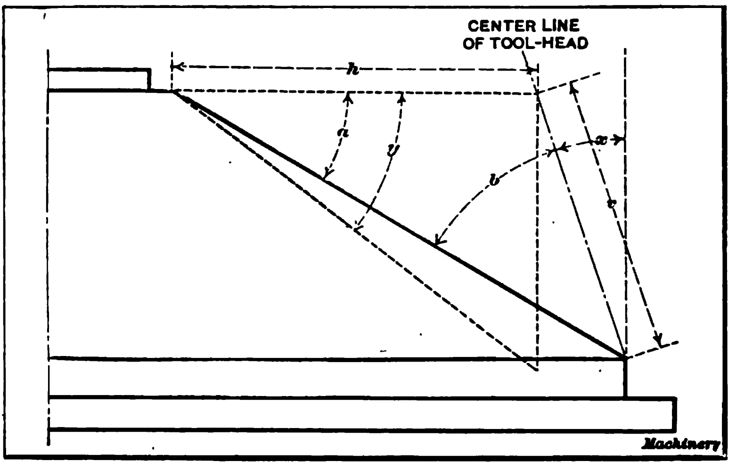

Fig. 15. Diagram showing Method of Obtaining Angular Position of Tool-head when Turning Conical Surfaces by using Vertical and Horizontal Feeding Movements

facing the hub, and the tools *C*, *D*, and *E* rough bore and finish the hole for the shaft.

Turning Taper or Conical Surfaces

Conical or taper surfaces are turned in a vertical boring mill by swiveling the tool-bar to the proper angle, as shown in Fig. 13. When the taper is given in degrees, the tool-bar can be set by graduations on the edge of the circular base *E*, which show the angle *a* to which the bar is swiveled from a vertical position. The base turns on a central stud and is secured to the saddle *S* by the bolts shown, which should be tightened after the tool-bar is set. The vertical power feed can be used for taper turning the same as for cylindrical work.

Occasionally it is necessary to machine a conical surface which has such a large included angle that the tool-bar cannot be swiveled far enough around to permit turning by the method illustrated in Fig. 13. Another method, which is sometimes resorted to for work of this class, is to use the combined vertical and horizontal feeds. Suppose we want to turn the conical casting *W* (Fig. 14), to an angle of 30 degrees, as shown, and that the tool-head of the boring mill moves horizontally 1/4 inch per turn of the screw and has a vertical movement of 3/16 inch per turn of the upper feed-shaft. If the two feeds are used simultaneously, the tool will move a distance h of say 8 inches, while it moves downward a distance v of 6 inches, thus turning the surface to an angle y. This angle is greater (as measured from a horizontal plane) than the angle required, but, if the tool-bar is swiveled to an angle x, the tool, as it moves downward, will also be advanced horizontally, in addition to the regular horizontal movement. The result is that angle y is diminished, and if the tool-bar is set over the right amount, the conical surface can be turned to an angle a of 30 degrees. The problem, then, is to determine what the angle x should be for turning to a given angle a. The way angle x is calculated will be explained in connection with the enlarged diagram, Fig. 15, which shows one-half of the casting.

The sine of the known angle a is first found in a table of natural sines. Then the sine of angle b is determined as follows: $\sin b = \frac{\sin a \times h}{v}$, in which h represents the rate of horizontal feed and v the rate of vertical feed. The angle corresponding to sine b is next found in the table of sines. We now have angles b and a, and by subtracting these angles from 90 degrees, the desired angle x is obtained. To illustrate:

The sine of 30 degrees is 0.5; then $\sin b = \frac{0.5 \times 1/4}{3/16} = 0.6666$; hence angle $b = 41$ degrees 49 minutes, and $x = 90° - (30° + 41° 49') = 18$ degrees 11 minutes.

If angle a were greater than angle y obtained from the combined feeds with the tool-bar in a vertical position, it would then be necessary to swing the lower end of the bar to the left rather than to the right of a vertical plane.

CHAPTER III

TURRET-LATHE TYPE OF VERTICAL BORING MILL

The machine illustrated in Fig. 16 was designed to combine the advantages of the horizontal turret lathe and the vertical boring mill. It is known as a "vertical turret lathe," but resembles, in many respects, a vertical boring mill. This machine has a turret on the cross-rail the same as the vertical boring mill, and, in addition, a side-head *S*. The side-head has a vertical feeding movement, and the tool-bar *T* can be fed horizontally. The tool-bar is also equipped with a four-sided turret for holding turning tools. This arrangement of the tool-heads makes it possible to use two tools simultaneously upon comparatively small work. When both heads are mounted on the cross rail, as with a double-head boring mill, it is often impossible to machine certain parts to advantage, because one head interferes with the other.

The drive to the table is from a belt pulley at the rear, and fifteen speed changes are available. Five changes are obtained by turning the pilot-wheel *A* and this series of five speeds is compounded three times by turning lever *B*. Each spoke of pilot-wheel *A* indicates a speed which is engaged only when the spoke is in a vertical position, and the three positions for *B* are indicated by slots in the disk shown. The number of table revolutions per minute for different positions of pilot-wheel *A* and lever *B*, are shown by figures seen through whichever slot is at *C*. There are five rows of figures corresponding to the five spokes of the pilot-wheel and three figures in a row, and the speed is shown by arrows on the sides of the slots. The segment disk containing these figures also serves as an interlocking device which prevents moving more than one speed controlling lever at a time, in order to avoid damaging the driving mechanism.

The feeding movement for each head is independent. Lever *D* controls the engagement or disengagement of the vertical or cross feeds for the head on the cross-rail. The feed for the side-head is controlled by lever *E*. When this lever is pushed inward, the entire head feeds vertically, but when it is pulled out, the tool-bar feeds horizontally. These two feeds can be disengaged by placing the lever in a neutral position. The direction of the feeding movement for either head can be reversed by lever *R*. The amount of feed is varied by feed-wheel *F* and clutch-rod *G*. When lever *E* is in the neutral position, the side-head or tool-bar can be adjusted by the hand-cranks *H* and *I*, respectively. The cross-rail head and its turret slide have rapid power traverse movements for making quick adjustments. This rapid traverse is controlled by the key-handles *J*. The feed screws for the vertical head have micrometer dials *K* for making accurate adjustments. There are also large dials at *L* which indicate vertical movements of the side head and horizontal movements of the tool slide. All of these dials have small adjustable clips *c* which are numbered to correspond to numbers on the faces of the respective turrets. These clips or "observation stops" are used in the production of duplicate parts. For example: suppose a tool in face No. 1 for the main turret is set for a given diameter and height of shoulder on a part which is to be duplicated. To obtain the same setting of the tools for the next piece, clips No. 1, on both the vertical feed rod and screw dials,

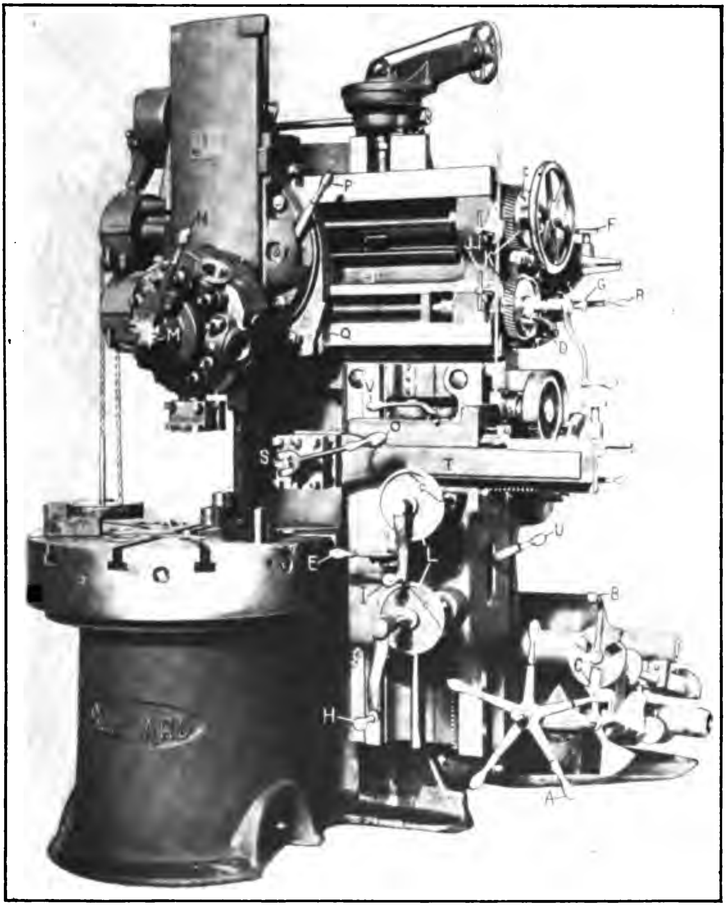

Fig. 16. Bullard Vertical Turret Lathe

are placed opposite the graduations which are intersected by stationary pointers secured to the cross-rail. The clips are set in this way after the first part has been machined to the required size and before disturbing the final position of the tools. For turning a duplicate part, the tools are simply brought to the same position by turning the feed screws until the clips and stationary pointers again coincide. For setting tools on other faces of either turret, this operation is repeated, except that clips are used bearing numbers corresponding to the turret face in use.

The main turret of this machine has five holes in which are inserted the necessary boring and turning tools, drills or reamers, as may be required. By having all the tools mounted in the turret, they can be quickly and accurately moved into working position. When the turret is indexed from one face to the next, binder lever N is first loosened. The turret then moves forward away from its seat, thus disengaging the indexing and registering pins which accurately locate it in any one of the five positions. The turret is revolved by turning crank *M*, one turn of this handle moving the turret 1/5 revolution or from one hole to the next. The side-head turret is turned by loosening lever *O*. The turret slide can be locked rigidly in any position by lever *P* and its saddle is clamped to the cross-rail by lever *Q*. The binder levers for the saddle and tool-slide of the side-head are located at *U* and *V* respectively. A slide that does not require feeding movements is locked in order to obtain greater rigidity.

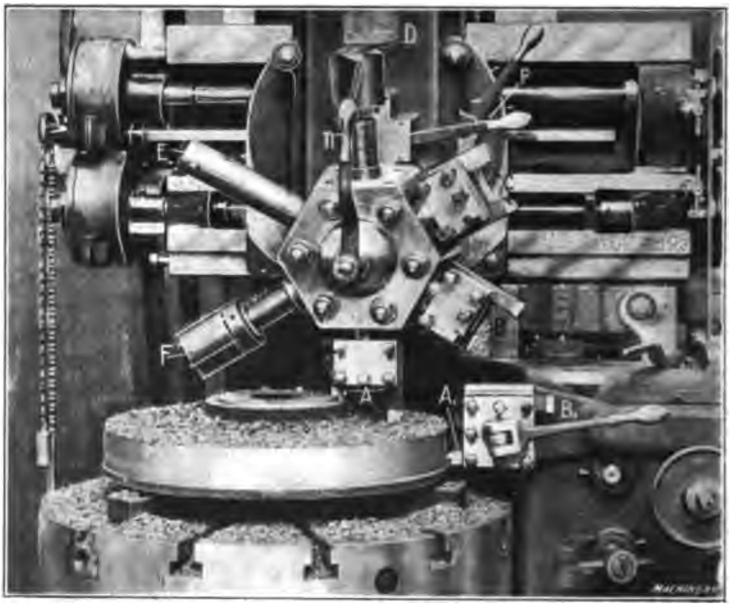

Fig. 17. Turning a Gear Blank on a Vertical Turret Lathe

The vertical slide can be set at an angle for taper turning, and the turret is accurately located over the center of the table for boring or reaming, by a positive center stop. The machine is provided with a brake for stopping the work table quickly, which is operated by lifting the shaft of pilot-wheel *A*. The side- and cross-rails are a unit and are adjusted together to accommodate work of different heights. This adjustment is effected by power on the particular machine illustrated, and it is controlled by a lever near the left end of the cross-rail. Before making this adjustment, all binder bolts which normally hold the rails rigidly to the machine column, must be released, and care should be taken to tighten them after the adjustment is made.

Examples of Vertical Turret Lathe Work

In order to illustrate how a vertical turret lathe is used, one or two examples of work will be referred to in detail. These examples also indicate, in a general way, the class of work for which this type of machine is adapted. Fig. 17 shows how a cast-iron gear blank is machined. The work is gripped on the inside of the rim by three chuck jaws, and all of the tools required for the various operations are mounted in the main and side turrets. The illustration shows the first operation which is that of rough turning the hub, the side of the blank and its

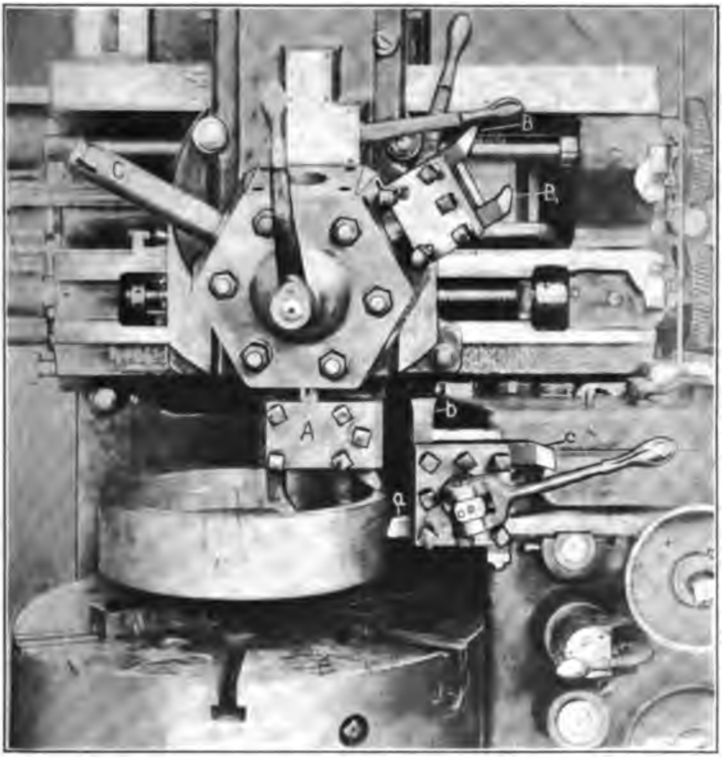

Fig. 18. Turning Gasoline Engine Flywheel on Vertical Turret Lathe—First Position

periphery. The tools *A* for the hub and side are both held in one tool-block on the main turret, and tool A_1 for roughing the periphery is in the side turret. With this arrangement, the three surfaces can be turned simultaneously. The main turret is next indexed one-sixth of a revolution which brings the broad finishing tools *B* into position, and the side turret is also turned to locate finishing tool B_1 at the front. (The indexing of the main turret on this particular machine is effected by loosening binder lever *n* and raising the turret lock-pin by means of lever *p*.) The hub, side and periphery of the blank are then finished. When tools *B* are clamped in the tool-blocks, they are, of course, set for turning the hub to the required height. The third operation is performed by the tools at *C*, one of which "breaks" or chamfers the corner of the cored hole to provide a starting surface for drill *D*, and the other turns the outside of the hub, after the chamfer tool is removed. The four-lipped shell-drill *D* is next used to drill the cored hole and then this hole is bored close to the finished size and concentric with the circumference of the blank by boring tool *E*, which is followed by the finishing reamer *F*. When the drill, boring tool and reamer are being used, the turret is set

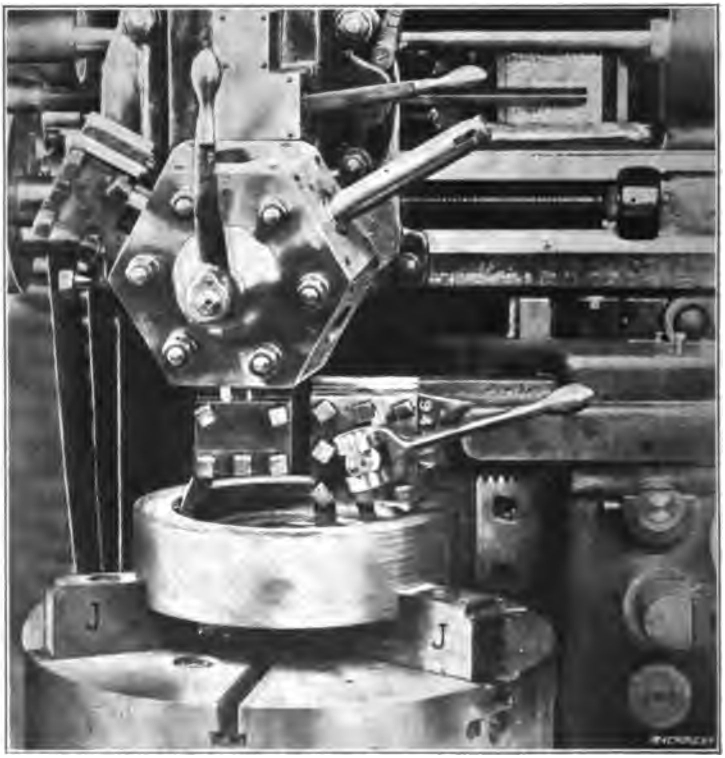

Fig. 19. Turning Gasoline Engine Flywheel—Second Position

over the center or axis of the table by means of a positive center stop on the left-side of the turret saddle. If it is necessary to move the turret beyond the central position, this stop can be swung out of the way.

Figs. 18 and 19 illustrate the machining of an automobile flywheel, which is another typical example of work for a machine of this type. The flywheel is finished in two settings. Its position for the first series of operations is shown in Fig. 18, and the successive order of the four operations for the first setting is shown by the diagrams, Fig. 20. The first operation requires four tools which act simultaneously. The three held in tool-block *A* of the turret, face the hub, the web and the rim of the flywheel, while tool *a* in the side-head rough turns the outside diameter. The outside diameter is also finished by broad-nosed tool *b* which is given a coarse feed. In the second operation, the under face of the rim is finished by tool *c*, the outer corners are rounded by tool *d* and the inner surface of the rim is rough turned by a bent tool *B*, which is moved into position by indexing the main turret. In the third operation, the side-head is moved out of the way and the inside of the rim is finished by another bent tool B_1. The final operation at this setting is the boring of the central hole, which is done with a bar *C* having in-

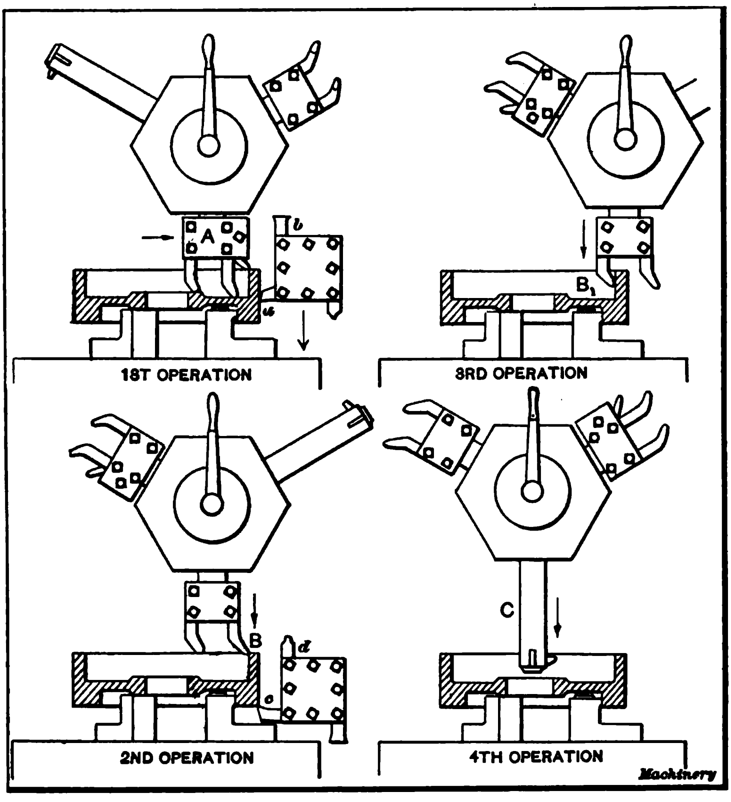

Fig. 20. Diagrams showing How Successive Operations are Performed by Different Tools in the Turret

terchangeable cutters which make it possible to finish the hole at one setting of the turret.

The remaining operations are performed on the opposite side of the work which is held in "soft" jaws *J* accurately bored to fit the finished outside diameter as indicated in Fig. 19. The tool in the main turret turns the inside of the rim and the side-head is equipped with two tools for facing the web and hub simultaneously. As the tool in the main turret operates on the left side of the rim, it is set with the cutting edge toward the rear. In order to move the turret to this position, which is beyond the center of the table, the center stop previously referred to is swung out of the way.

CHAPTER IV

HORIZONTAL BORING, DRILLING AND MILLING MACHINE

A boring machine of the horizontal type is shown in Fig. 21. The construction and operation of this machine is very different from that of a vertical boring mill and it is also used for a different class of work. The horizontal machine is employed principally for boring, drilling or milling, whereas the vertical design is especially adapted to turning and boring. The horizontal type is also used for turning or facing flanges or similar surfaces when such an operation can be performed to advantage in connection with other machine work on the same part.

The type of machine illustrated in Fig. 21 has a heavy base or bed to which is bolted the column *C* having vertical ways on which the spindle-head *H* is mounted. This head contains a sleeve or quill in which the spindle *S* slides longitudinally. The spindle carries cutters for boring, whereas milling cutters or the auxiliary facing arm, are bolted to the end *A* of the spindle sleeve. The work itself is attached either directly or indirectly to platen *P*. When the machine is in operation, the cutter or tool revolves with the spindle sleeve or spindle and either the cutter or the part being machined is given a feeding movement, depending on the character of the work. The spindle can be moved in or out by hand for adjustment, or by power for feeding the cutter as when boring or drilling. The entire spindle-head *H* can also be moved vertically on the face of the column *C*, by hand, for setting the spindle to the proper height, or by power for feeding a milling cutter in a vertical direction. When the vertical position of the spindle-head is changed, the back-rest block *B* also moves up or down a corresponding amount, the two parts being connected by shafts and gearing. Block *B* steadies the outer end of the boring-bar and the back-rest in which this block is mounted, can be shifted along the bed to suit the length of the work, by turning the squared end of shaft *D* with a crank. The platen *P* has a cross-feed, and the saddle *E* on which it is mounted can be traversed lengthwise on the bed; both of these movements can also be effected by hand or power. There is a series of power feeding movements for the cutters and, in addition, rapid power movements *in a reverse direction from the feed* for returning a cutter quickly to its starting position, when this is desirable.

This machine is driven by a belt connecting pulley *G* with an overhead shaft. When the machine is in operation, this pulley is engaged with the main driving shaft by a friction clutch *F* controlled by lever *L*. This main shaft drives through gearing a vertical shaft *I*, which by means of other gears in the spindle head imparts a rotary movement to the spindle. As a machine of this type is used for boring holes of various diameters and for a variety of other work, it is necessary to

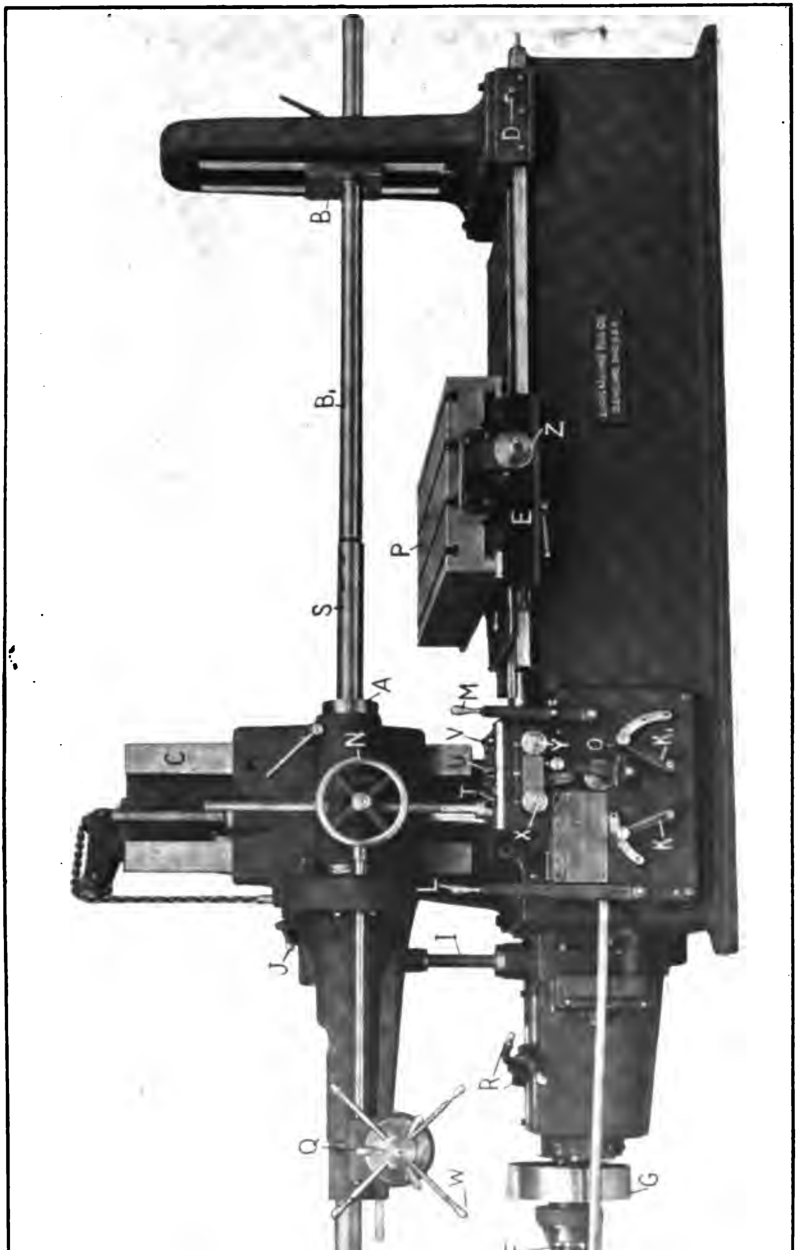

Fig. 21. Lucas Horizontal Boring, Drilling and Milling Machine

have a number of speed changes for the spindle. Nine speeds are obtained by changing the position of the sliding gears controlled by levers *R* and this number is doubled by back-gears in the spindle-head and controlled by lever *J*.

The amount of feed for the spindle, spindle-head, platen or saddle is varied by two levers *K* and K_1 which control the position of sliding gears through which the feeding movements are transmitted. The direction of the feed can be reversed by shifting lever *O*. With this particular machine, nine feed changes are available for each position of the spindle back-gears, making a total of eighteen changes which range from 0.004 to 0.006 inch per revolution of the spindle. The feeding movement is transmitted to the spindle-head, spindle, platen or saddle, as required, by the three distributing levers *T*, *U* and *V*, which control clutches connecting with the transmission shafts or feed screws. When lever *T* is turned to the left, the longitudinal power feed for the spindle is engaged, whereas turning it to the right throws in the vertical feed for the spindle-head. Lever *U* engages the cross-feed for platen *P* and lever *V*, the longitudinal feed for saddle *E*. These levers have a simple but ingenious interlocking device which makes it impossible to engage more than one feed at a time. For example, if lever *T* is set for feeding the spindle, levers *U* and *V* are locked against movement.

The feeds are started and stopped by lever *M* which also engages the rapid power traverse when thrown in the opposite direction. This rapid traverse operates for whatever feed is engaged by the distributing levers and, as before stated, in a reverse direction. For example, if the reverse lever *O* is set for feeding the spindle to the right, the rapid traverse would be to the left, and *vice versa*. The cross-feed for the platen can be automatically tripped at any point by setting an adjustable stop in the proper position and the feed can also be tripped by a hand lever at the side of the platen.

All the different feeding movements can be effected by hand as well as by power. By means of handwheel *N*, the spindle can be moved in or out slowly, for feeding a cutter by hand. When the friction clamp *Q* is loosened, the turnstile *W* can be used for traversing the spindle, in case a hand adjustment is desirable. The spindle-head can be adjusted vertically by turning squared shaft *X* with a crank, and the saddle can be shifted along the bed by turning shaft *Y*. The hand adjustment of the platen is effected by shaft *Z*. The spindle-head, platen and saddle can also be adjusted from the end of the machine, when this is more convenient. Shafts *X*, *Y* and *Z* are equipped with micrometer dials which are graduated to show movements of one-thousandth inch. These dials are used for accurately adjusting the spindle or work and for boring holes or milling surfaces that must be an exact distance apart.

Horizontal Boring Machine with Vertical Table Adjustment

Another design of horizontal boring machine is illustrated in Fig. 22. This machine is of the same type as that shown in Fig. 21, but its construction is quite different, as will be seen. The spindle cannot be adjusted vertically as with the first design described, but it is mounted

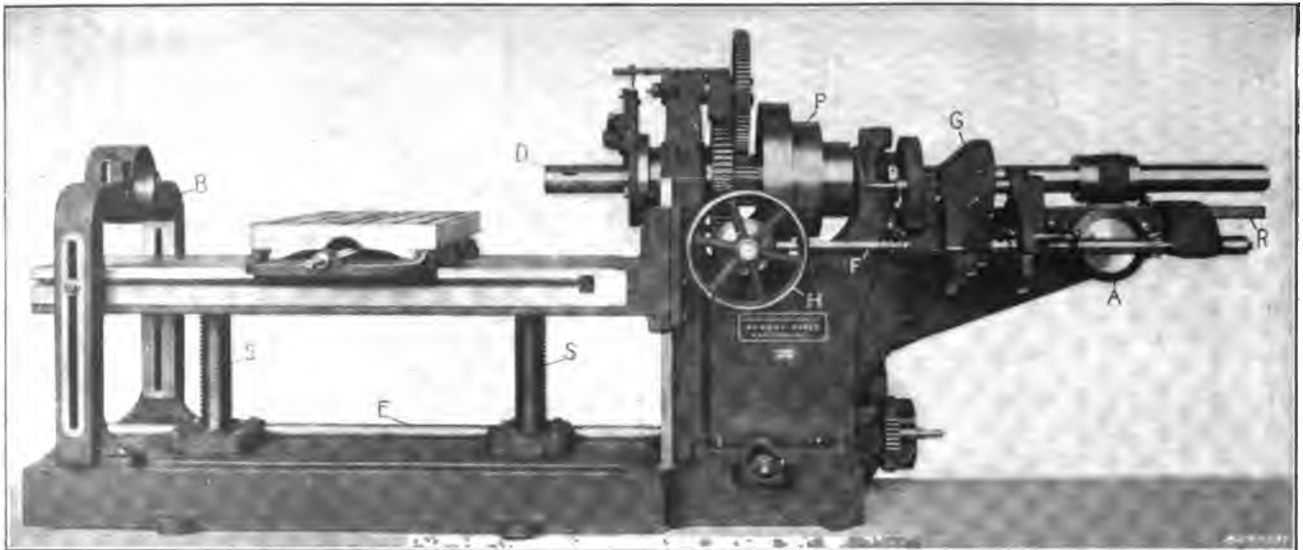

Fig. 22. Bement Horizontal Boring and Drilling Machine

and driven very much like the spindle of a lathe, and adjustment for height is obtained by raising or lowering the work table. The design is just the reverse, in this respect, of the machine shown in Fig. 21, which has a vertical adjustment for the spindle, and a work table that remains in the same horizontal plane. The raising or lowering of the table is effected by shaft *E*, which rotates large nuts engaging the screws *S*. Shaft *E* is turned either by hand or power.

The main spindle is driven by a cone pulley *P*, either directly, or indirectly through the back-gears shown. This arrangement gives six spindle speeds, and double this number is obtained by using a two-speed countershaft overhead. The motion for feeding the spindle longitudinally is transmitted to shaft *F*, which rotates bevel gear *A* and a pinion meshing with rack *R* which traverses the spindle. The large handwheel *H* and a corresponding wheel on the opposite side are used for adjusting the spindle rapidly by hand. The nest of gears at *G* gives the required feed changes by engaging different combinations. The yoke or outboard bearing *B* for the boring-bars can be clamped in any position along the bed for supporting the bar as close to the work as possible.

Horizontal boring machines are built in many other designs, but they all have the same general arrangement as the machines illustrated and operate on the same principle, with the exception of special types intended for handling certain classes of work exclusively. In the next chapter some examples of work done on these machines will be illustrated and described.

CHAPTER V

TOOLS FOR BORING—EXAMPLES OF HORIZONTAL BORING MACHINE WORK

The horizontal boring, drilling and milling machine is very efficient for certain classes of work because it enables all the machining operations on some parts to be completed at one setting. To illustrate, a casting which requires drilling, boring and milling at different places, can often be finished without disturbing its position on the platen after it is clamped in place. Frequently a comparatively small surface needs to be milled after a part has been bored. If this milling operation can be performed while the work is set up for boring, accurate results will be obtained (provided the machine is in good condition) and the time saved that would otherwise be required for re-setting the part on another machine. Some examples of work on which different operations are performed at the same setting will be referred to later. The horizontal boring machine also makes it possible to machine duplicate parts without the use of jigs, which is important, especially on large work, owing to the cost of jigs.

Drilling and Boring—Cutters Used for Boring

Holes are drilled in a horizontal machine by simply inserting a drill of required size either directly in the spindle (*S*, Fig. 21, and *D*, Fig. 22) or in a reducing socket, and then feeding the spindle outward either by hand or power. When a hole is to be bored, a boring-bar B_1 (Fig. 21) is inserted in the spindle and the cutter is attached to this bar. The latter is then fed through the hole as the cutter revolves. The distinction made by machinists between drilling and boring is as follows: A hole is said to be drilled when it is formed by sinking a drill into solid metal, whereas boring means the enlargement of a drilled or cored hole.

There are various methods of attaching cutters to boring-bars and the cutters used vary for different classes of work. A simple style of cutter which is used widely for boring small holes is shown at *A* in Fig. 23. The cutter *c* is made from flat stock and the cutting is done by the front edges *e* and e_1, which are beveled in opposite directions. The cutter is held in the bar by a taper wedge *w* and it is centered by shoulders at *s*. The outer corners at the front should be slightly rounded, as a sharp corner would be dulled quickly. These cutters are made in different sizes and also in sets for roughing and finishing. The roughing cutter bores holes to within about 1/32 inch of the finish size and it is then replaced by the finishing cutter. A cutter having rounded ends as

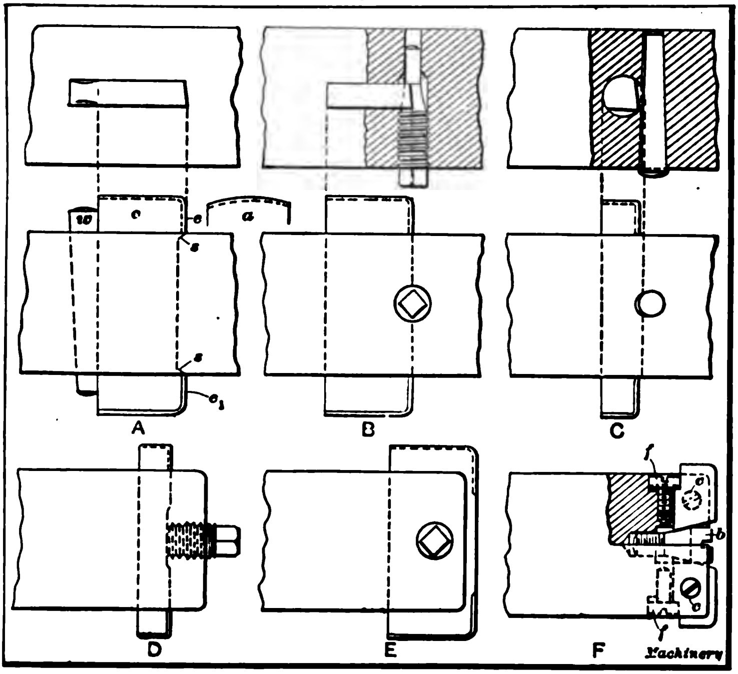

Fig. 23. Boring-cutters of Different Types

shown by the detail sketch *a*, is sometimes used for light finishing cuts. These rounded ends form the cutting edges and give a smooth finish. Another method of holding a flat cutter is shown at *B*. The conical end of a screw bears against a conical seat in the cutter, thus binding the latter in its slot. The conical seat also centers the cutter. A very simple and inexpensive form of cutter is shown at *C*. This is made from a piece of round steel, and it is held in the bar by a taper pin which bears against a circular recess in the side of the cutter. This form has the advantage of only requiring a hole through the boring-bar, whereas it is necessary to cut a rectangular slot for the flat cutter.

Fig. 24 illustrates how a hole is bored by cutters of the type referred to. The bar rotates as indicated by the arrow *a* and at the same time feeds longitudinally as shown by arrow *b*. The speed of rotation depends upon the diameter of the hole and the kind of material being bored, and the feed per revolution must also be varied to suit conditions. No definite rule can be given for speed or feed. On some classes of work a long boring-bar is used, which passes through the hole to be bored and is steadied at its outer end by the back-rest *B*, Figs. 21 and 22. On

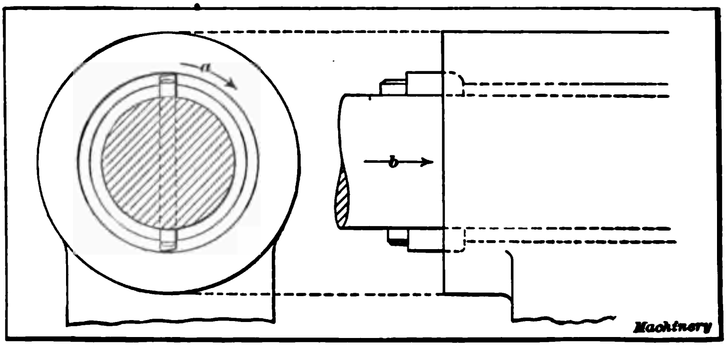

Fig. 24. Boring with a Flat Double-ended Cutter

other work, a short bar is inserted in the spindle and the cutter is attached at the outer end. An inexpensive method of holding a cutter at the end of a bar is shown at *D*, Fig. 23. The cutter passes through a slot and is clamped by a bolt as shown. When it is necessary to bore holes that are "blind" or closed at the bottom, a long boring-bar which passes through the work cannot, of course, be used. Sometimes it is

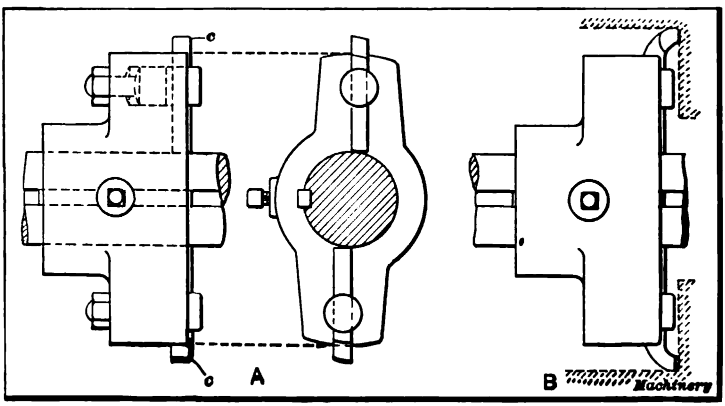

Fig. 25. Cutter-heads for Boring Large Holes

necessary to have a cutter mounted at the extreme end of a bar in order to bore close to a shoulder or the bottom of a hole. One method of holding a cutter so that it projects beyond the end of a bar is indicated at *E*. A screw similar to the one shown at *B* is used, and the conical end bears in a conical hole in the cutter. This hole should be slightly offset so that the cutter will be forced back against its seat. The tool shown at *F* has adjustable cutters. The inner end of each cutter is tapering and bears against a conical-headed screw *b* which gives the required outward adjustment. The cutters are held against the central bolt by filister-head screws *f* and they are clamped by the screws *c*. Boring tools are made in many different designs and the number and form of the cutters is varied somewhat for different kinds of work.

Cutter-heads for Boring Large Holes

When large holes are to be bored, the cutters are usually held in a cast-iron head which is mounted on the boring-bar. One type of cutter-head is shown in Fig. 25. This particular head is double-ended and carries two cutters *c*. The cutter-head is bored to fit the bar closely and it is prevented from turning by a key against which a setscrew is tightened. By referring to the end view, it will be seen that each cutter

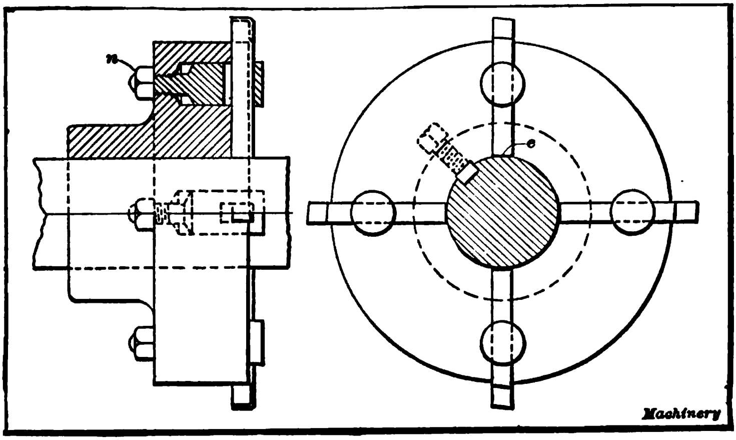

Fig. 26. Cutter-head with Four Boring Tools

is offset with relation to the center of the bar, in order to locate the front of the tool on a radial line. The number of cutters used in a cutter-head varies. There should be at least two, and three or four are often used. By having several cutters, the work of removing a given amount of metal in boring is distributed, and holes can be bored more quickly with a multiple cutter-head, although more power is required to drive the boring-bar. The boring-bar is also steadied by a multiple cutter-head, because the tendency of any one cutter to deflect the bar is counteracted by the cutters on the opposite side.

A disk-shaped head having four cutters is illustrated in Fig. 26. The cutters are inserted in slots or grooves in the face of the disk and they are held by slotted clamping posts. The shape of these posts is shown by the sectional view. The tool passes through an elongated slot and it is tightly clamped against the disk by tightening nut *n*. This head is also driven by a key which engages a keyway in the boring-bar.

Two other designs of cutter-heads are shown in Fig. 27. The one illustrated at *A* has three equally spaced cutters which are held in an inclined position. The cutters are clamped by screws *c* and they can be adjusted within certain limits by screws *s*. The cutters are placed at an angle so that they will extend beyond the front of the head, thus permitting the latter to be moved up close to a shoulder. The cutter-heads shown in Figs. 25 and 26 can also be moved up close to a shoulder

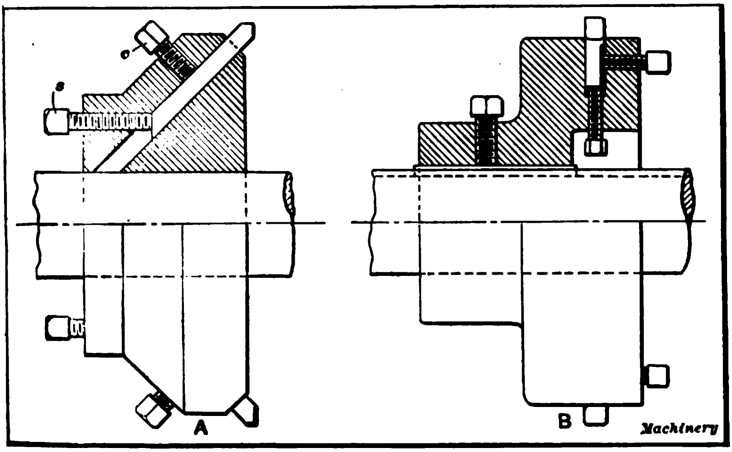

Fig. 27. Cutter-heads equipped with Adjustable Tools

if bent cutters are used as shown in the right-hand view, Fig. 25. The idea in bending the cutters is to bring the cutting edges in advance of the clamping posts so that they will reach a shoulder before the binding posts strike it. The arrangement of cutter head *B* (Fig. 27) is clearly shown by the illustration.

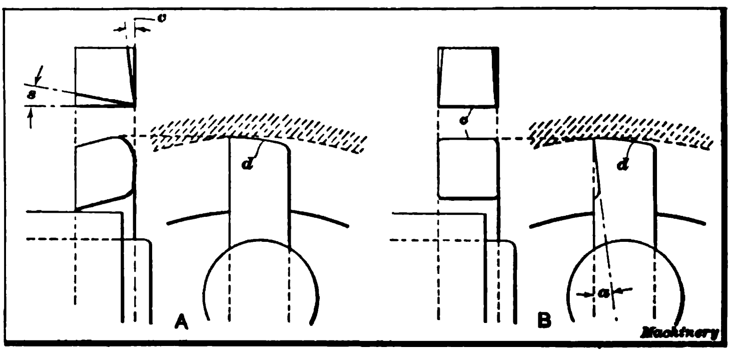

Fig. 28. Boring Tools for Roughing and Finishing Cuts

Fig. 29 illustrates the use of a cutter-head for cylinder boring. After the cylinder casting is set on the platen of the machine, the boring-bar with the cutter-head mounted on it, is inserted in the spindle. The bar *B* has a taper shank and a driving tang similar to a drill shank, which fits a taper hole in the end of the spindle. The cutter-head *C* is fastened to the bar so that it will be in the position shown when the spindle is shifted to the right, as the feeding movement is to be in the opposite direction. The casting *A* should be set central with the bar by adjusting the work-table vertically and laterally, if necessary, and the outer support *F* should be moved close to the work, to make the bar as rigid as possible.

The cylinder is now ready to be bored. Ordinarily, one roughing and one finishing cut would be sufficient, unless the rough bore were considerably below the finish diameter. As previously explained, the speed and feed must be governed by the kind of material being bored and the diameter of the cut. The power and rigidity of the boring machine and the quality of the steel used for making the cutters also effect the cutting speed and feed. Of course, the finishing cut is very light, and a

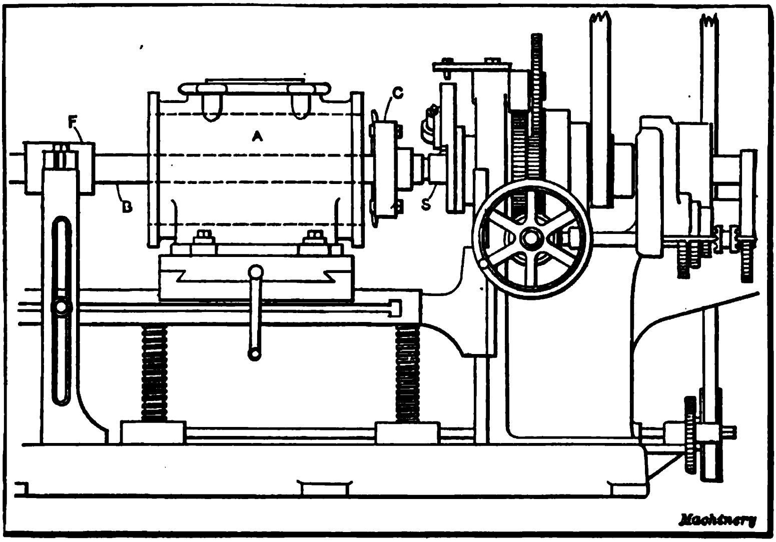

Fig. 29. Cylinder mounted on Horizontal Machine for Boring

tool having a flat cutting edge set parallel to the bar, is ordinarily used when boring cast iron. The coarse feed enables the cut to be taken in a comparatively short time and the broad-nosed tool gives a smooth finish if properly ground.

The coarse finishing feed is not always practicable, especially if the boring machine is in poor condition, owing to the chattering of the tool, which results in a rough surface. The last or finishing cut should invariably be a continuous one, for if the machine is stopped before the cut is completed, there will be a ridge in the bore at the point where the tool temporarily left off cutting. This ridge is caused by the cooling and resulting contraction and shortening of the tool during the time that it is stationary. For this reason independent drives are desirable for boring machines.

Cutter heads are often provided with two sets of cutters, one set being used for roughing and the other for finishing. It is a good plan to make these cutters so that the ends *e* (Fig. 26) will rest against the bar or bottom of the slot, when the cutting edge is set to the required radius. The cutters can then be easily set for boring duplicate work. One method of making cutters in sets is to clamp the annealed stock in

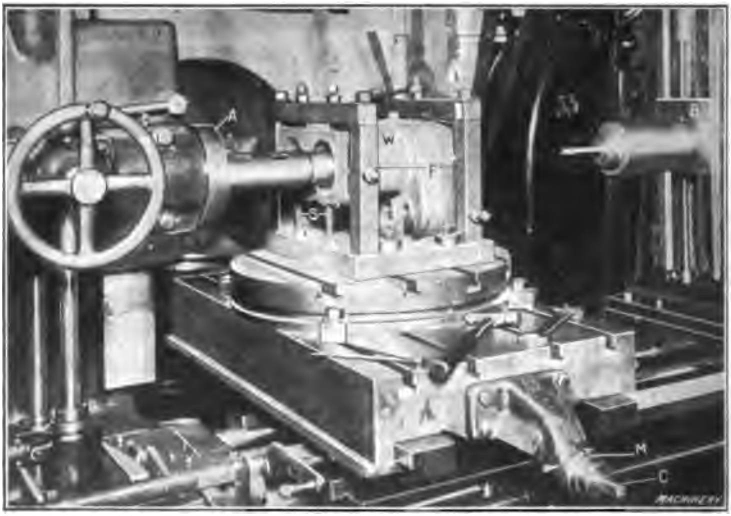

Fig. 30. Boring a Duplex Cylinder on a Horizontal Machine

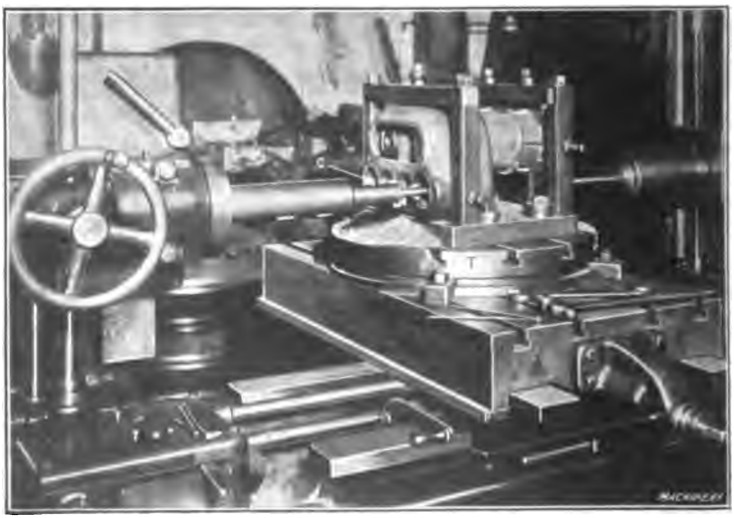

Fig. 31. Cylinder turned around for Machining Valve Seats

the cutter-head and then turn the ends to the required radius by placing the head in the lathe. After both sets of cutters have been turned in this way, they are ground to shape and then hardened.

Boring cutters intended for roughing and finishing cuts are shown in the detail view Fig. 28 at *A* and *B*, respectively. The side of the roughing cutter *A* is ground to a slight angle *c* to provide clearance for the cutting edge, and the front has a backward slope *s* to give the tool keenness. This tool is a good form to use for roughing cuts in cast iron. The finishing tool at *B* has a broad flat edge *e* and it is intended for coarse feeds and light cuts in cast iron. If a round cutting edge is used for finishing, a comparatively fine feed is required in order to obtain a smooth surface. The corners of tool *B* are rounded and they should be ground to slope inward as shown in the plan view. The top or ends *d* of both of these tools are "backed off" slightly to provide clearance. This end clearance should be just enough to prevent the surface back of cutting edge from dragging over the work. Excessive end clearance not

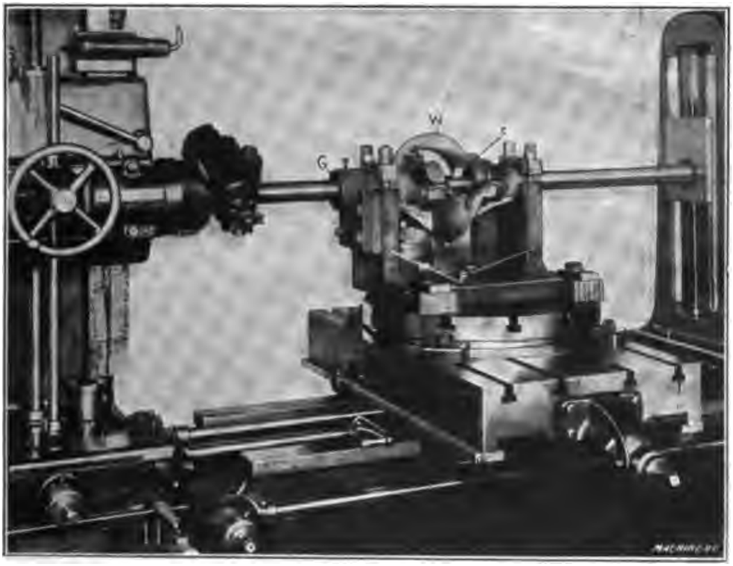

Fig. 32. Boring Differential Gear Casing

only weakens the cutting edge, but tends to cause chattering. As a finishing tool cuts on the upper end instead of on the side, the front should slope backward as shown in the side view, rather than side-wise as with a roughing cutter. The angle of the slope should be somewhat greater for steel than cast iron, unless the steel is quite hard.

Miscellaneous Examples of Boring, Facing and Milling

The method of holding work on a horizontal boring machine depends on its shape. A cylinder or other casting having a flat base can be clamped directly to the platen, but pieces of irregular shape are usually held in special fixtures. Fig. 30 shows how the cylinder casting of a gasoline engine is set up for the boring operation. The work *W* is placed in a fixture *F* which is clamped to the machine table. One end of the casting rests on the adjustable screws *S* and it is clamped by setscrews located in the top and sides of the fixture. There are two cylinders cast integral and these are bored by a short stiff bar mounted in the end of the spindle and having cutters at the outer end. A long bar of the type which passes through the work and is supported by the out-board bearing *B* could not be used for this work, as the top of each cylinder is closed.

When one cylinder is finished the other is set in line with the spindle by adjusting the work-table laterally. This adjustment is effected by screw *C*, and the required center-to-center distance between the two cylinders is obtained by the micrometer dial *M* on the cross-feed screw. After the first cylinder is bored, the dial is set to the zero position by loosening the small knurled screw shown, and turning the dial around.

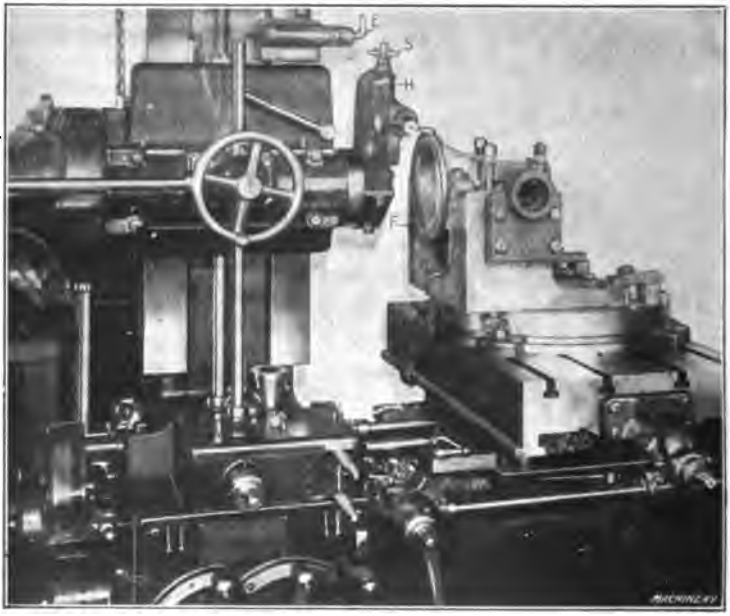

Fig. 33. Facing and Turning Flange of Differential Gear Casing

The feed screw is then rotated until the dial shows that the required lateral adjustment is made, which locates the casting for boring the second cylinder. The end of the casting is also faced true by a milling cutter. Ordinarily, milling cutters are bolted directly to the spindle sleeve *A* on this particular machine, which gives a rigid support for the cutter and a powerful drive.

The next operation is that of boring and milling the opposite end of the cylinder. This end is turned toward the spindle (as shown in Fig. 31) without unclamping the work or fixture, by simply turning the circular table *T* half way around. This table is an attachment which is clamped to the main table for holding work that must be turned to different positions for machining the various parts. Its position is easily changed, and as the work remains fixed with relation to the table, the alignment between different holes or surfaces is assured, if the table is turned the right amount. In this case, the casting needs to be rotated one-half a revolution or 180 degrees, and this is done by means of angular graduations on the base of the table. The illustration shows the casting set for boring the inlet and exhaust valve chambers. The different cutters required for boring are mounted on one bar as shown, and the work is adjusted cross-wise to bring each valve chamber in position, by using the micrometer dial. The single-ended cutter *c* forms a shallow circular recess or seat in the raised pad which surrounds the opening. The cover joint directly back of the cylinders is finished by milling.

Another example of boring, in which the circular table is used, is shown in Fig. 32. The work *W* is a casing for the differential gears of

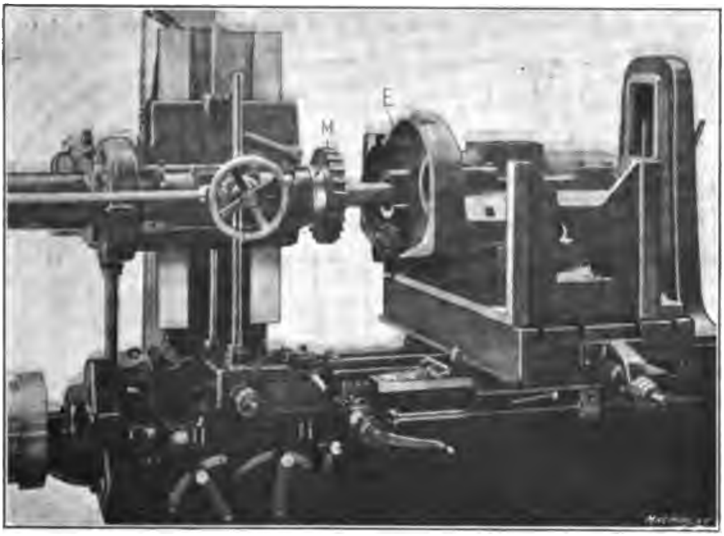

Fig. 34. Example of Work requiring Boring and Milling

an automobile. It is mounted in fixture *F* which is bolted to the table. The casting has round ends, which are clamped in V-blocks, thus aligning the work. This fixture has a guide-bushing *G* which is centered with the bar and cutter in order to properly locate the casting. There is a bearing at each end of the casing, and two larger ones in the center. These are bored by flat cutters similar to the style illustrated at *A* in Fig. 23. The cutter for the inner bearings is shown at *c*. After the bearings are bored, the circular table is turned 90 degrees and the work is moved closer to the spindle (as shown in Fig. 33) for facing flange *F* at right angles to the bearings. Circular flanges of this kind are faced in a horizontal boring machine by a special facing- arm or head *H*. For this particular job this head is clamped directly to the spindle sleeve, but it can also be clamped to the spindle if necessary. The turning tool is held in a slotted tool-post, and it is fed radially for turning the side or face of the flange, by the well-known star feed at *S*. When this feed is in operation the bent finger *E* is turned downward so that it strikes one of the star wheel arms for each revolution; this turns the wheel slightly, and the movement is transmitted to the tool-block by a feed screw. The illustration shows the tool set for turning the outside or periphery of the flange. This is done by setting the tool to the proper radius and then feeding the work horizontally by shifting the work-table along the bed. By referring to Fig. 32 it will be seen that the facing head does not need to be removed for boring, as it is attached to the spindle driving quill and does not interfere with the longitudinal adjustment of the spindle. This facing head is also used frequently for truing the flanges of cylinders which are to be bored, and for similar work.

Fig. 34 shows another example of work which requires boring and milling. This casting is mounted on a fixture which is bolted to the

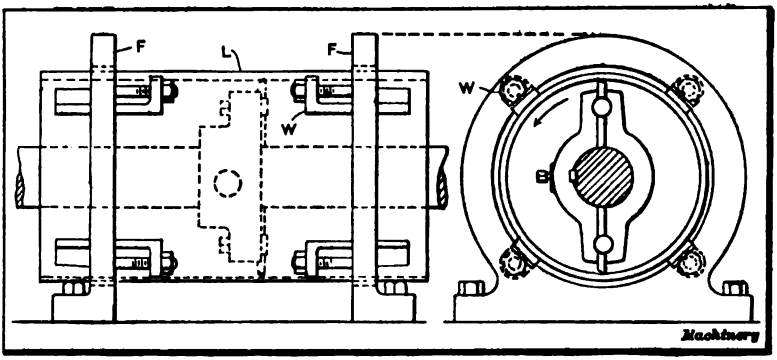

Fig. 35. Cylinder Lining Mounted in Fixture for Boring

main table. In this case the circular table is not necessary, because the work can be finished without swiveling it around. After the boring is completed the edge *E* is trued by the large-face milling cutter *M* bolted to the spindle sleeve. The irregular outline of the edge is followed by moving the table crosswise and the spindle vertically, as required.

A method of holding a lining or bushing while it is being bored is shown in Fig. 35. The lining *L* is mounted in two cast-iron fixtures *F*. These fixtures are circular in shape and have flat bases which are bolted to the table of the machine. On the inside of each fixture, there are four equally spaced wedges *W* which fit in grooves as shown in the end view. These wedges are drawn in against the work by bolts, and they prevent the lining from rotating when a cut is being taken. This form of fixture is especially adapted for holding thin bronze linings, such as are used in pump cylinders, because only a light pressure against the wedges is required, and thin work can be held without distorting it. If a very thin lining is being bored, it is well to loosen the wedges slightly before taking the finishing cut, so that the work can spring back to its normal shape.

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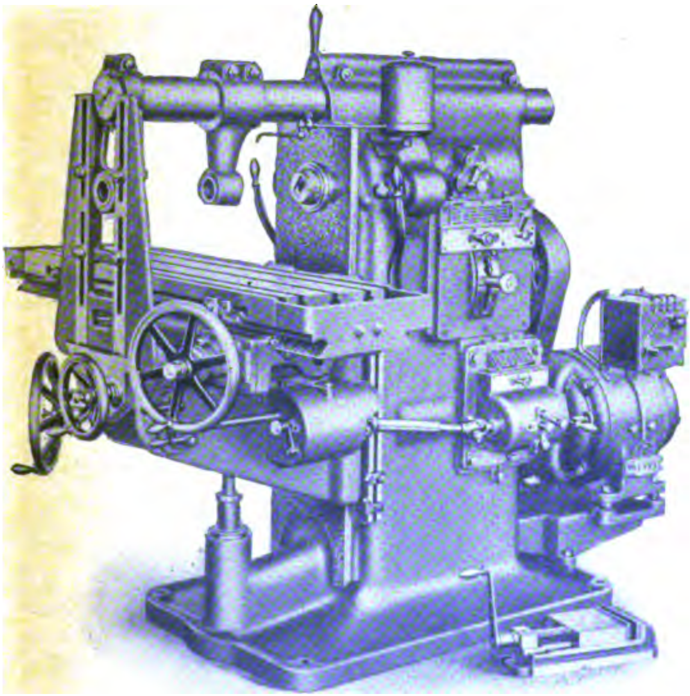
OPERATION OF MACHINE TOOLS

BY FRANKLIN D. JONES

MILLING MACHINES—PART I

SECOND EDITION



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CONTENTS

CHAPTER I

PLAIN TYPE OF MILLING MACHINE

Milling machines are used for a great variety of operations, and many types have been designed for milling certain classes of work to the best advantage. The milling machine was originally developed in armories for manufacturing the small irregular-shaped parts used in the construction of fire-arms, and the milling process is still employed very extensively in the production of similar work, especially when intricate profiles are required and the parts must be interchangeable. Milling machines are also widely used at the present time for milling many large castings or forgings, which were formerly finished exclusively by planing; in fact, it is sometimes difficult to determine whether certain parts should be planed or milled in order to secure the best results.

The operation of milling is performed by one or more circular cutters, having a number of teeth or cutting edges which successively mill away the metal as the cutter rotates. These cutting edges may be straight and parallel to the axis of the cutter for milling flat surfaces, or they may be inclined to it for forming an angular-shaped groove or surface, or they may have an irregular outline corresponding to the shape or profile of the parts which are to be milled by them. An end view of a cylindrical or "plain" cutter is shown in Fig. 1, which illustrates, diagrammatically, one method of producing a flat surface by milling. The cutter *C* rotates, as shown by the arrow, but remains in one position, while the work *W*, which is adjusted vertically to give the required depth of cut, slowly feeds to the left in a horizontal direction. Each tooth on the periphery of the cutter removes a chip every revolution, and, as the work moves along, a flat surface is formed.

The function of the milling machine is to rotate the cutter and, at the same time, automatically feed the work in the required direction. As it is necessary to vary the feeding movement and the speed of the cutter, in accordance with the material being milled and the depth of the cut, the milling machine must be equipped with feed- and speed-changing mechanisms and other features to facilitate its operation. As the variety of work that is done by milling is almost endless, milling machines differ widely as to their form, size, and general arrangement. Some are designed for doing a great variety of work, whereas others are intended for performing, as efficiently as possible, a comparatively small number of operations. Some machines are arranged for rotating the cutter horizontally, whereas with other types, the cutter rotates about a vertical axis. In this treatise, no attempt will be made to describe all the different types of milling machines, but rather to refer briefly to the more common designs, and then to illustrate their application and the principles of milling by showing typical examples of common milling operations.

Plain Milling Machine of the Column-and-Knee Type

A type of milling machine that is widely used, especially for milling large numbers of duplicate parts, is shown in Fig. 2. This is known as a plain, horizontal milling machine of the column-and-knee type. The principal parts are the column *C* and knee *K*, the work table *T*, the main spindle *S* which drives the cutter, and the speed- and feed-changing mechanisms encased at *A* and *B*, respectively. The spindle receives its motion from belt-pulley *P* at the rear. This pulley is connected to the driving shaft by a friction clutch operated by lever *M* which is used for starting and stopping the machine. When the friction clutch is engaged, power is transmitted to the main spindle

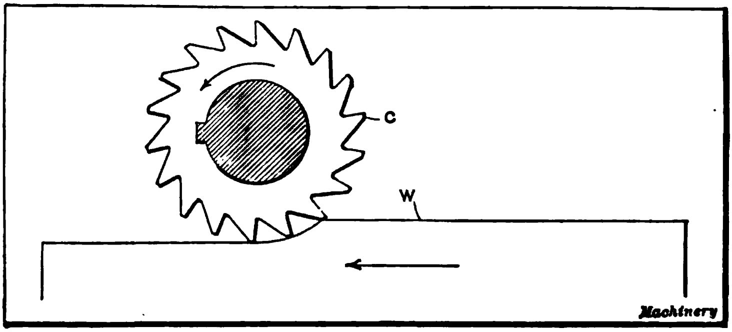

Fig. 1. End View of Cylindrical Cutter Milling Flat Surface

S through gearing, and, by varying the combination of this gearing, the required speed changes are obtained. Knee *K* is free to slide vertically on the front face of the column, and it carries saddle *Z* and the table *T*. The saddle has an in-and-out or cross movement on the knee, and the table can be traversed at right-angles to the axis of the spindle. Either of these three movements, that is, the longitudinal, cross, and vertical movements, can be effected by hand or power. The hand movements are used principally for adjusting the table and work to the required position when starting a cut, whereas the automatic power feed is employed when milling. The hand-crank *D* is used for raising or lowering the knee with its attached parts, handwheel *E* is for the cross feed of the saddle and table, and handle *F* is for the longitudinal adjustment of the table. The table can also be traversed rapidly by the large handwheel *N* at the front of the machine.

The work to be milled is held either in a vise *V*, or it is attached to the table by other means. When duplicate parts are to be milled in quantity, they are usually held in a special fixture bolted to the table in place of the vise. Some pieces are also clamped directly to the table. The milling cutter is ordinarily mounted on an arbor which is driven by spindle *S* and is rigidly supported by the bearing *I* and arbor-brace *J* which is attached to a clamp on the knee. Many machines do not have the extra bearing *I*, but this is desirable for many classes of work, as it can be adjusted along the overhanging arm and provides a support for the arbor close to the cutter.

The speed of the spindle is varied by changing the positions of the levers *L*, L_1, and the handwheel *W*. Each lever has two positions, making four in all, which are marked with the letters A, B, C and D,

Fig. 2. Cincinnati Plain Milling Machine

and the positions for the handwheel are numbered 1, 2, 3, and 4. An index-plate or table attached to the casing shows just what the speed will be for any position of the levers. For example, to obtain 115 revolutions per minute, the positions given on the index-plate under 115 are 3—BC, which means that the handwheel is set to position 3, one lever is engaged with hole B and the other with hole C. This particular machine has a total of sixteen speed changes. If there is any interference between the gears when changing the speeds, they can readily be engaged by pressing foot-lever *O*, which operates an auxiliary disk clutch and revolves the gears slightly.

The power-feed mechanism at *B* transmits its movement to the front of the machine by shaft *U* equipped with universal joints and a telescopic connection to permit raising or lowering the knee on the column. Shaft *U* drives gearing in the feed-tripping and reversing box *G*, and from this point the power is transmitted to the knee, saddle or table, as may be required. The table feed is engaged or disengaged by lever *Y* and it is controlled by another lever located at *Q*, but not seen in the illustration. The direction in which lever *Q* is inclined from the vertical, determines the direction of the table feed. For instance, if it is shifted to the right the table will travel toward the right, and *vice versa*. This lever *Q* also controls any feed that happens to be engaged, as well as the table feed. Lever *X* engages either the vertical or cross feeds, and all of the feeding movements can be controlled by lever *R* by means of which they are reversed.

The rate or amount of feed per revolution of the cutter can be varied by the levers and handwheel on case *B*. There are 16 changes, and an index-plate shows what the rate of feed is for any position of the levers. The longitudinal, cross or vertical feeding movements can be automatically stopped at any predetermined point by the trip-plungers *l*, *c*, and *v*, respectively. These plungers are operated by dogs which can be adjusted so that the automatic trip will operate after the cut is completed. The dogs *H* and H_1, for the table feed, are clamped to the front of the table as shown. One of these dogs trips the feed by lifting the plunger and the other by depressing it. A movement of the plunger in either direction disengages a clutch at *G* and places it in a neutral position. This is the same clutch that is operated by feed-reverse lever *R*. The automatic trip mechanism is a very convenient feature, as it prevents feeding too far, and makes the machine more independent of the operator.

The principal features of a plain milling machine, so far as the operation of the machine is concerned, have now been described, but it should be remembered that while plain machines of other makes have the speed- and feed-changing mechanisms, the automatic trips, etc., the arrangement of these parts varies in different designs. When the construction of one machine is thoroughly understood, however, the changes in other designs in the location of the speed- and feed-control levers, and the functions of the different parts, can readily be understood.

CHAPTER II

ADJUSTING AND OPERATING A MILLING MACHINE

Before a milling machine can be used, it is necessary, of course, to arrange it for doing the work in hand, which includes mounting the cutter in position, and adjusting the driving and feed mechanisms for giving the proper speed to the cutter and feed to the work. The part to be milled must also be securely attached to the machine, so that it can be fed against the revolving cutter by moving the table in whatever direction may be required. The way a milling machine

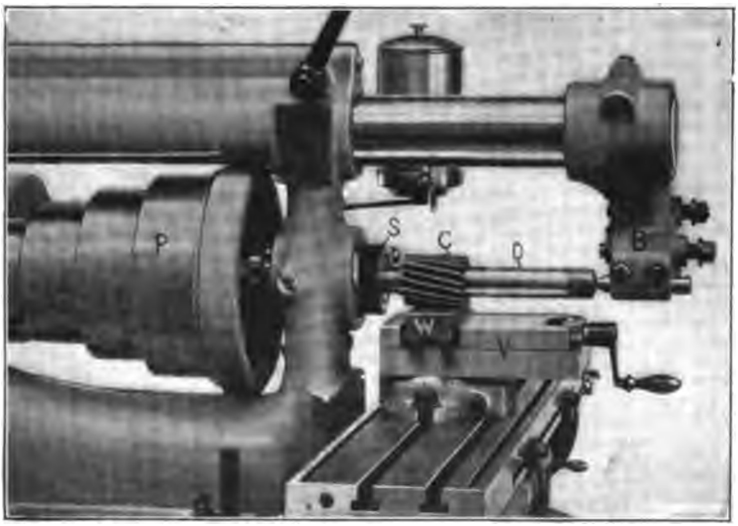

Fig. 3. Milling a Small Rectangular Block

is arranged, and the kind of cutter used, depends on the nature of the milling operation. The character of the work, and other considerations which will be referred to later, also affect the speed and feed, as well as the method of clamping the work to the table; hence, judgment and experience are needed to properly decide the questions that arise in connection with milling practice, and no definite rules or methods of procedure can be given. We shall explain, however, in a general way, how milling machines are arranged and used under varying conditions, by giving illustrated descriptions covering typical examples of work representing the various classes that are machined by the milling process.

A very simple example of milling is shown in Fig. 3, the operation being that of milling a flat surface on top of a steel block *W*.

Before referring to this work, it might be well to explain that the spindle of the machine shown in this illustration, is driven by a stepped or cone pulley *P*, instead of by a single, constant-speed pulley as in Fig. 2. Speed changes are obtained by shifting the driving belt to different steps of the cone, and the number of changes secured in this way can be doubled by the engagement of back-gears located at the side of the cone, the arrangement being the same as the back-gearing on an engine lathe.

Method of Holding and Driving the Cutter

The first thing to be done in connection with milling block *W*, is to select the cutter. As a flat surface is to be milled, a plain cylindrical cutter *C* would be used (in a machine of this type), having a width somewhat greater than the surface to be milled. This cutter

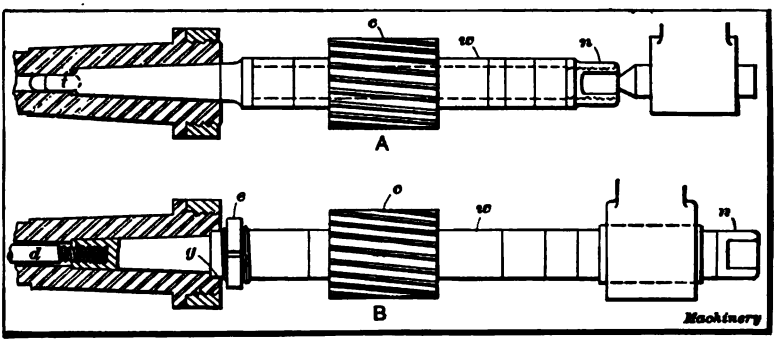

Fig. 4. Cutter Arbors

is mounted on an arbor *D* which is rotated by the spindle and is supported at its outer end by arm *B*. This is the usual method of mounting and driving the cutter, when a horizontal milling machine of the column-and-knee type is used, although some cutters or mills are made with a taper shank which is inserted directly in the spindle *S*. When an arbor is placed in the machine, its outer end, in some instances, is supported by a center (similar to a lathe center), which is inserted in the centered end of the arbor as shown at *A* in Fig. 4. Another method of supporting the arbor, which is very common, is shown at *B*. In this case, the arbor passes through a bearing in the arm. The particular machine shown in Fig. 3 has an arm containing a center and also a bearing, so that the arbor can be supported in whichever way is most convenient. The inner end of the arbor has a taper shank which fits the spindle hole, and it is usually locked with the spindle, either by a flat tang at the end or by a draw-in bolt which passes through the spindle and holds the arbor tightly in the taper hole. An arbor having a tang *t* is shown at *A*, Fig. 4, and the style having a draw-in bolt *d* is illustrated at *B*. The latter form also has a collar *g* with flattened sides which engage a slot cut in the end of the spindle, thus giving a strong, positive drive. This particular style of arbor is removed by forcing nut *e* against the end of the spindle.

The cutter *c* is clamped between cylindrical bushings *w* which are placed on the arbor and tightened by nut *n*. These bushings are of different lengths, so that the lateral position of the cutter can be varied. Many small cutters are driven simply by friction, but medium and large sizes, especially when used for taking deep roughing cuts, are mounted on splined arbors, and keys are used to give a positive drive and prevent the cutter from slipping. The cutter should always

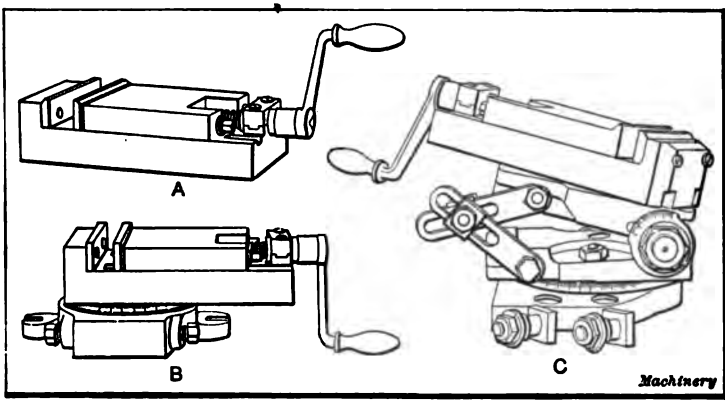

Fig. 5. Milling Machine Vises

be placed as near the spindle as circumstances will permit, in order to give a strong drive and reduce the torsional strain on the arbor.

Holding Work on the Milling Machine

The next thing to consider is the method of holding or fastening the part while it is being milled. In this case, the block is clamped between the jaws of a vise *V* (see Fig. 3), which, in turn, is bolted to the table of the machine. Vises are frequently used for holding small pieces, but are not suitable for many classes of work. The proper method of clamping, in any case, is governed by the size of the work, its shape, and the nature of the milling operation. The number of duplicate parts required should also be taken into consideration. Some pieces are clamped directly to the machine table which has T-slots for receiving the clamping bolts. It is necessary, of course, that the work be held securely enough to prevent its shifting when a cut is being taken, and it is equally important that it should be supported so as to overcome any springing action due either to its own weight or to the pressure of the cut Some parts are also sprung out of shape by applying the clamps improperly or by omitting to place supports under some weak or flexible section; as a result, the milled surface is not true after the clamps are removed and the casting springs back to its natural shape. Generally speaking, work should be clamped more securely for milling than for planing, because the pressure of the cut, when milling, is usually greater than when planing, although this depends altogether upon the depth of the cut and the size of the cutter.

Three types of milling machine vises which are commonly used, are shown in Fig. 5. The one illustrated at *A* is called a plain vise. It is held to the table by a screw which passes through the vise bed and threads into a nut inserted into one of the table T-slots. This same style is also made with flanges so that it can be secured by ordinary clamps. The vise shown at *B* has a swiveling base and it can be adjusted to any angle in a horizontal plane, the posisition being shown by graduations. This adjustment is used for angular milling. The vise shown at *C* is known as the universal type. It can be swiveled in a horizontal plane and can be set at any angle up to 90 degrees in a vertical plane, the position, in either case,

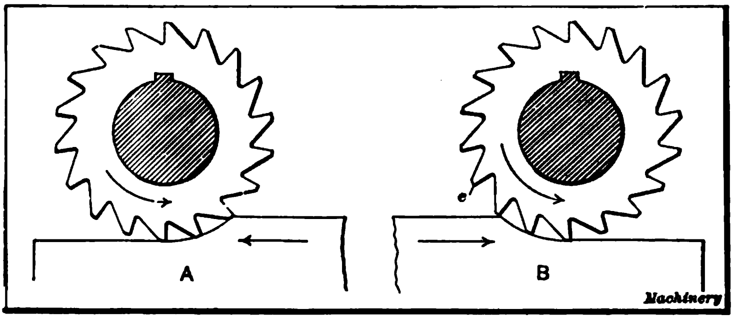

Fig. 6. (A) Work feeding against Rotation of Cutter. (B) Work feeding with Rotation of Cutter

being shown by graduations. The hinged knee which gives the vertical adjustment, can be clamped rigidly by the nut on the end of the bolt forming the hinge, and by bracing levers at the left which are fastened by the bolts shown. This style of vise is used principally by die- and tool-makers, and, owing to its universal adjustment, can often be utilized in place of a jig or fixture. When large quantities of duplicate pieces are to be milled, they are usually held in special fixtures which are so designed that the work can quickly be clamped in position for milling. The arrangement or form of a fixture depends, of course, on the shape of the part for which it is intended and the nature of the milling operation. A number of different fixtures will be shown in connection with the examples of milling given in succeeding chapters.

Direction of Feeding Movement and Relative Rotation of Cutter

After the cutter is mounted on the arbor and the part is clamped to the table, we are ready to begin milling. Before starting a cut, the table is shifted lengthwise and crosswise, if necessary, until the cutter is at one end of the work. The knee *K*, (Fig. 2) with the table, is then raised sufficiently to give the required depth of cut, and the trip-dog at the front of the table is set to disengage the power feed after the cut is completed. The longitudinal power feed for the table is then engaged, and the part *W* feeds beneath the revolving cutter *C*, which mills a flat surface.

By referring to Fig. 6, it will be seen that the direction of the feeding movement might be either to the right or left, as indicated at *A* and *B*. When the cutter rotates as shown at *A*, the part being milled feeds *against* the direction of rotation, whereas at *B*, the movement is *with* the cutter rotation. In the first case, the cutter tends to push the work away, but when the relative movements are as at *B*, the cutter tends to draw the part forward, and if there is any backlash or lost motion between the table feed-screw and nut, this actually occurs when starting a cut; consequently, the cutter teeth which happen to be in engagement, take deeper cuts than they should, which may result in breaking the cutter or damaging the work. Therefore, the work should ordinarily feed *against the rotation of the cutter.* When milling castings which have a hard sandy scale, the cutting edges of the teeth will also remain sharp for a longer period when feeding against the rotation, as at *A*. This is because the teeth move up through the metal and pry off the scale from beneath, whereas at *B*, the sharp edges *e* strike the hard scale each revolution, which dulls them in a comparatively short time. Occasionally, a part can be milled to better advantage by feeding it with the cutter. This is especially true when the work is frail and cannot be held very securely, because a cutter rotating as at *B* tends to keep the work down, whereas the upward movement at *A* tends to lift it. When the work moves with the cutter, the table gib-screws should be set up tighter than usual to prevent a free movement of the table, because this would allow the cutter teeth to "dig in" at the beginning of the cut. Some machines are designed to prevent this, and counterweights are sometimes used to hold the table back.

It should be mentioned that a cutter does not always rotate in the direction shown at *A* and *B*. If it were turned end for end on the arbor, thus reversing the position of the teeth, the rotation would have to be in a clockwise direction, and the feeding movement to the right. A cutter which rotates to the right (clockwise), as viewed from the spindle side, is said to be right-hand, and, inversely, a left-hand cutter is one that turns to the left (counter-clockwise) when milling.

The Cutting Speed and Feed

The proper speed for the cutter, and the feeding movement of the work for each revolution of the cutter, are governed by so many different things that no definite rule can be given to determine just what the speed and feed should be unless the conditions are known. The speed of the cutter depends partly on the kind of material being milled. Tool steel cannot be cut as fast as soft machine steel or cast iron, and brass can be milled at much higher speed. The condition of the cutter also affects the speed, it being possible to operate a sharp cutter faster than a dull one, because the dull edges generate an excessive amount of heat. When milling steel or wrought iron, the application of a lubricant to the cutter enables higher speeds to be used. Lard oil or any animal or fish oil is used as a lubricant, and some manufacturers mix mineral oil with lard or fish oil. The lubricant is usually applied to the cutter through a pipe or spout which can be adjusted to the proper position. Some machines have a special pump for supplying the lubricant, and others are equipped with a can from which the lubricant flows to the cutter by gravity. Cast iron and brass are milled dry.

A general idea of the speeds that are feasible when using carbon steel cutters may be obtained from the following figures which repre-

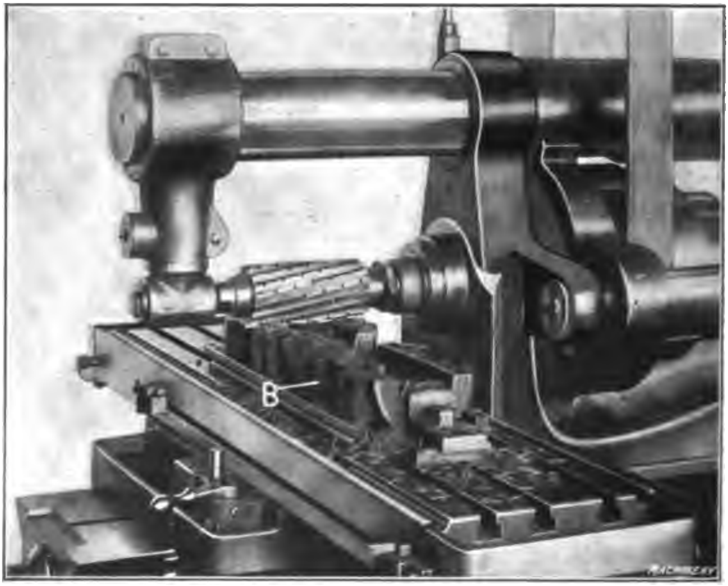

Fig. 7. Milling Cast-iron Bearing Caps

sent the velocity (in feet per minute) at the circumference of the cutter. For taking roughing cuts: for cast iron, 40 feet per minute; for machine steel, 60 feet per minute; for tool steel, 25 feet per minute; and for brass, 75 feet per minute. Finishing cuts are to be taken at speeds varying from 50 to 55 feet for cast iron; 75 to 80 feet for machine steel; 30 to 35 feet for tool steel; and 95 to 100 feet for brass. These figures are not given as representing the maximum speeds that can be used successfully, even with ordinary carbon cutters, and with high-speed steel cutters they can be doubled, owing to the superior cutting qualities of high-speed steel.

The distance that the work feeds per revolution of the cutter must also be varied to suit conditions. When milling cutters were first made, they had fine, closely-spaced teeth between which the chips clogged, thus preventing any cutting action except with fine feeds. Modern cutters, however, have much coarser teeth and, consequently, deeper cuts and heavier feeds can be used. Aside from the question of cutter design, the feed is affected by the depth of the cut, the kind of material being milled, the quality of the finish required, and the rigidity of the work. As a general rule, a relatively low cutting speed and a heavy feed is used for roughing, whereas for finishing, the speed is increased and the feed diminished. The data given in connection with some of the examples of milling referred to in this treatise, will show, in a general way, what speeds and feeds are practicable when using a well-built machine and modern cutters.

Milling Cast-iron Bearing Caps

Another example of milling which is similar in principle to the one illustrated in Fig 3, is shown in Fig. 7. The operation is that of milling flat surfaces on the edges of cast-iron bearing caps *B*. Two of these caps are placed in line and milled by one passage of the cutter. They are mounted on parallel strips placed under the bolt lugs on the side and are held by ordinary clamps as shown. The cutter used is cylindrical in form and has helical or "spiral" teeth which are nicked at intervals along the cutting edges in order to break up the chips and reduce the power required for driving. The proper depth of cut is obtained by adjusting the knee vertically, and then the edges are milled by traversing the castings beneath the revolving cutter. By clamping two of the castings in line and milling them together, they are finished, of course, more quickly than if one were machined at a time. The following figures will give a general idea of the feeds and speeds used for this particular operation. The cutter is 3 inches in diameter and rotates 53 revolutions per minute. The average depth of cut is about ⅛ inch and the table feeds 0.250 inch per revolution of the cutter or over 13 inches per minute. This cutter is made of high-speed steel and, therefore, can be run faster without injuring the cutting edges, than if made of ordinary carbon steel.

CHAPTER III

DIFFERENT TYPES OF MILLING CUTTERS

As the processes of milling can be applied to an almost unlimited range of work, the cutters used on milling machines are made in a great variety of forms. Some of the different types can be used for general work of a certain class, whereas other cutters are made especially for milling one particular part. Of course, the number of different types that are used on any one machine, depends altogether on the variety of milling operations done on that machine. When

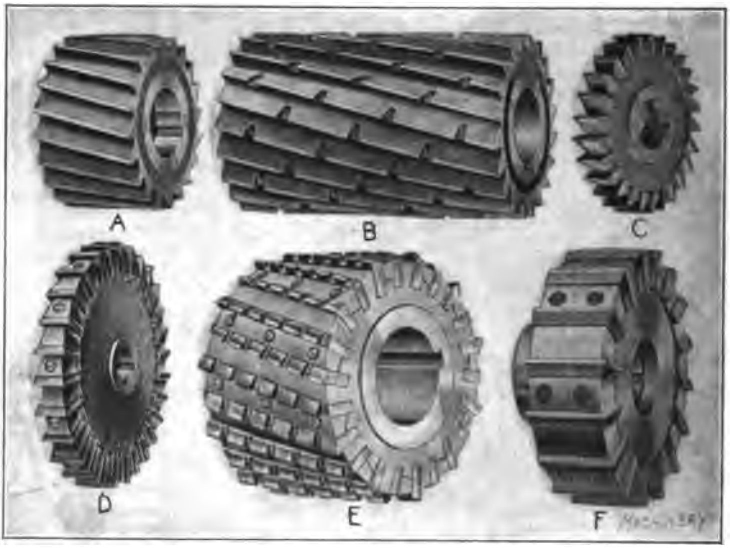

Fig. 8. Cylindrical, Side, and Face Milling Cutters

the nature of the work varies widely, the stock of cutters must be comparatively large, and, inversely, when a machine is used for milling only a few parts, a large cutter equipment is not necessary.

A number of different types of cutters in common use are shown in Figs. 8, 9, and 10. The form illustrated at *A*, Fig. 8, is called a cylindrical or plain cutter. This form is used for producing flat surfaces and it is made in various diameters and lengths. Another cutter of the cylindrical type is shown at *B*. This differs from cutter *A* in that the teeth are nicked at intervals along the cutting edges. The idea in nicking the teeth is to break up the chips, as previously mentioned. This enables heavier or deeper cuts to be taken with the same expenditure of power; hence, the nicked cutter is extensively used for roughing cuts. It will be noted that the teeth of these two cutters are not parallel with the axis, but are helical or "spiral."

Cutters having helical teeth are generally used in preference to the type with straight or parallel teeth, especially for milling comparatively wide surfaces, because the former cut more smoothly. When teeth are parallel to the axis, each tooth begins to cut along its entire width at the same time; consequently, if a wide surface is being milled, a shock is produced as each tooth engages the metal. This difficulty is not experienced with helical teeth which, being at an angle, begin to cut at one side and continue across the work with a smooth shaving action. Helical cutters also require less power for driving and produce smoother surfaces.

A side milling cutter is shown at *C*. This type has teeth on both sides, as well as on the periphery, and it is used for cutting grooves

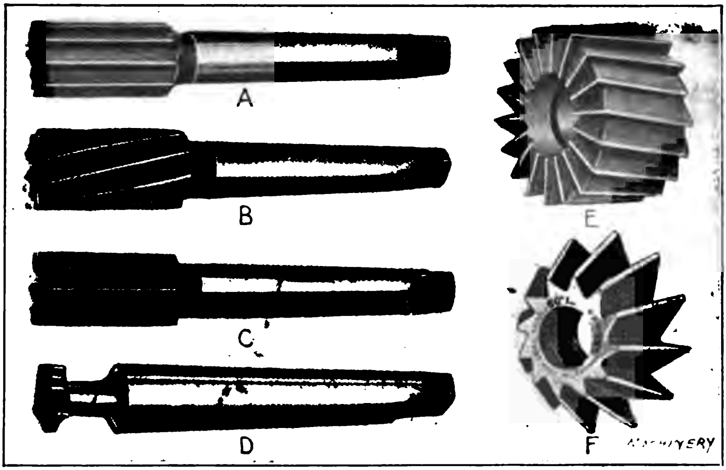

Fig. 9. End Mills, T-slot Cutter, Shell End Mill, and Angular Cutter

or slots and for other operations, examples of which will be shown subsequently. The sides of this form of cutter are recessed between the hub and inner ends of the teeth, in order that they will clear a surface being milled. Two side mills are often mounted on the same arbor and used in pairs for milling both sides of a part at the same time. This type of cutter is also employed in conjunction with other forms for milling special shapes, as will be shown later. Another side milling cutter is shown at *D*. This mill, instead of being made of one solid piece of steel, has a cast-iron body into which tool steel teeth are inserted. These teeth fit into slots and they are held in place by flat-sided bushings which are forced against them by the screws shown. There are many different methods of holding teeth in cutters of this type. The inserted-tooth construction is ordinarily used for large cutters, in preference to the solid form, because it is cheaper, and the inserted teeth can readily be replaced when necessary. When solid cutters are made in large sizes, there is danger of their cracking while being hardened, but with the inserted-tooth type, this is eliminated. A large cylindrical cutter with inserted teeth is shown at *E*. The cutter illustrated at *F* also has inserted teeth and is called a face milling cutter. This form is especially adapted to end or face milling operations. When in use, the cutter is mounted on a short arbor which is inserted in the milling machine spindle.

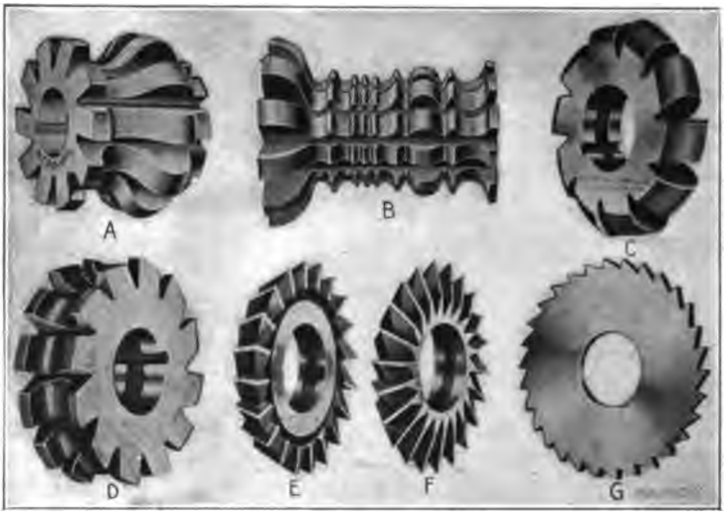

Fig. 10. Formed Cutters, Angular Cutters, and Slitting Saw

The three cutters, *A*, *B*, and *C*, Fig. 9, are called end mills because they have teeth on the end as well as on the periphery or body; hence, they can cut in an endwise as well as a sidewise direction. These mills, instead of being mounted on an arbor, have taper shanks which are driven into a hole of corresponding taper in the machine

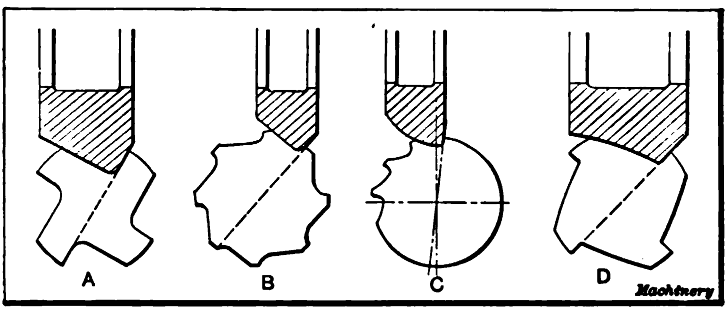

Fig. 11. Diagrams illustrating use of Formed Cutters for fluting Taps, Reamers, etc.

spindle. The shanks have a flat end or tang which engages a slot in the spindle and prevents the mill from slipping when taking a cut. The mill shown at *A* has straight teeth, whereas the form *B* has spiral teeth. The type shown at *C* is adapted to slot milling, especially when it is necessary to cut in to the required depth with the end of the mill, because the inner ends of the teeth are sharp, and can more readily cut a path from the starting point.

The cutter illustrated at *D* is a special form used for cutting T-slots, after the central groove has been milled. The larger sizes of end mills do not have solid taper shanks, but are made in the form of shells (as at *E*) which are fastened to an arbor that serves as a shank.

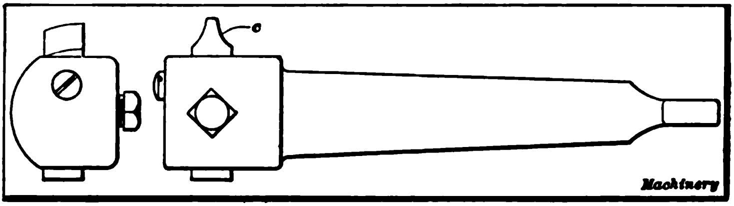

Fig. 12. Fly-cutter and Arbor

This arbor has a taper end that fits the machine spindle, and the mill is attached to the outer end which is equipped with a driving key that engages a slot cut across the inner end of the mill. This type of cutter can often be used when a long arbor with an outboard support would be in the way. The angular cutter *F* has teeth which are at an angle of 60 degrees with the axis. This form is used for milling dovetailed slots and for similar work. The particular style shown has a threaded hole and it is screwed onto an arbor.

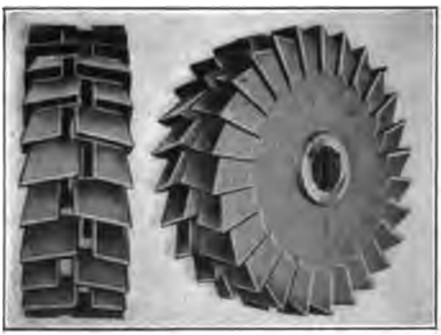

Fig. 13. Interlocking Side Milling Cutter

The two cutters illustrated at *A* and *B*, Fig. 10, are examples of formed milling cutters. The cutting edges of this type are made to the same shape as the profile of the piece to be milled. The small parts of sewing machines, guns, typewriters and other pieces having an irregular and intricate shape, are milled with formed cutters. The teeth of these cutters are "backed off" so that they can be sharpened without changing the profile, provided the front faces are ground radial. The convex and concave cutters, *C* and *D*, which are also of the formed type, are for milling half-circles, one cutting half-round grooves and the other, forming half-round edges. Formed cutters are made in a great variety of shapes and they are used for many different purposes. The diagrams, Fig. 11, illustrate how formed cutters are used for fluting taps, reamers, and four-lipped drills. Sketch *A* shows how the grooves or flutes are cut in a tap. As will be seen, the groove is milled to the same shape as the cutter. The sketches at *B* and *C* show cutters of different shapes for fluting reamers, and *D* illustrates how the grooves are cut in four-lipped twist drills, of the type used in screw and chucking machines for roughing out holes prior to reaming. The angular cutters, *E* and *F* (Fig. 10), are used extensively for forming teeth on milling cutters. The style *E* is employed for cutting straight teeth, whereas the double-angle cutter *F* is especially adapted to milling spiral grooves. The thin cutter illustrated at *G* is known as a slitting saw, and it is used for milling narrow slots, cutting off stock, and for similar purposes.

Fig. 12 shows a simple type of cutter that is often used for operations that will not warrant the expense of a regular formed cutter. This is called a fly-cutter. The milling is done by a single tool *c* which has the required outline. This tool is held in an arbor having

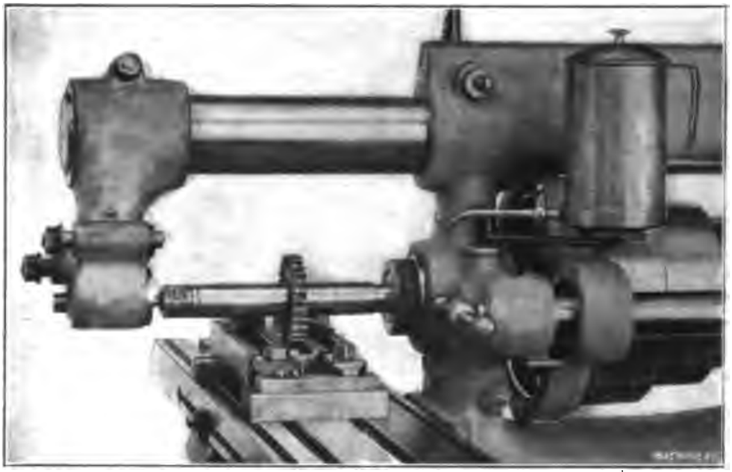

Fig. 14. Milling Groove with Interlocking Cutter

a taper shank the same as an end mill. The advantage of the fly-cutter is that a single tool can be formed to the desired shape, at a comparatively small expense.

The milling cutter shown in Fig. 13 is similar to a side mill, but it is composed of two units instead of being made of one solid piece of steel. These two sections are joined as shown by the view to the left, there being projections on each half which engage corresponding slots in the other half, thus locking both parts together. This type of cutter is largely used for milling grooves or slots, because as the side teeth wear or are ground away, the two sections of the mill can be spread apart by washers in order to maintain a standard width. An example of slot milling with an interlocking cutter is shown in Fig. 14. The cutter is mounted on an arbor the same as a regular side mill, and the part to be grooved is bolted directly to the table, one end being supported on parallel strips. When it is necessary to mill a large number of grooves to a standard size, the interlocking cutter is the best type to use, owing to its adjustment for width.

CHAPTER IV

FORM MILLING—STRADDLE AND GANG MILLING—END MILLING

One of the great advantages of the milling process is that duplicate parts having intricate shapes can be finished within such close limits as to be interchangeable. Because of this fact, milling machines are widely used for manufacturing a great variety of small machine parts having an irregular outline. The improved high-speed steel cutters now used, and the powerful machines which have been de-

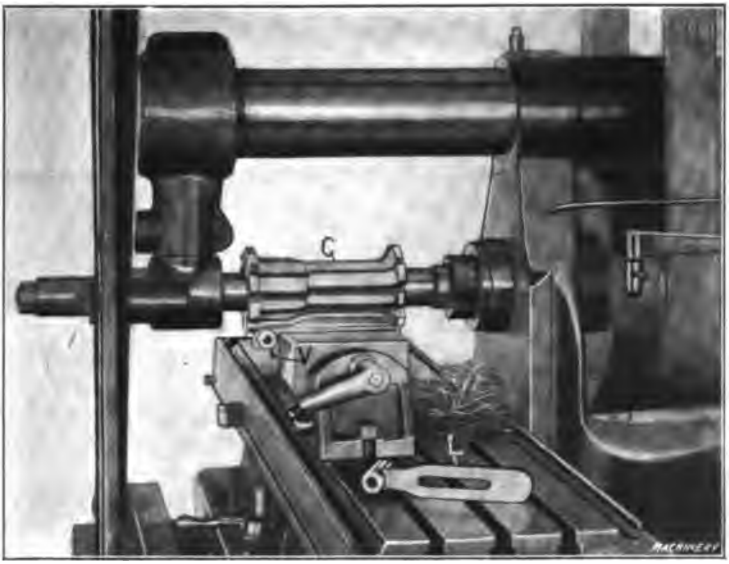

Fig. 15. Example of Form Milling

veloped for driving these cutters, also make it possible to machine many heavy parts more rapidly by milling than in any other way.

When pieces having an irregular outline are to be milled, it is necessary to use a cutter having edges which conform to the profile of the work. Such a cutter is called a form or formed cutter, as explained in Chapter III. There is a distinction between a *form* cutter and a *formed* cutter, which according to the common use of these terms is as follows: A formed cutter has teeth which are so relieved or "backed off" that they can be sharpened by grinding, without changing the tooth outline, whereas the term form cutter may be applied to any cutter for form milling, regardless of the manner in which the teeth are relieved.

An example of form milling is illustrated in Fig. 16, which shows a steel piece *W* having an irregular edge which is milled by form cutter *C*. The part *W* is held in a vise which is equipped with special false jaws having the samo outline as the work, to provide a more rigid support. These special jaws are attached to the vise in place of the regular jaws, which are removable. When the cutter feeds across the work, its form is reproduced. A large number of duplicate parts can be milled in a comparatively short time, in this way.

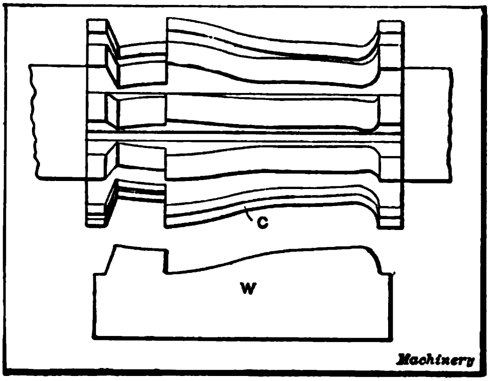

Fig. 16. Formed Cutter for Milling Part W

Of course, form milling is not economical, unless the number of parts wanted is sufficient to warrant the expense of the formed cutter. Another form milling operation is shown in Fig. 15. The small levers *L* are finished on the edges to the required outline by cutter *C*. These levers are malleable castings and they are held in a vise *V* attached

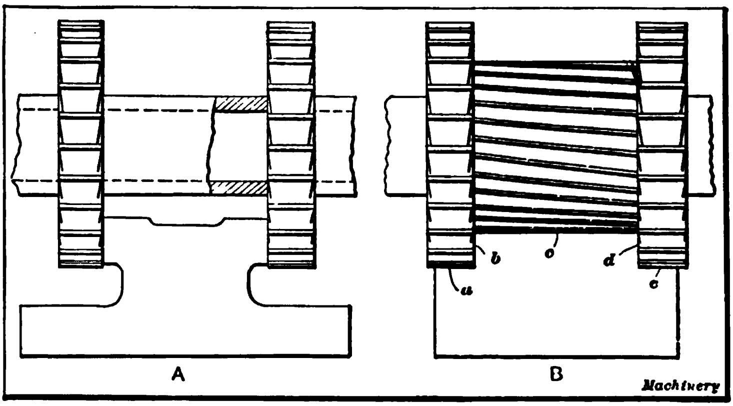

Fig. 17. (A) Straddle Milling. (B) Gang Milling

to the table. When milling, the cutter makes 50 R. P. M. and the feed is 0.053 inch, giving a table travel of 2.65 inches per minute.

Straddle and Gang Milling

When it is necessary to mill opposite sides of duplicate parts so that the surfaces will be parallel, two cutters can often be used simultaneously. This is referred to as straddle milling. The two cutters which form the straddle mill, are mounted on one arbor, as shown at *A*, Fig. 17, and they are held the right distance apart by one or more collars and washers. Side mills which have teeth on the sides as well as on the periphery (as shown at *C* and *D*, Fig. 8), are used for work of this kind. Duplicate pieces can be milled very accurately by this method, the finished surfaces being parallel and

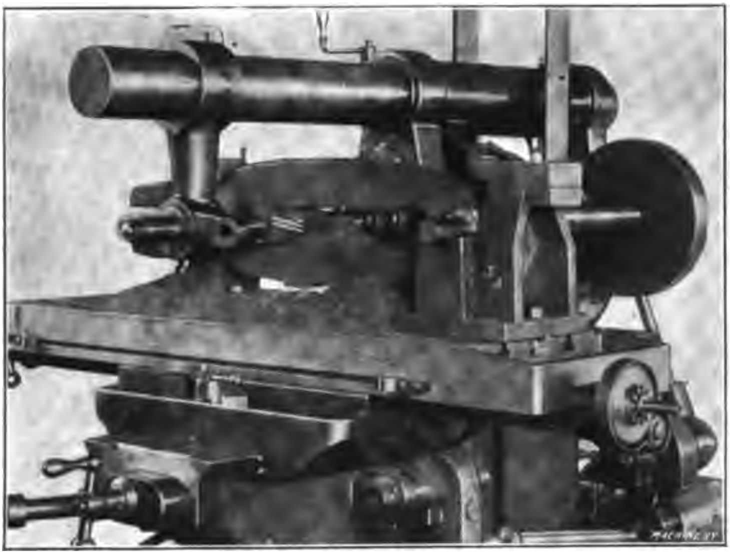

Fig. 18. Milling Slot of Crank-shaper Rocker-arm

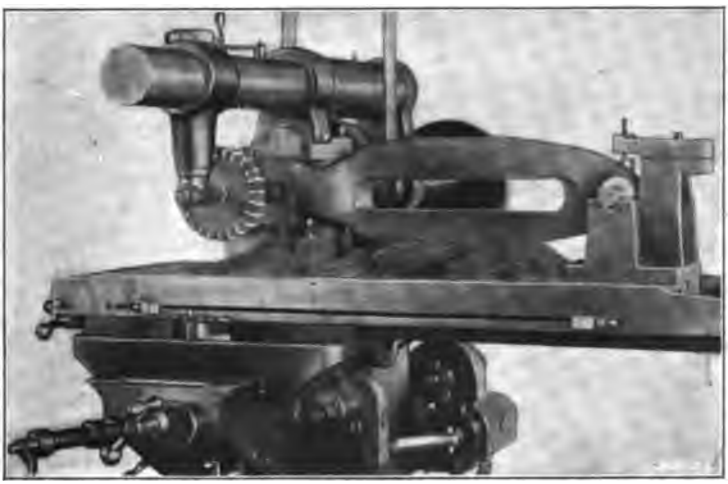

Fig. 19. Finishing End of Rocker-arm with Straddle Mill

to a given width within close limits. If the proper distance between the cutters cannot be obtained with the arbor collars available, fine adjustments are made by using metal or paper washers. When considerable accuracy is necessary, the final test for width should be made by taking a trial cut and measuring the finished surface. When the teeth on one side of each mill become dull, the opposite sides can be used by placing the right-hand cutter on the left-hand side and *vice versa;* that is by exchanging the positions of the mills on the arbor.

Figs. 18 and 19 show how the rocker-arm of a crank-shaper is finished by milling. This work requires two operations, one of which is a good example of straddle milling. A cylindrical cutter is used to mill both sides of the central slot, as shown in Fig. 18. The short slot at the left end of the rocker-arm is also milled by this same

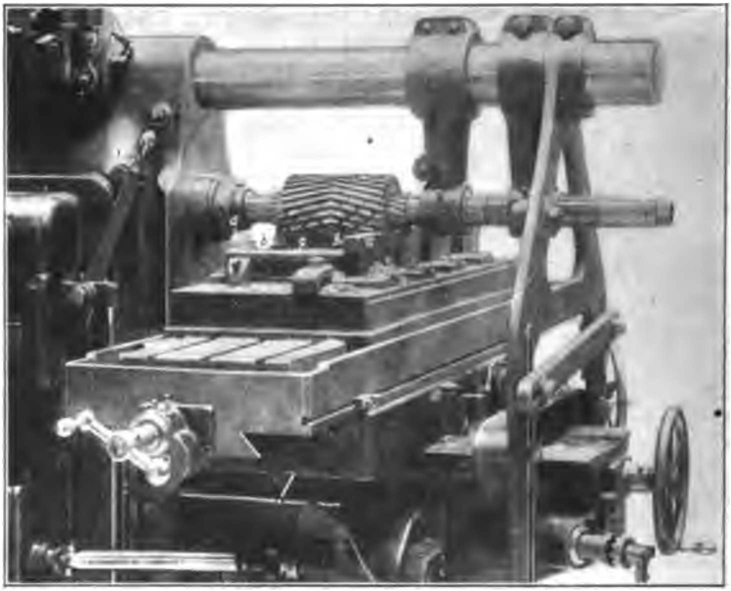

Fig. 20. Example of Gang Milling

cutter, as well as the raised pads on the top and bottom of the arm. This cutter is 2¾ inches in diameter, and when milling the long central slot, a 1/16 inch cut is taken at the top and bottom with a feed of 3 inches per minute. The second operation consists in milling the sides of the slotted end, as shown in Fig. 19. Two 8½-inch cutters of the inserted-tooth type, are used to form a straddle mill, which machines both sides at the same time. The time required for milling each arm is 2¼ hours. The casting is held in a special two-part fixture which is bolted to the table. That section of the fixture which supports the right-hand end, has V-shaped notches which receive a trunnion as shown, thus setting the casting vertically, whereas the left-hand end is clamped between setscrews that are adjusted to locate the casting horizontally. After this fixture is once set up and adjusted, very little time is required for setting one of these rocker-arms in position for milling, but it would be rather difficult to hold a casting of this shape by the use of ordinary clamps.

A great deal of the work done in a milling machine (especially of the plain horizontal type), is machined by a combination or "gang" of two or more cutters mounted on one arbor. This is known as gang milling. If a plain cylindrical cutter were placed between the side mills shown at *A* in Fig. 17, a gang cutter *B* would be formed for milling the five surfaces *a*, *b*, *c*, *d*, and *e*, simultaneously. This would not only be a rapid method, but one conducive to uniformity when milling duplicate parts.

An example of gang milling is shown in Fig. 20. Four castings are clamped to a fixture and are machined at one time by a gang-

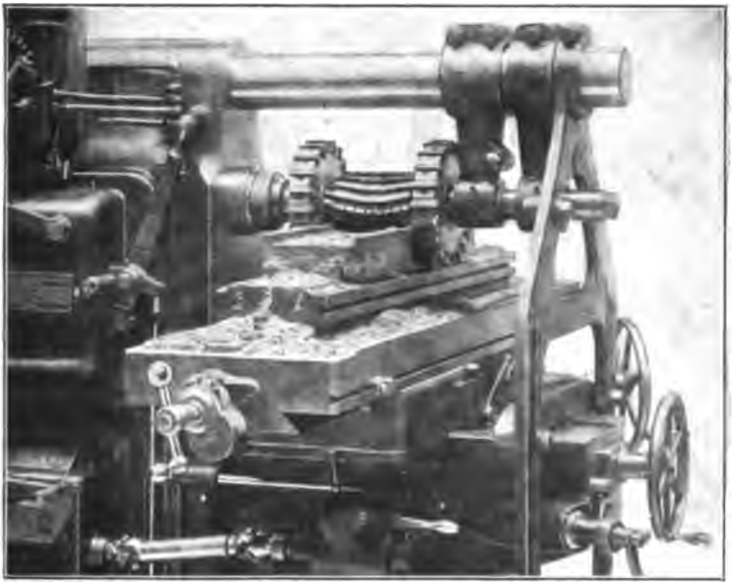

Fig. 21. Milling Top and Sides of Casting with Gang Mill

cutter which mills the top edges *a*, the inner sides *b*, and also the top surfaces *c* between the projecting ends. This cutter is formed of four independent units. The surfaces *c* are milled by two cutters of the same size, which have right- and left-hand spiral teeth, as shown, and the tops *a* of the end flanges are finished by two narrower cutters of smaller diameter. The two central cutters have a combined width of 9⅜ inches and they are 6 inches in diameter. The speed of the cutter is 32 revolutions per minute and the greatest depth of cut about 3/16 inch.

Another gang milling operation is shown in Fig. 21. The cutter, in this case, is similar to the one illustrated in Fig. 20, except that large side mills are employed for finishing the sides of the castings while the top surfaces are being milled. These side mills are 10½ inches in diameter and have inserted teeth or blades. The speed of a gang-mill which is composed of cutters that vary considerably in diameter, must be regulated to suit the largest cutters. In this instance, the cutter only makes 21 revolutions per minute, a comparatively slow speed being necessary owing to the large side mills.

Gang milling is usually employed when duplicate pieces are milled in large quantities, and the application of this method is almost unlimited. Obviously, the form of a gang-cutter and the number of cutters used, depends altogether on the shape of the part to be milled. Gang-cutters are sometimes made by combining cylindrical and formed cutters, for producing an irregular or intricate profile.

Fig. 22 shows an example of gang milling in which two castings are placed side by side and rough milled simultaneously. The gang-

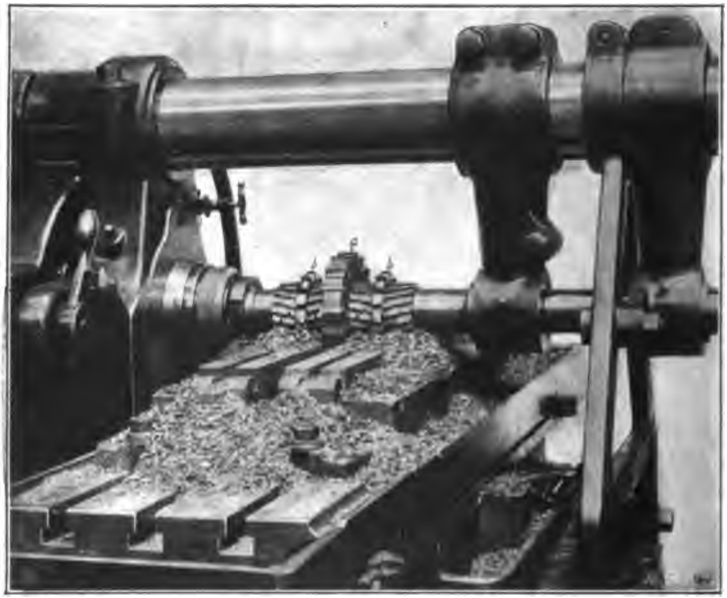

Fig. 22. Milling Two Parts Simultaneously

cutter is composed of seven units, as the illustration shows. The large inserted-tooth cutter *a* in the center mills the inner sides of each casting, while the top surfaces are machined by the four cylindrical cutters shown. The cutters *b*, placed between the cylindrical cutters, mill channels or grooves which, by another operation, are formed into T-slots. All of these cutters are made of high-speed steel and the speed is 36 revolutions per minute. The work table feeds 0.112 inch per revolution, thus giving a travel of 4 inches per minute. Two of these castings are milled in 18 minutes, which includes the time required for clamping them to the machine.

It shoulu be noted that when more than one spiral toothed cylindrical cutter is mounted on one arbor, for forming a gang-mill, cutters having both right- and left-hand spirals are used. For example the central part of the cutter shown in Fig. 20 is composed of two cutters having teeth which incline in opposite directions; that is the teeth of one cutter form a right-hand spiral and the teeth of the other cutter, a left-hand spiral. The reason why cutters of opposite hand are used, is to equalize the end thrust, the axial pressure caused by the angular position of the teeth of one cutter being counteracted by a pressure in the opposite direction from the other cutter.

Still another gang milling operation is shown in Fig. 23. In this instance, the top surface of the casting is milled and two tongue-pieces are formed by the central gang of five cutters, which are of the straight-tooth type and vary in diameter to give the required outline. The large angular mills at the ends finish the sloping sides

Fig. 23. Another Gang Milling Operation

of the casting, as the illustration indicates. The speed of rotation is 33 revolutions per minute, and the table travel, 6⅛ inches per minute. The feeding movement is to the left or against the rotation of the cutters, which is also true of Figs. 20, 21 and 22.

End and Face Milling

All of the milling operations referred to so far have been performed with cutters mounted on an arbor, the latter being driven by the spindle and supported by an out-board bearing. For some classes of work, the cutter, instead of being placed on an arbor, is attached directly to the machine spindle. End mills, for instance, are driven in this way, as previously mentioned, and large face milling cutters are also fastened to the end of the spindle. Surfaces are frequently machined by end mills, when using a horizontal milling machine, because it would not be feasible to use a cutter mounted on an arbor.

Sketch *A*, Fig. 24, illustrates how a pad or raised part on the side of a casting would be machined by an end mill. The surface is milled by the radial teeth on the end as well as by the axial teeth, as the work is traversed at right-angles to the cutter. Occasionally, an end mill is used in this way, after the top surface of a casting has been milled with one or more cutters mounted on an arbor, in order to finish the work at one setting, which not only saves time, but insures accuracy of alignment between the finished parts.

Sketch *B* indicates how an end mill is used for cutting grooves in a vertical surface. The cutter is set to the required depth by moving the table inward, and then the longitudinal feed is engaged, which causes a groove to be milled equal in width to the diameter of the

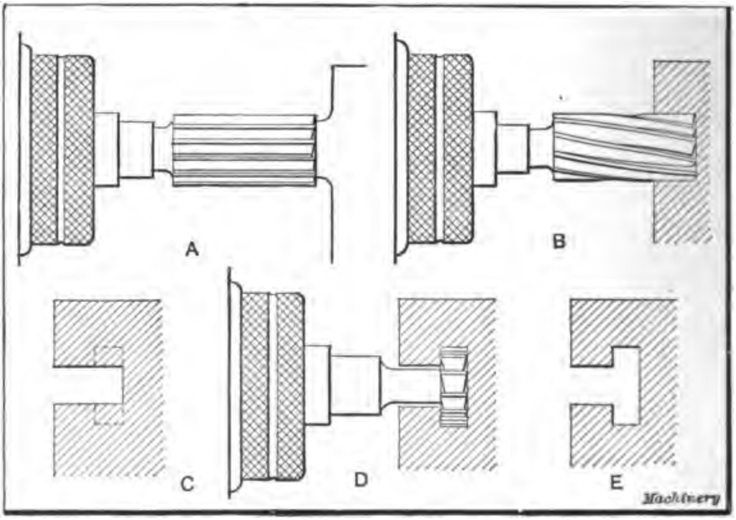

Fig. 24. End Milling—Diagrams illustrating use of T-slot Cutter

cutter. As mentioned in Chapter III, if it is necessary to start a groove by sinking the cutter in to depth, without first drilling a hole as a starting place, the form of mill shown at *C*, Fig. 9, is preferable, as the radial end-teeth have cutting edges on the inside so that they can more readily cut a path from the starting point, when the work is fed laterally. An end mill should not be used for cutting grooves or slots if a regular cutter mounted on an arbor can be employed.

When milling T-slots such as are cut in the tables of machine tools for receiving clamping bolts, a plain slot is first milled to the depth of the T-slot as shown by sketch *C*, Fig. 24. This preliminary operation is usually done with a side mill of the proper width, while the work is clamped in a horizontal position. The enlarged or T-section is then milled as shown by sketch *D*, the casting being clamped in a vertical position, provided a horizontal milling machine is employed. The T-slot cutter enlarges the bottom of the straight groove, as indicated at *E*, which shows the finished slot.

Fig. 25 shows how an end mill is used for cutting an elongated slot in a link *L*. Prior to milling, holes are drilled at each end of the slot, one of which forms a starting place for the milling cutter. The link is held in a vise and the metal between the two holes is

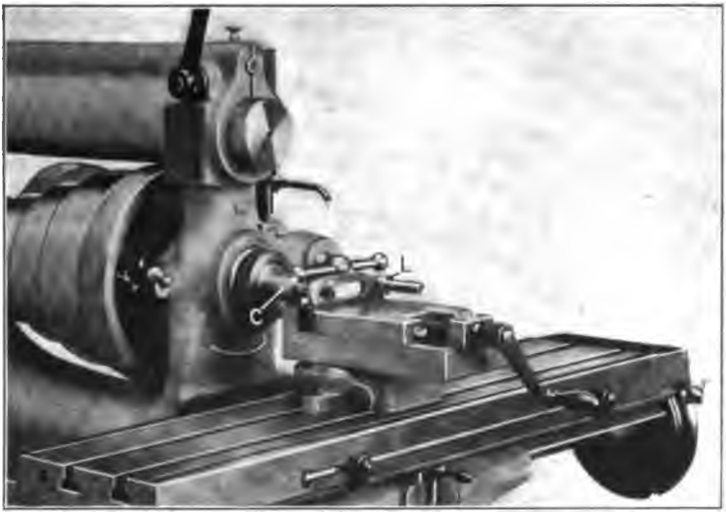

Fig. 25. Milling Slot with End Mill

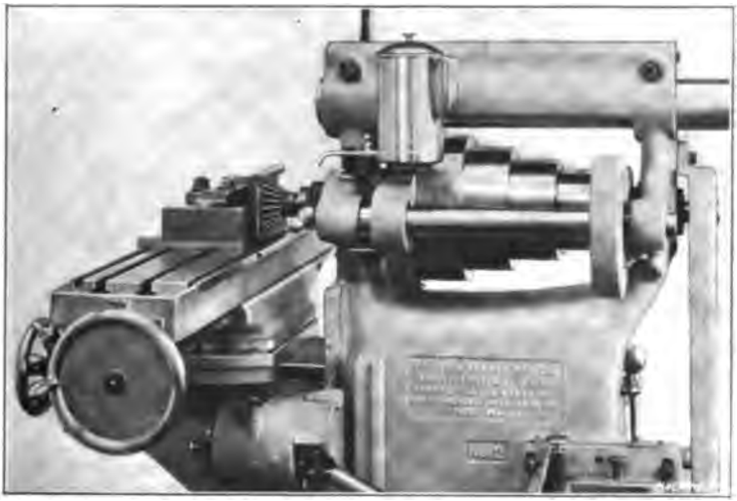

Fig. 26. Milling a Dovetail Groove

cut away to form the slot, by feeding the table lengthwise. By means of the automatic stop, the feed is disengaged when the cutter has reached the end of the slot. The shank of the end mill is not inserted directly into the spindle of the machine, but into a reducing collet *C*. This collet fits into the taper hole of the spindle and is bored out to receive the end mill, the shank of which is too small to be placed directly in the spindle.

One method of machining a dovetail groove for a slide is shown in Fig. 26, which illustrates another end milling operation. The cutter used for this work has radial teeth on the end, and also angular teeth which incline 30 degrees with the axis of the cutter. The radial end teeth mill the bottom or flat surface of the groove and the angular teeth finish the sides and form the dovetail. The way the casting is clamped to the table is plainly shown by the illustration. The cutter is mounted on an arbor which is inserted in the spindle.

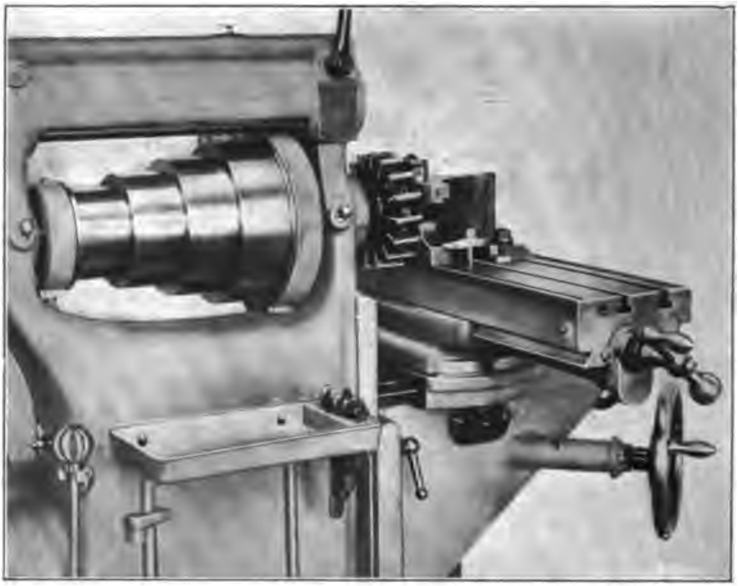

Fig. 27. Finishing Vertical Surface with Face Mill

An end milling operation is shown in Fig. 27, which differs from those previously referred to, in that a large face cutter is used, which, in this instance, is screwed onto the end of the spindle. Large face mills are employed on horizontal machines for milling flat surfaces that lie in a vertical plane. Some cutters of this type, instead of being threaded directly to the spindle, are mounted on a short arbor, whereas other designs fit over interchangeable sleeves threaded to the spindle. The casting illustrated in Fig. 27 is clamped against an angle-plate to hold it securely, and a strap at the rear prevents it from shifting backward when a cut is being taken. The surface is milled by feeding the table longitudinally, and only one cut is necessary, as the work is finished afterward by a surface grinder. The number of cuts required, when milling, is governed by the amount of metal to be removed and also by the accuracy of the work, as well as the quality of finish desired.

CHAPTER V

UNIVERSAL MILLING MACHINE

The milling machine illustrated in Fig. 28 is referred to as a universal type, because it is adapted to such a wide variety of milling operations. The general construction is similar to that of a plain milling machine, although the universal type has certain adjustments and attachments which make it possible to mill a greater variety of work. On the other hand, the plain machine is more simple, and, for a given size, more rigid in construction; hence, it is better adapted for milling large numbers of duplicate parts in connection with manufacturing operations.

The universal machine has a column *C*, a knee *K* which can be moved vertically on the column, and a table with cross and longitudinal adjustments the same as a machine of the plain type. There is a difference, however, in the method of mounting the table on the knee. As explained in Chapter I, the table of a plain machine is carried by a saddle *Z* (see Fig. 2), which is free to move in a crosswise direction, whereas, the table"s line of motion is at right angles to the spindle. The table of a universal machine also has these movements, and, in addition, it can be fed at an angle to the spindle by swiveling saddle *Z*, Fig. 28, on clamp-bed *B*, which is interposed between the saddle and knee. The circular base of the saddle has degree graduations which show the angle at which the table is set. When the zero mark of these graduations coincides with the zero mark on the clamp-bed, the table is at right angles to the spindle. The saddle is held rigidly to the clamp-bed, in whatever position it may be set, by bolts which must be loosened before making an adjustment. The utility of this angular adjustment will be explained later in connection with examples of universal milling operations.

The feed motion is derived from the main spindle, which is connected with the feed change mechanism enclosed at *F* by a chain and sprockets located inside of the column. The power is transmitted from *F* to gear-case *A* containing the reverse mechanism operated by lever *R*, which serves to start, stop, or reverse all feeds. Levers *T* and *V* control the automatic transverse and vertical feeds, respectively, and the longitudinal feed to the table is controlled or reversed by lever *L*. The longitudinal feed is automatically tripped by the adjustable dogs or tappets *D*. The vertical feed also has an automatic trip mechanism operated by dogs D_1. The table can be traversed by handles at each end and the cross movement is effected by wheel *E*. The vertical hand adjustment for the knee is controlled by handwheel *G*, which operates a telescopic elevating screw *H*. Adjustable dials, graduated to thousandths of an inch, indicate the longitudinal, traverse and vertical movements of the table. The spindle on this

machine is driven by pulley *P*. Speed changes are obtained by shifting levers *O*, *Q* and *S*, and the speed obtained for any position of the levers is shown by a table or plate attached to the column. The machine is started or stopped by lever *U* which operates a clutch that engages or disengages belt pulley *P*. There is an outboard support for the arbors, having a bronzed-bush bearing and also an ad-

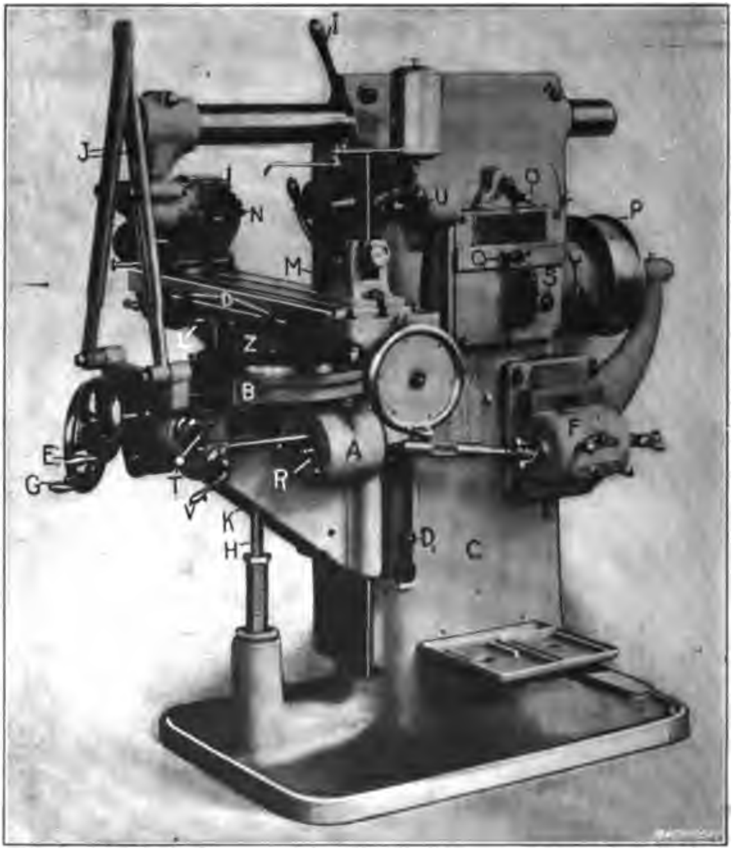

Fig. 28. Brown & Sharpe Universal Milling Machine

justable center (similar to a lathe center), which is inserted in the centered end of the arbor when in use. The overhanging arm is rigidly clamped in any position by lever *I*, and it can be pushed back out of the way when the arbor support is not needed. The arm braces *J* are attached to a clamp fastened to the top of the knee.

Indexing or Spiral Head

We have now considered, in a general way, the principal features of a universal machine, so far as the machine itself is concerned, but before referring to its practical application, the construction and

use of the attachment seen at *N* should be explained. This attachment is called the spiral or indexing head and it forms a part of the equipment of all milling machines of the universal type. The spiral head, when in use, is bolted to the table of the machine. It is employed in connection with the foot-stock *M*, when milling work that must be supported between the centers. The spiral head is also used independently, that is, without the foot-stock, in which case the work is usually held in a chuck attached to the spindle. By means of the spiral head, the circumference of a cylindrical part can be divided into almost any number of equal spaces, as, for example, when it is necessary to cut a certain number of teeth in a gear. It is also used for imparting a rotary motion to work, in addition to the longitudinal feeding movement of the table, for milling helical or spiral grooves.

As a great deal of the work done in a universal milling machine requires a spiral head, its construction and operation should be thoroughly understood. The general arrangement of the design used on Brown & Sharpe machines is shown in Fig. 29. The main spindle *S* has attached to it a worm-gear *B* (see the cross-sectional view) which meshes with the worm *A* on shaft *O*, and the outer end of this shaft carries a crank *J* which is used for rotating the spindle when indexing. Worm-wheel *B* has forty teeth and a single-threaded worm *A* is used, so that forty turns of the crank are required to turn spindle *S* one complete revolution; hence, the required number of turns to index a fractional part of a revolution is found by simply dividing forty by the number of divisions desired. (As there are different methods of indexing, this subject is referred to separately to avoid confusion). In order to turn crank *J* a definite amount, a plate *I* is used, having several concentric rows of holes that are spaced equidistant in each separate row. When indexing, spring-plunger *P* is withdrawn by pulling out knob *J* and the crank is rotated as many holes as may be required. The number of holes in each circle of the index plate varies, and the plunger is set in line with any circle by adjusting the crank radially. One index plate can be replaced by another having a different series of holes, when this is necessary in order to obtain a certain division.

Sometimes it is desirable to rotate the spindle *S* independently of crank *J* and the worm gearing; then worm *A* is disengaged from worm-wheel *B*. This disengagement is effected by turning knob *E* about one-quarter of a revolution in a reverse direction to that indicated by the arrow stamped on it, thus loosening nut *G* which holds eccentric bushing *H*. Both knobs *E* and *F* are then turned at the same time, which rotates bushing *H* and throws worm *A* out of mesh. The worm is re-engaged by turning knobs *E* and *F* in the direction of the arrow; knob *E* should then be tightened with a pin wrench. The worm is disengaged in this way when it is desired to index rapidly by hand, and when the number of divisions required can be obtained by using plate *C*. This plate is attached to the spindle and contains a circle of holes which are engaged by pin *D*, operated by lever D_1, (see cross-section). This direct method of indexing can often be employed to advantage when milling flutes, reamers, taps, etc., but, as only a limited number of divisions can be obtained by this method, it is necessary to use crank *J* and index plate *I* for most of the work requiring indexing.

When the spiral head is used in connection with the milling of helical grooves (which are commonly but erroneously called spiral grooves), the main spindle *S* is rotated slowly by change gears as

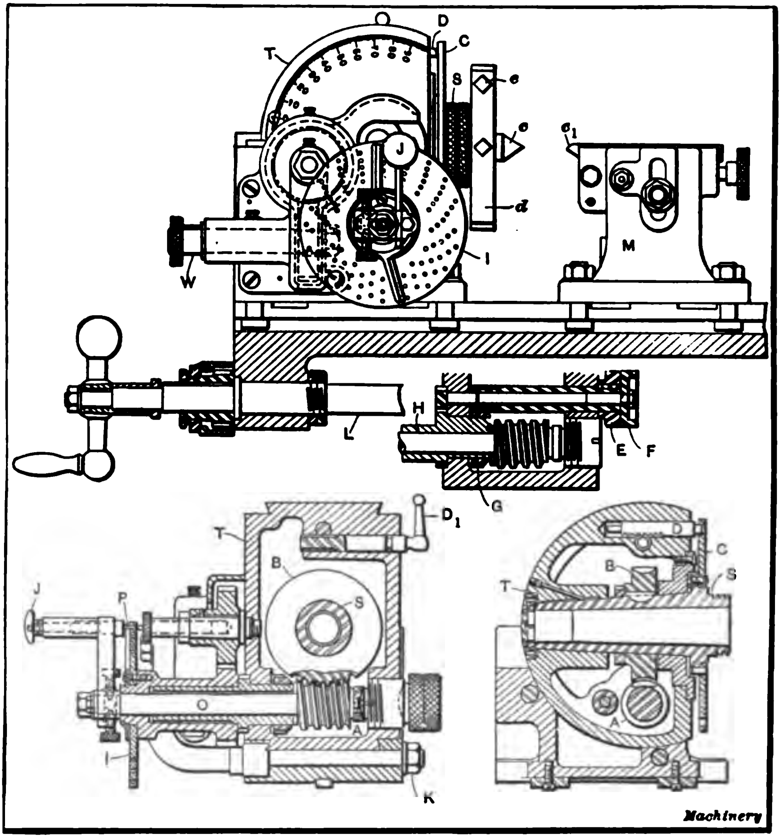

Fig. 29. Spiral Head used for Spiral Milling and Indexing

the work feeds past the cutter. These change gears transmit motion from the table feed-screw *L* to shaft *W*, which, in turn, drives spindle *S* through spiral gears, spur gears and the worm-gearing *A* and *B*. The method of determining what size gears to use for milling a helix of given lead is explained in Part II of this treatise.

There is one other feature of the spiral head which should be referred to, and that is the angular adjustment of the main spindle. It is necessary for some classes of taper work to set the spindle at an angle with the table, and this adjustment is made by loosening bolts *K* and turning the circular body *T* in its base. The angle to which the head is set, is shown by graduations reading to ½ a degree. The spindle of this particular head can be set to any angle between 10 degrees below the horiontal and 5 degrees beyond the perpendicular. This adjustment is needed when milling taper work which must be set at an angle with the table.

The footstock *M*, which is used in connection with the spiral head when milling parts that are supported between centers, is also adjustable so that the centers c and c_1 can be aligned when milling flutes in taper reamers, etc. The foot stock center is set in line with center c, when the latter is in a horizontal position, by two taper pins on the rear side. When it is desired to set the center at an angle, these pins are removed and the nuts shown are loosened; the center can then be elevated or depressed by turning a nut at the rear, which moves the center through a rack and pinion.

Work mounted between the centers is caused to rotate with the spindle, either when indexing or when cutting helical grooves, by a dog which engages driver plate *d*. The tail of the dog should be confined by a set-screw *e*, to prevent any rocking movement of the work.

Spiral heads of different makes vary more or less in their arrangement, which is also true of milling machines, or, in fact, of any other kinds of machine tools. Machines or attachments of a given type, however, usually have the same general features, and if one or two typical designs are understood, it is comparatively easy to become familiar with other makes. Of course, the operator of any machine tool should be acquainted with its general construction, but it is even more important to have a clear understanding of its appplication to various kinds of work.

CHAPTER VI

USE OF THE SPIRAL HEAD—SIMPLE INDEXING

The spiral head is ordinarily used for such work as milling the teeth in milling cutters, fluting reamers and taps, cutting teeth in small gears, or for holding any part which must be rotated either at the time it is being milled or between successive cuts. As an example of the work that requires indexing between successive cuts, suppose we have a cylindrical milling cutter blank which requires 18 equally-spaced teeth to be cut across the circumference parallel to the axis and with the front face of each tooth on a radial line. The first step would be to press the blank on an arbor, assuming that it has previously been bored and turned to the proper diameter. The arbor and work is then placed between the centers of the spiral head and footstock, as shown in Fig. 30. After attaching a dog to the left-hand end, set-screw *e* is set against the dog to take up any play between these parts, and the footstock center is adjusted rather tightly into the center of the arbor to hold the latter securely.

The form of cutter to use is the next thing to consider. As the grooves which form the teeth are angular, the cutter must have teeth which incline to the axis a corresponding amount. A cutter of this type which is largely used for milling straight teeth, is shown at *E* in Fig. 10. The cutting edges (in this instance) have an inclination of 60 degrees with the side, and the cutter is known as a 60-degree, single-angle cutter, to distinguish it from the double-angle type, the use of which will be mentioned later. After the cutter is mounted on an arbor *b*, as indicated in Fig. 30, the straight side or vertical face is set in line with the center of the arbor as shown by the detail end-view *A*. There are several ways of doing this: A simple method is to draw a horizontal line across the end of the blank with an ordinary surface gage (the pointer of which should be set to the height of the spiral head center) and then rotate the work one-quarter of a revolution to place the line in a vertical position, after which the side of the cutter is set to coincide with this line. The side of the cutter can also be set directly by the centers. The table is first adjusted vertically and horizontally until the cutter is opposite the spiral head center. A scale or straightedge held against the side of the cutter is then aligned with the point of the center, by shifting the table laterally.

The next step is to set the cutter to the right depth for milling the grooves. The depth is regulated according to the width which the tooth must have at the top, this width being known as the land. The usual method is to raise the knee, table and blank far enough to take a cut, which is known to be somewhat less than the required depth. The blank is then indexed or turned 1/18 of a revolution (as there are to be 18 teeth) in the direction shown by arrow *a*, and a second groove is started as at *B*. Before taking this cut, the blank is raised until the required width of land is obtained. The second groove is then milled, after which the blank is again indexed 1/18 of a revolution, thus locating it as at *C*. This operation of cutting a groove and indexing is repeated, without disturbing the position of the cutter, until all the teeth are formed as shown at *D*.

Plain or Simple Indexing

The dividing of a cylindrical part into an equal number of divisions by using the spiral head, is called indexing. The work is rotated

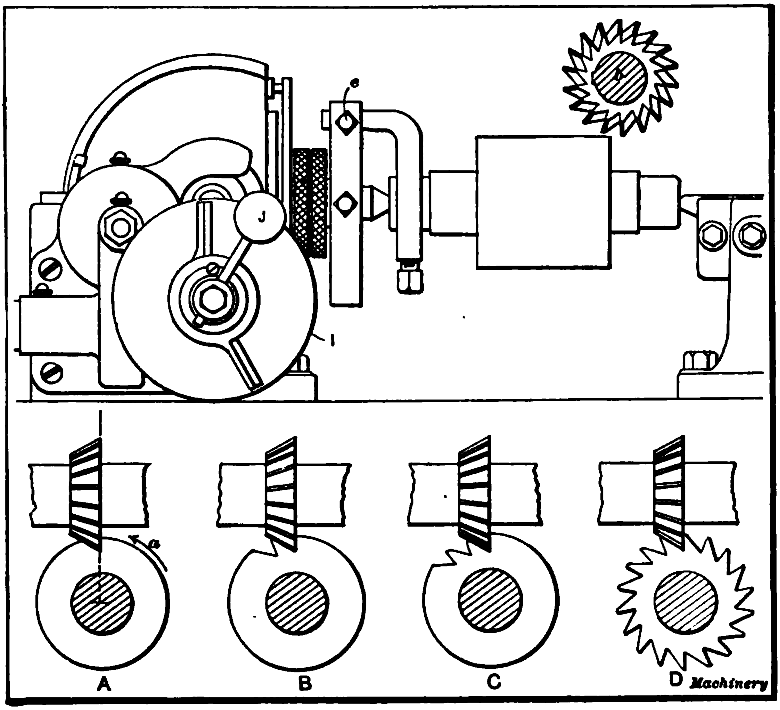

Fig. 30. Views illustrating use of Spiral Head for Indexing

whatever part of a revolution is required, by turning crank *J*. As previously explained, the shaft carrying this crank has a worm which meshes with a worm-wheel on the spiral-head spindle. As the worm is single-threaded, and as there are 40 teeth in the worm-wheel, 40 turns of the crank are necessary to rotate the spindle one complete revolution. If only a half revolution were wanted, the number of turns would equal 40 ÷ 2, or 20, and for 1/12 of a revolution, the turns would equal 40 ÷ 12, or 3-1/3, and so on. In each case, the number of turns the index crank must make, is obtained by dividing the number of turns required for one revolution of the index-head spindle, by the number of divisions wanted. As the number of turns for one revolution is always 40, the rule then is as follows: Divide 40 by the number of divisions into which the periphery of the work is to be divided, to obtain the number of turns for the index crank.

By applying this rule to the job illustrated in Fig. 30, we find that the crank *J* must be turned 2-2/9 times to index the cutter from one tooth to the next, because there are 18 teeth, or divisions, and $40 \div 18 = 2\text{-}2/9$. The next question that naturally arises is, how is the crank to be rotated exactly 2/9 of a turn? This is done by means of the index plate *I*, which has six concentric circles of holes. These holes have been omitted in this illustration owing to its reduced scale, but are shown in the detail view, Fig. 31. The number of holes in the different circles of this particular plate are 33, 31, 29, 27, 23, and 21. Now, in order to turn crank *J* 2/9 of a revolution, it is first necessary to adjust the crank radially until the latch-pin is opposite a circle having a number of holes exactly divisible by the denominator of the fraction (when reduced to its lowest terms) representing the part of a turn required. As the denominator of the fraction in this case is 9, there is only one circle on this plate that can be used, namely, the 27-hole circle. In case none of the circles have a number which is exactly divisible by the denominator of the fractional turn required, the index plate is replaced by another having a different series of holes. The number of holes that the latch-pin would have to move for 2/9 of a turn equals $27 \times 2/9$, or 6 holes. After the latch-pin is adjusted to the 27-hole circle, the indexing of the cutter 1/18 of a revolution is accomplished by pulling out the latch-pin and turning the crank 2 complete turns, and then 2/9 of a turn, or what is the same thing, 6 holes in a 27-hole circle. After each tooth groove is milled in the cutter, this indexing operation is repeated, the latch-pin being moved each time 2-2/9 of a turn from the position it last occupied, until the work has been indexed one complete revolution and all the teeth are milled.

Use of the Sector

After withdrawing the latch-pin, one might easily forget which hole it occupied, or become confused when counting the number of holes for the fractional turn, and to avoid mistakes of this kind, as well as to make it unnecessary to count, a device called a sector is used. The sector has two radial arms *A* and *B* (Fig. 31), which have an independent angular adjustment for varying the distance between them. The sector is used by so adjusting these arms that when the latch-pin is moved from one to the other, it will traverse the required number of holes for whatever fractional turn is necessary. Arm *A* is first set against the left side of the latch-pin, and then arm *B* is shifted to the right until there are 6 holes between it and the latch-pin, as shown in the illustration. When indexing, the latch-pin is withdrawn from hole *a* and the crank is first given two complete turns and then 2/9 of a turn by moving the crank until the latch-pin enters hole *b* adjacent to the arm *B* of the sector. The sector is then revolved until arm *A* again rests against the pin, as shown by the dotted lines. After the next groove is milled, the crank is turned two complete revolutions as before, with hole *b* as a starting point, and then 2/9 of a revolution, by swinging the latch-pin around to arm *B* and into engagement with hole *c*. This operation of indexing and then moving the sector is repeated after each tooth is milled, until the work has made one complete revolution.

When setting the sector arms, the hole occupied by the latch-pin should not be counted or, in other words, the arms should span one

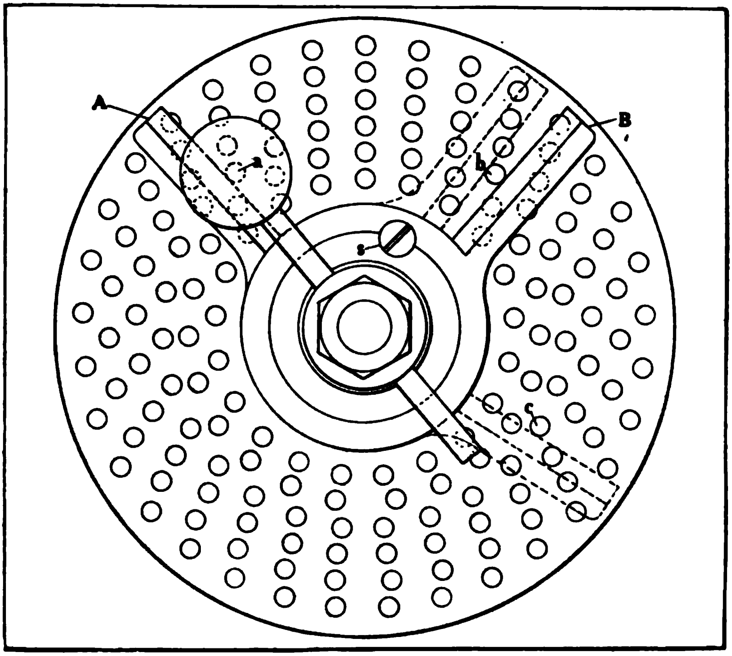

Fig. 31. Diagram showing how Sector is used when Indexing

more hole than the number needed to give the required fractional turn. In the example referred to, 6 holes in the 27-hole circle are required, but the sector arms are adjusted to span 7 holes or 6 spaces, as shown in the illustration. The two arms are locked in any position by tightening the small screw *s*. The sectors now applied to spiral heads made by the Brown & Sharpe Mfg. Co., have graduations which make it unnecessary to count the holes when adjusting the sector arms. The setting is taken directly from the index table accompanying the machine, the sector being adjusted to whatever number is given in the column headed "Graduation."

In actual practice, the number of turns of the index crank for obtaining different divisions, is determined by referring to index tables. These tables give the numbers of divisions and show what circle of holes in the index plate should be used, and also the turns or fractional part of a turn (when less than one revolution is necessary) for the index crank. The fractional part of a turn is usually given as a fraction having a denominator which equals the number of holes in the index circle to be used, whereas the numerator denotes the number of holes the latch-pin should be moved, in addition to the complete revolutions, if one or more whole turns are required. For example: the movement for indexing 24 divisions would be given as 1-26/39 of a turn, instead of 1-2/3, the denominator 39 representing the number of holes in the index circle, and 26 the number of holes that the crank must be moved for obtaining 2/3 of a revolution, after making one complete turn.

Indexing for Angles

Sometimes it is desirable to index a certain number of degrees instead of a fractional part of a revolution. As there are 360 degrees in a circle and 40 turns of the index crank are required for one revolution of the spiral-head spindle, one turn of the crank must equal $\frac{360}{40} = 9$ degrees. Therefore, two holes in an 18-hole circle, or three holes in a 27-hole circle, is equivalent to a one-degree movement, as this is 1/9 of a turn. If we want to index 35 degrees, the number of turns the crank must make equals $35 \div 9 = 3\text{-}8/9$, or three complete turns and 8 degrees. As a movement of two holes in an 18-hole circle equals one degree, a movement of 16 holes is required for 8 degrees. If we want to index 11½ degrees, the one-half degree movement is obtained by turning the crank one hole in the 18-hole circle, after the 11 degrees have been indexed by making one complete revolution (9 degrees), and four holes (2 degrees). Similarly, one and one-third degree can be indexed by using the 27-hole circle, three holes being required to index one degree, and one hole, one-third degree.

When it is necessary to index to minutes, the required movement can be determined by dividing the total number of minutes represented by one turn of the index crank or 540 ($9 \times 60 = 540$), by the number of minutes to be indexed. For example, to index 16 minutes requires approximately 1/34 turn ($540 \div 16 = 34$, nearly), or a movement of one hole in a 34-hole circle. As the 33-hole circle is the one nearest to 34, this could be used and the error would be very small.

The following is a general rule for the approximate indexing of angles, assuming that forty revolutions of the index crank are required for one turn of the spiral-head spindle:

Divide 540 by the number of minutes to be indexed. If the quotient is nearly equal to the number of holes in any index circle available, the angular movement is obtained by turning the crank one hole in this circle; but, if the quotient is not approximately equal, multiply it by any trial number which will give a product equal to the number of holes in one of the index circles, and move the crank in the circle as many holes as are represented by the trial number.

If the quotient of 540 divided by the number of minutes to be indexed, is greater than the largest indexing circle, it is not possible to obtain the movement by the ordinary method of simple indexing.

Use of Chuck on the Spiral Head

It is often necessary to use a spiral head in connection with milling of parts which cannot be held between centers and must be attached directly to the spiral head spindle. A common method of holding work of this kind is to place it in a chuck which is screwed onto the spiral head spindle. An example of chuck work is shown in Fig. 32. The operation is that of milling a square head on bolt *B*. As the illustration shows, the spiral head spindle is set in a vertical position. This is done by loosening the clamp bolts *C* and turning the head 90 degrees, as shown by the graduations on the front side.

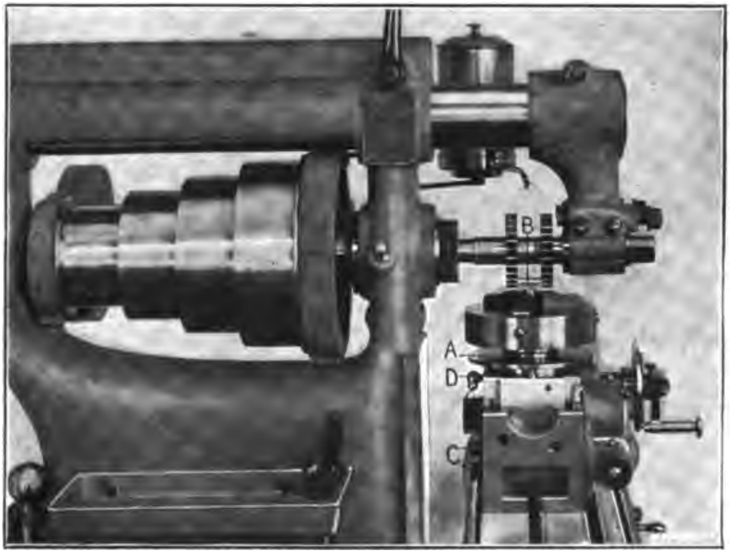

Fig. 32. Straddle Milling a Square Bolt-head

These clamp bolts should be tightened after the adjustment is made. The bolt is held in a three-jawed chuck and the body of the bolt extends into the hollow spindle of the spiral head. The square bolt head is machined to the required width by a straddle mill. One passage of this mill finishes two sides and then the spiral head spindle is indexed ¼ of a turn for milling the remaining sides. This indexing is done by using plate *A* which is attached directly to the spindle. The latch-pin engaging this plate is withdrawn by lever *D* and then the spindle and chuck are turned ¼ of a revolution, after which the latch-pin is again moved into engagement. This direct method of indexing requires little time and is used for simple operations of this kind, whenever the required movement can be obtained.

There is quite a variety of work which is milled either while held in a chuck or on some form of arbor inserted in the spiral head spindle. Whether a chuck or arbor is used, depends on the shape of the work, and, in some instances, on the nature of the milling operation. Chucks are frequently employed for holding cylindrical parts that are too long to go between the centers, but are small enough to pass through the hole in the spiral head spindle. The foot-stock

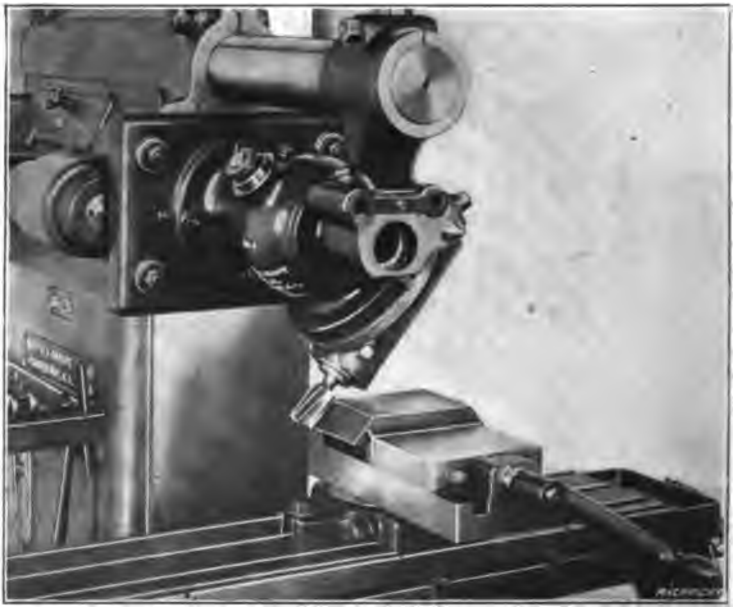

Fig. 33. Vertical Attachment applied to a Horizontal Milling Machine

center is used to support work of this class whenever feasible. When it is necessary to hold a part true with a bored hole, arbors of the expanding type are often used. These have a taper shank which fits the taper hole in the spindle, and the outer end is so arranged that it can be expanded tightly into the hole in the work. Small chucks of the collet type are sometimes used for holding small parts, instead of a jaw chuck.

CHAPTER VII

ATTACHMENTS FOR THE MILLING MACHINE

The range of a milling machine or the variety of work it is capable of doing, can be greatly extended by the use of special attachments. Many of these are designed to enable a certain type of milling machine to perform operations that ordinarily would be done on a different machine; in other words, the attachment temporarily converts one type of machine into another. There are quite a number

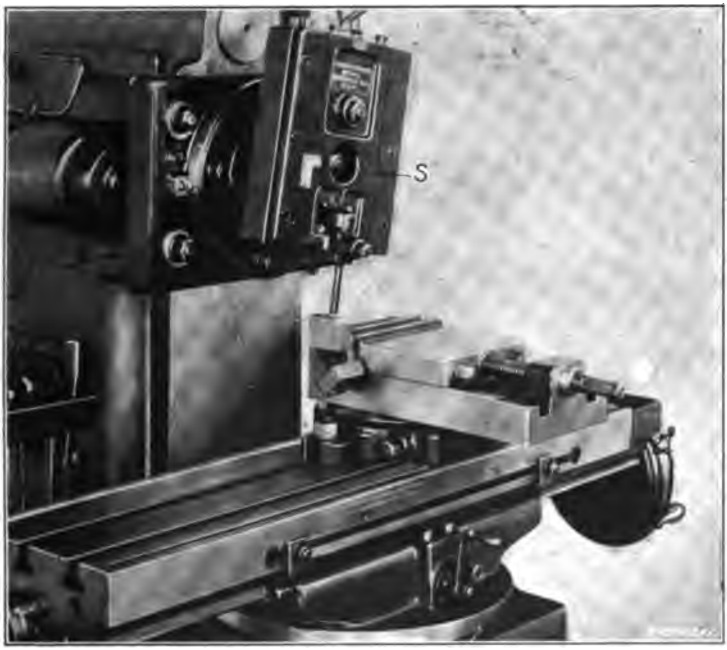

Fig. 34. Slotting Attachment applied to a Milling Machine

of different attachments for the milling machine, some of which are rarely used in the average shop. There are, however, three types that are quite common; namely, the vertical spindle milling attachment; the slotting attachment; and the circular milling and dividing attachment.

Vertical Milling Attachment

The way a vertical spindle milling attachment is applied to a horizontal milling machine is shown in Fig. 33. The base of the attachment is securely clamped to the column of the machine by four bolts and the outer end is inserted in the regular arbor support. The spindle is driven through bevel gears connecting with a horizontal shaft inserted in the main spindle of the machine. The spindle of this particular attachment can be set at any angle in a vertical or horizontal plane, and its position is shown by graduations reading to degrees. For the operation illustrated, which is that of milling the edge of the steel block shown, the spindle is set at an angle of 45 degrees from the vertical. The block is held in an ordinary vise and it is fed past the cutter by using the cross feed. The opposite edge

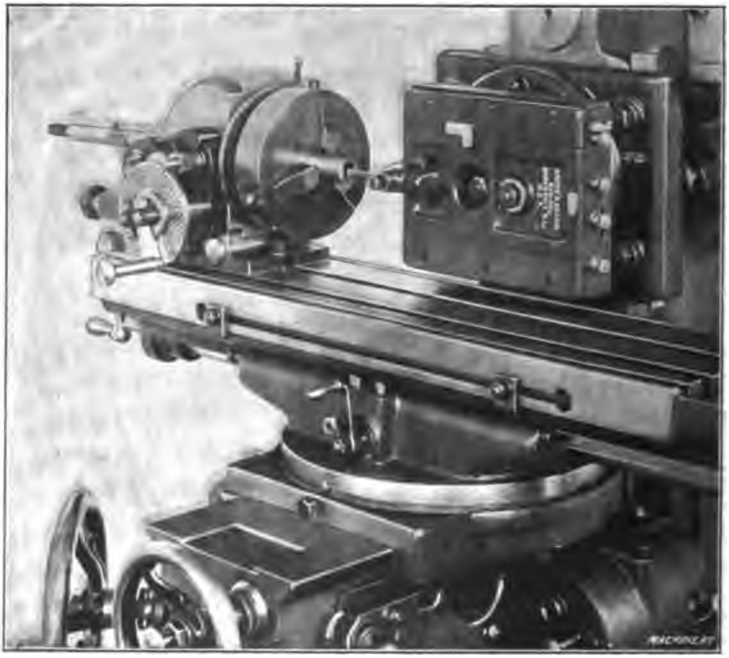

Fig. 35. Slotting Attachment finishing Square Hole in Long Rod held in Spiral Head

is milled by simply swinging the spindle 45 degrees to the right of the vertical. Vertical attachments are used in connection with horizontal machines whenever it is desirable to have the cutter in a vertical or angular position. There are several different types designed for different classes of work. The style shown in the illustration is referred to as a universal attachment because of its two-way adjustment, and it can be used for a variety of purposes, such as drilling, milling angular slots or surfaces, cutting racks, milling keyseats, etc.

Slotting Attachment

The slotting attachment, as its name implies, is used for converting a milling machine into a slotter. The base *B* is clamped to the column of the machine as shown in Fig. 34. The tool slide *S*, which has a reciprocating movement like the ram of a slotter, is driven from the main spindle of the machine by an adjustable crank which enables the stroke to be varied. The tool slide can be set in any position from the vertical to the horizontal, in either direction, the angle being indicated by graduations on the base. When the attachment is in use, a slotting tool of the required shape is clamped to the end of the slide by the bolt shown, and it is prevented from being pushed upward by a stop that is swung over the top of the tool shank. Fig. 34 shows the attachment slotting a rectangular opening in a screw machine tool which is held in the vise. As this open-

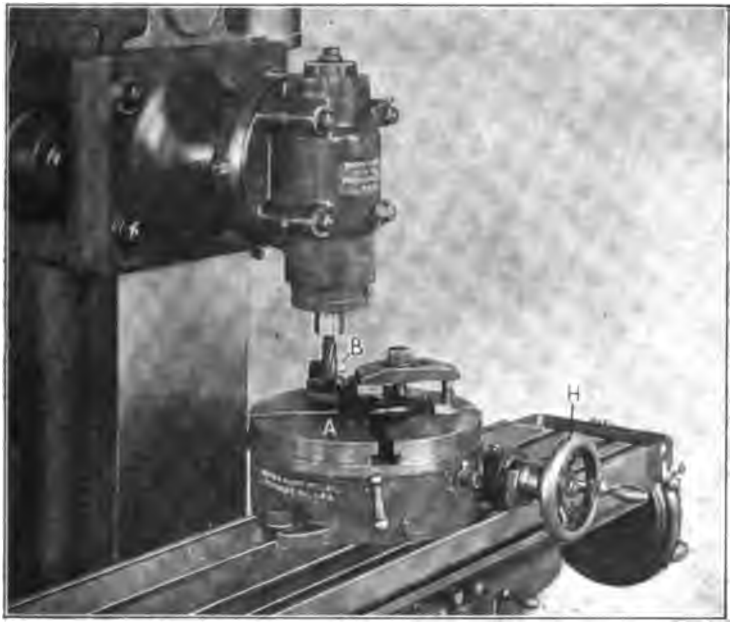

Fig. 36. Combined use of Vertical and Circular Milling Attachments

ing must be at an angle, the tool slide is inclined to the vertical, as shown. A previously drilled hole forms a starting place for the slotting tool.

Fig. 35 shows another application of the slotting attachment. The operation in this case is that of cutting a square hole in the end of a rod. As this rod is too long to be placed in a vertical position, it is inserted through the hollow spindle of the spiral head and is held in a three-jaw chuck as shown. The slotting attachment is swung around to the horizontal position, and after one side of the opening is finished, the rod is indexed ¼ of a turn by using the direct indexing plate attached to the spindle back of the chuck.

Circular Milling Attachment

A circular milling attachment is shown in Fig. 36. It is bolted to the machine and has a round table *A* which can be rotated for milling circular parts. This attachment is generally used in connection with the vertical spindle attachment, as shown in this illustration. The operation is that of milling a segment-shaped end on a small casting *B*. The bored hub of this casting is placed over a bushing in the center of the table, and is held by a clamp. The top or flat surface of the outer end is first milled, and then the table is raised for finishing the circular part as shown. The table of the attachment is given a circular feeding movement by turning handwheel *H*. Incidentally this view shows another type of vertical attachment which differs from the one illustrated in Fig. 33 in that it can only be adjusted at right-angles to the axis of the spindle. This type is designed for comparatively heavy vertical milling operations.

CHAPTER VIII

GASHING AND HOBBING A WORM-WHEEL IN A MILLING MACHINE

The universal milling machine is sometimes used for cutting the teeth in worm-wheels, although when there is much of this work to be done, regular gear-cutting machines are generally used. The worm itself should be finished first, as it can be used advantageously for testing the center distance when hobbing the worm-wheel. We shall assume that the worm has been made, and that the wheel blank has been turned to the required size.

The teeth of the worm-wheel are formed by two operations, which are illustrated in Figs. 37 and 38. First it is necessary to gash the blank and then the teeth are finished by hobbing. Gashing consists in cutting teeth around the periphery of the blank, which are approximately the shape of the finished teeth. This is done, preferably, by the use of an involute gear cutter of a number and pitch corresponding to the number and pitch of the teeth in the wheel. If a gear cutter is not available, a plain milling cutter, the thickness of which should not exceed three-tenths of the circular pitch, may be used. The corners of the teeth of the cutter should be rounded, as otherwise the fillets of the finished teeth will be partly removed.

As the worm which meshes with and drives the worm-wheel is simply a short screw, it will be apparent that if the axes of the worm-wheel and worm are to be at right angles to each other, the teeth of the wheel must be cut at an angle to its axis, in order to mesh with the threads of the worm. The method of setting the work and obtaining this angle will first be considered.

After the dividing head and tailstock have been clamped to the table and the cutter has been fastened on its arbor, the table is adjusted until the centers of the dividing head and the center of the cutter lie in the same vertical plane. If the cutter used has a center-line around its periphery, the table can be set by raising it high enough to bring the index head center in line with the cutter; the table can then be adjusted laterally until the center coincides with the center-line on the cutter. When the table is set, it should be clamped to the knee slide.

The blank to be gashed is pressed on a true-running arbor which is mounted between the centers of the dividing head and tailstock as illus-

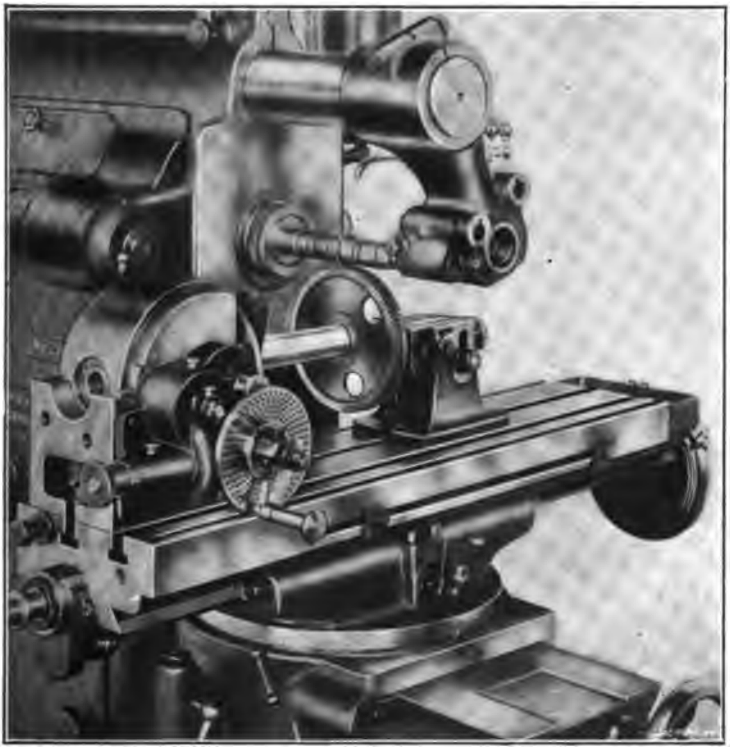

Fig. 37. Gashing a Worm-wheel in a Universal Milling Machine

trated in Fig. 37, and the driving dog is secured, to prevent any vibration of the work. The table is next moved longitudinally until a point midway between the sides of the blank is directly beneath the center of the cutter arbor. To set the blank in this position, place a square blade or straightedge against it first on one side and then on the other and adjust the table longitudinally until the distances between the blade and arbor are the same on both sides.

Angular Position of Table for Gashing

The table should now be set to the proper angle for gashing the teeth. This angle, if not given on the drawing, may be determined either graphically or by calculation. The first method is illustrated in

Fig. 39. Some smooth surface should be selected, having a straight edge as at *A*. A line having a length *B* equal to the lead of the worm thread, is drawn at right angles to the edge *A*, and a distance *C* is laid off equal to the circumference of the pitch circle of the worm. If the diameter of the pitch circle is not given on the drawing, it may be

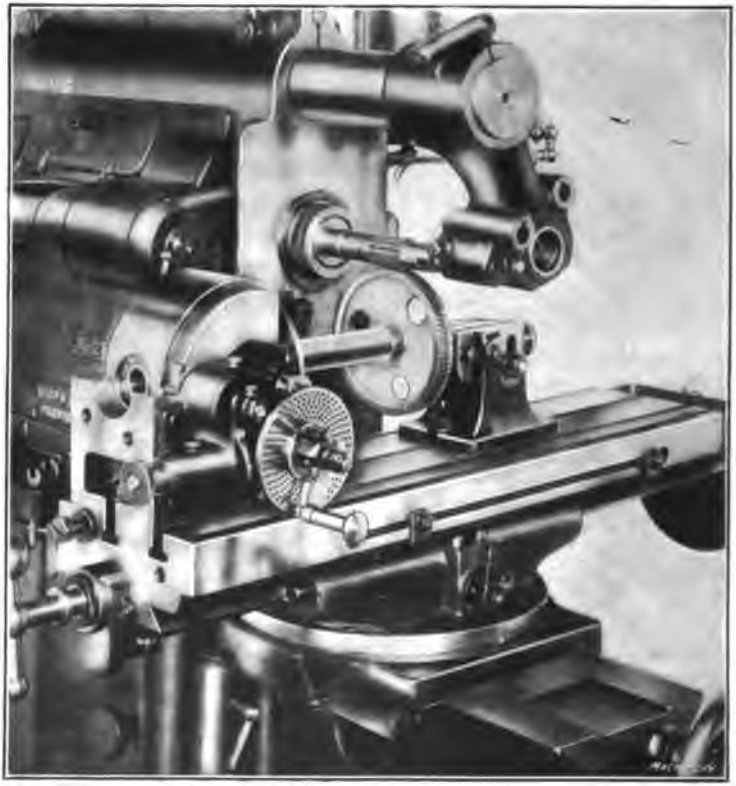

Fig. 38. Hobbing the Teeth of a Worm-wheel

found by subtracting twice the addendum of the teeth from the outside diameter of the worm. The addendum equals the linear pitch × 0.3183. The angle *x* is next measured with a protractor, as shown in the illustration. The table of the machine is then swiveled to a corresponding angle, as shown by the graduations provided on all universal milling machines. If the front of the table is represented by the edge *A*, and the worm has a right-hand thread, the table should be swiveled as indicated by the line *ab*; whereas if the worm has a left-hand thread, the table should be turned in an opposite direction.

The angle that the teeth of the worm-wheel make with its axis, or the angle to which the table is to be swiveled, may also be found by dividing the lead of the worm thread by the circumference of the pitch circle; the quotient will equal the tangent of the desired angle. This angle is then found by referring to a table of natural tangents.

Milling the Gashes in a Worm-wheel

When the table is set and clamped in place, as many gashes are cut in the periphery of the wheel as there are to be teeth. If the diameter of the cutter is no larger than the diameter of the hob to be used, the depth of the gashes should be slightly less than the whole depth of the tooth. This whole depth may be found by multiplying the linear pitch by 0.6866. Before starting a cut, bring the cutter into contact with the wheel blank, set the dial on the elevating screw at zero, and sink the cutter to the proper depth as indicated by the dial. The blank is then lowered to clear the cutter and indexed for gashing the next tooth.

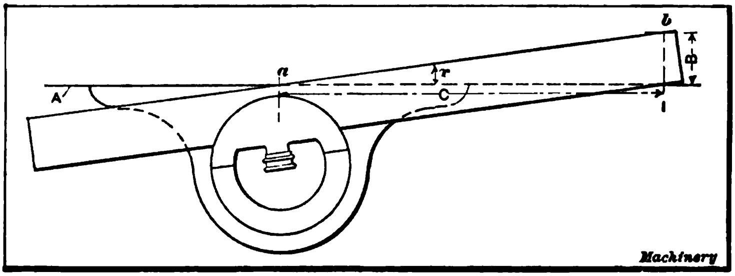

Fig. 39. Method of obtaining Helix Angle of Worm

When the cutter is larger than the hob, the whole depth of tooth should be laid off on the side of the blank, and a gash cut in to this line. The depth as indicated on the dial should then be noted and all the gashes cut to a corresponding depth.

Hobbing the Teeth of a Worm-wheel

When the gashing is finished, the table is set at right angles with the spindle of the machine, and the cutter is replaced with a hob, as shown in Fig. 38. The latter is practically a milling cutter shaped like the worm with which the wheel is to mesh, except that the thread on the hob has several lengthwise flutes or gashes to form cutting edges. The outside diameter of the hob and the diameter at the bottom of the teeth, are slightly greater than the corresponding dimensions of the worm, to provide clearance between the worm and worm-wheel. Before hobbing, the dog is removed from the arbor to permit the latter to turn freely on its centers. The hob is then placed in mesh with the gashed blank, and the teeth of the worm-wheel are finished by revolving the blank and hob together. As the two rotate, the blank is gradually raised until the body of the hob between the teeth just grazes the throat of the blank. The latter is then allowed to make a few revolutions to insure well-formed teeth.

If the center-to-center distance between the worm and worm-wheel must be accurate, this dimension can be tested by placing the finished worm in mesh with the wheel (after the latter has been hobbed), and measuring the center distance directly. The worm is placed on top of the wheel, after removing the chips from the teeth, and it is turned along until its axis is parallel with the top of the table. It can be set in this position by testing the threads at each end with a surface gage. The distance from the top of the worm to the top of the arbor is then measured, and the *difference* between the radii of the arbor and worm is either added to or subtracted from this dimension, to obtain the center-to-center distance.

If the worm is accurately made and the worm-wheel blank of the correct size, this center distance should be very close to the dimension required. If necessary, the hob may be again engaged with the wheel and another light cut taken. When testing the center distance, as explained in the foregoing, it is better to lower the knee sufficiently to make room for the worm beneath the hob, and not disturb the longitudinal setting of the table. The relation between the wheel and hob will then be maintained, which is desirable in case it is necessary to re-hob the wheel to reduce the center distance.

The center-to-center distance can also be measured with a fair degree of accuracy (when using the machine in Figs. 37 and 38) at the time the wheel is being hobbed. This is done by elevating the knee and blank until the distance from the top of the column knee-slide to the line on the column marked *cènter*, equals the required center-to-center distance. When the knee coincides with this line, the index centers are at the same height as the spindle; hence the position of the knee with relation to this mark, shows the distance betweeen the centers of the arbor on which the worm-wheel is mounted, and the hob.

When worm-wheels are cut in machines especially designed for this purpose, the wheel blanks, instead of being mounted on a free-running arbor, are driven by gearing at the proper speed. This makes gashing the blank previous to hobbing unnecessary, as the change gears insure a correct spacing of the worm-wheel teeth.

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CHAPTER I

COMPOUND INDEXING—DIFFERENTIAL INDEXING

Ordinarily, the index crank of a spiral head must be rotated a fractional part of a revolution, when indexing, even though one or more complete turns are required. As explained in Part I of this treatise, this fractional part of a turn is measured by moving the latch-pin a certain number of holes in one of the index circles; but occasionally, none of the index plates furnished with the machine, has circles of holes containing the necessary number for obtaining a certain division. One method of indexing for divisions which are beyond the range of those secured by the direct method, is to first turn the crank a definite amount in the regular way, and then the index plate itself, in order to locate the crank in the proper position. This is known as compound indexing, because there are two separate movements which are, in reality, two simple indexing operations. The index plate is normally kept from turning, by a stationary stop-pin at the rear, which engages one of the index holes, the same as the latch-pin. When this stop-pin is withdrawn, the index plate can be turned.

To illustrate the principle of the compound method, suppose the latch-pin is turned one hole in the 19-hole circle and the index plate is also moved one hole in the 20-hole circle and in the same direction that the crank is turned. These combined movements will cause the worm (which engages the worm-wheel on the spiral head spindle) to rotate a distance equal to $\frac{1}{19} + \frac{1}{20} = \frac{39}{380}$ of a revolution. On the other hand, if the crank is moved one hole in the 19-hole circle, as before, and the index plate is moved one hole in the 20-hole circle, ***but in the opposite direction***, the rotation of the worm will equal $\frac{1}{19} - \frac{1}{20} = \frac{1}{380}$ revolution. By the simple method of indexing, it would be necessary to use a circle having 380 holes to obtain these movements, but by rotating both the index plate and crank the proper amount, either in the same or opposite directions, as may be required, it is possible to secure divisions beyond the range of the simple or direct system.

To illustrate the use of the compound method, suppose 69 divisions were required. In order to index the work $\frac{1}{69}$ revolution, it is necessary to move the crank $\frac{40}{69}$ of a turn $(40 \div 69 = \frac{40}{1} \times \frac{1}{69} = \frac{40}{69})$, and this would require a circle having 69 holes, if the simple method of indexing were employed, but by the compound system, this division can be

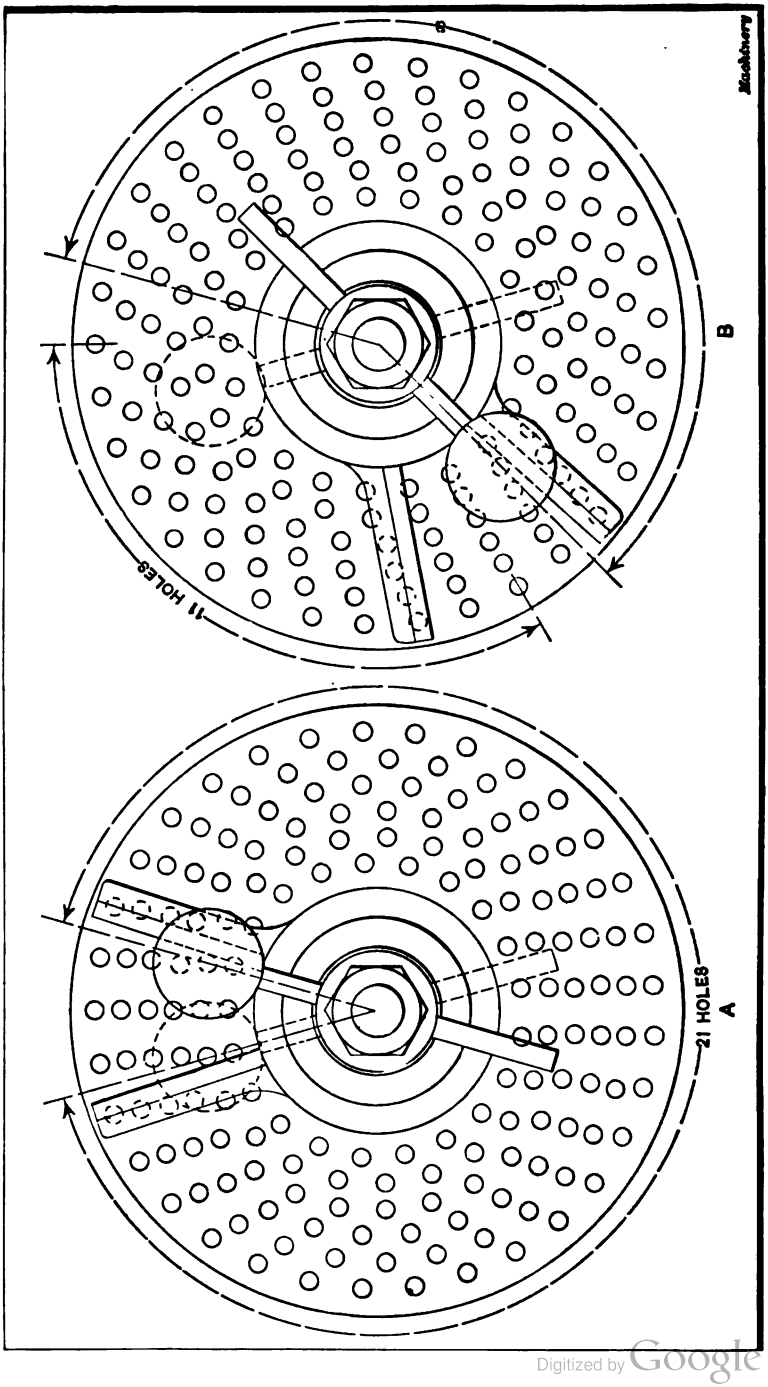

Fig. 1. Diagrams illustrating the Principle of Compound Indexing

obtained by using the 23- and 33-hole circles, which are found on one of the three standard plates furnished with Brown & Sharpe spiral heads. The method of indexing $\frac{1}{69}$ revolution by the compound system is as follows: The crank is first moved to the right 21 holes in the 23-hole circle, as indicated at *A* in Fig. 1 and it is left in this position; then the stop-pin at the rear, which engages the 33-hole circle of the index plate, is withdrawn, and the plate is turned backward, or to the left, 11 holes in the 33-hole circle. This rotation of the plate also carries the crank to the left, or from the position shown by the dotted lines at *B*, to that shown by the full lines, so that after turning the plate backward, the crank is moved from its original position a distance x which is equal to $\frac{21}{23} - \frac{11}{33} = \frac{40}{69}$ which is the fractional part of a turn the crank must make, in order to index the work $\frac{1}{69}$ of a revolution.

One rule for determining what index circles can be used for indexing by the compound method, is as follows: Resolve into its factors the number of divisions required; then choose at random two circles of holes, subtract one from the other, and factor the difference. Place the two sets of factors thus obtained above a horizontal line. Next factor the number of turns of the crank required for one revolution of the spindle (or 40) and also the number of holes in each of the chosen circles. Place the three sets of factors thus obtained below the horizontal line. If all the factors above the line can be cancelled by those below, the two circles chosen will give the required number of divisions; if not, other circles are chosen and another trial made.

To illustrate this rule by using the example given in the foregoing, we have:

$$
\begin{array}{r}
69 = \not{3} \times \not{2}\not{3} \\
33 - 23 = 10 = \not{2} \times \not{5} \\
\hline
40 = \not{2} \times 2 \times 2 \times \not{5} \\
33 = \not{3} \times 11 \\
23 = \not{2}\not{3} \times 1
\end{array}
$$

As all the factors above the line cancel, we know that the index plate having 23- and 33-hole circles can be used. The next thing to determine is how far to move the crank and the index plate. This is found by multiplying together all the uncancelled factors below the line; thus: $2 \times 2 \times 11 = 44$. This means that to index $\frac{1}{69}$ of a revolution, the crank is turned *forward* 44 holes in the 23-hole circle, and the index plate is moved *backward* 44 holes in the 33-hole circle. The movement can also be forward 44 holes in the 33-hole circle and backward 44 holes in the 23-hole circle, without affecting the result. The movements obtained by the foregoing rule are expressed in compound indexing tables in the form of fractions, as for example: $+\frac{44}{23}-\frac{44}{33}$. The numerators represent the number of holes indexed and the denominators the circles used, whereas, the + and — signs show that the movements of the crank and index plate are opposite in direction. These fractions can often be reduced and simplified so that it will not be necessary to move so many holes, by adding some number to them algebraically. The number is chosen by trial, and its sign should be opposite that of the fraction to which it is added. Suppose, for example, we add a fraction representing one complete turn, to each of the fractions referred to; we then have:

$$
\begin{array}{r}
+\frac{44}{23}-\frac{44}{33} \\
-\frac{23}{23}+\frac{33}{33} \\
\hline
+\frac{21}{23}-\frac{11}{33}
\end{array}
$$

If the indexing is governed by these simplified fractions, the crank is moved forward 21 holes in the 23-hole circle and the plate is turned backward 11 holes in the 33-hole circle, instead of moving 44 holes, as stated. The result is the same in each case, but the smaller movements are desirable, especially for the index plate, because it is easier to count 11 holes than 44 holes. For this reason, the fractions given in index tables are simplified in this way. Ordinarily, the number of circles to use and the required number of movements to make when indexing, is determined by referring to a table as this eliminates all calculations, and lessens the chance of error.

Sometimes the simple method of indexing can be used to advantage in conjunction with the compound system. For example, if we want to cut a 96-tooth gear, every other tooth can be cut first by using the simple method and indexing for 48 teeth, which would require a movement of 15 holes in an 18-hole circle. When half of the tooth spaces have been cut, the work is indexed $\frac{1}{96}$ of a revolution by the compound method, for locating the cutter midway between the spaces previously milled. The remaining spaces are then finished by again indexing for 48 divisions by the simple system.

Compound indexing should only be used when necessary, because of the chances of error, owing to the fact that the holes must be counted when moving the index plate. As previously explained, the number of holes that the crank is turned, is gaged by a sector. This counting also requires considerable time and, because of these disadvantages, the compound system is not used to any great extent; in fact, the more modern spiral heads are so arranged that divisions formerly obtained by this system, can now be secured in a more simple and direct way.

Differential Indexing

One of the improved indexing systems, which is applied to the universal milling machines built by the Brown & Sharpe Mfg. Co., is known as the differential method. This system is the same in principle as compound indexing, but differs from the latter in that the index plate is rotated by suitable gearing which connects it to the spiral-head spindle, as shown in Figs. 2 and 3. This rotation or differential motion of the index plate takes place when the crank is turned, the plate moving either in the same direction as the crank or opposite to it, as may be required. The result is that the *actual* movement of the crank, at every indexing, is either greater or less than its movement with relation to the index plate. This method of turning the index plate by gearing instead of by hand, makes it possible to obtain any division liable to arise in practice, by using one circle of holes and simply turning the index crank in one direction, the same as for plain indexing. As the hand movement of the plate and the counting of holes is eliminated, the chances of error are also greatly reduced.

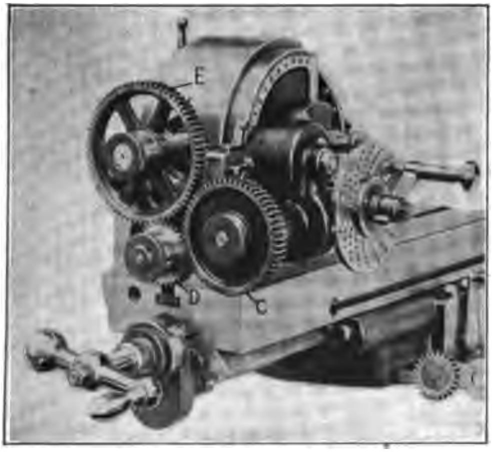

Fig. 2. Index Head geared for Differential Indexing

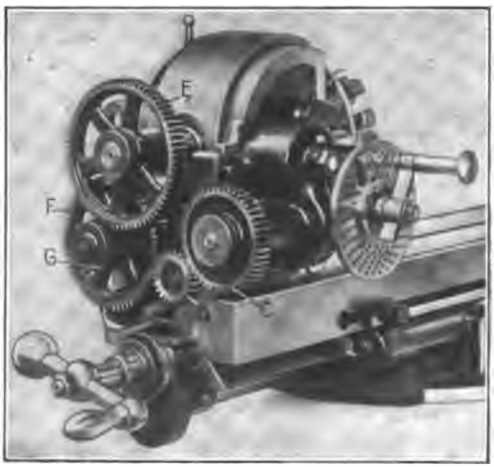

Fig. 3. Index Head equipped with Compound Gearing for Differential Indexing

The proper sized gears to use for moving the index plate the required amount, would ordinarily be determined by referring to a table which accompanies the machine. This table (a small part of which is illustrated in Fig. 4) gives all divisions from 1 to 382 and includes both plain and differential indexing; that is, it shows what divisions can be obtained by plain indexing, and also when it is necessary to use gears and the differential system. For example, if 130 divisions are required, the 39-hole index circle is used and the crank is moved 12 holes (see fourth column of table) but no gears are required. For 131 divisions, a 40-tooth gear is placed on the worm-shaft and a 28-tooth gear is mounted on the spindle. These two gears are connected by the 44-tooth idler gear, which serves to rotate the plate in the same direction as the crank. To obtain some divisions, it is necessary to

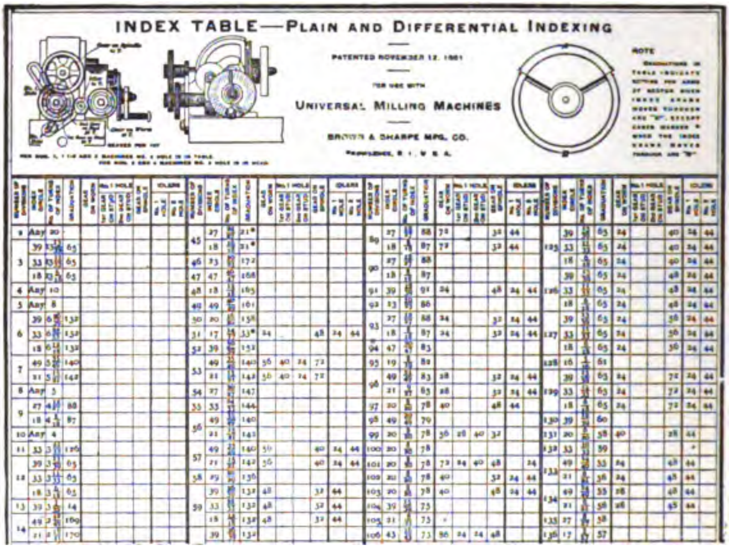

Fig. 4. Part of Index Table for Plain and Differential Indexing

rotate the plate and crank in opposite directions, and then two idler gears are interposed between the spindle and wormshaft gears.

Fig. 2 shows a spiral head geared for 271 divisions. The table calls for a gear *C* having 56 teeth; a spindle gear *E* with 72 teeth and one idler *D*. The sector should be set for giving the crank a movement of 7 holes in the 49-hole circle or 3 holes in the 21-hole circle, either of which equals $\frac{1}{7}$ of a turn. If an index plate having a 49-hole circle happens to be on the spindle head, this would be used. Now if the spindle and index plate were not connected through gearing, 280 divisions would be obtained by successively moving the crank 7 holes in the 49-hole circle, but the gears *E*, *D*, and *C* cause the index plate to turn in the same direction as the crank at such a rate that when 271 indexings have been made, the work is turned one complete revolution; therefore, we have 271 divisions instead of 280, the number being reduced because the total movement of the crank, for each indexing, is equal to its movement relative to the index plate, *plus* the movement of the plate itself when (as in this case) the crank and plate rotate in the same direction. If they were rotated in opposite directions, the crank would have a total movement equal to the amount it turned relative to the plate, *minus* the plate's movement.

Sometimes it is necessary to use compound gearing, in order to move the index plate the required amount for each turn of the crank. Fig. 3 shows a spiral head equipped with compound gearing for obtaining 319 divisions. The gears given in the table are as follows: Gear *C* on the worm, 48 teeth; first gear *F* placed on the stud, 64 teeth; second gear *G* on the stud, 24 teeth; gear *E* on the spindle, 72 teeth; and one idler gear *D*, having 24 teeth.

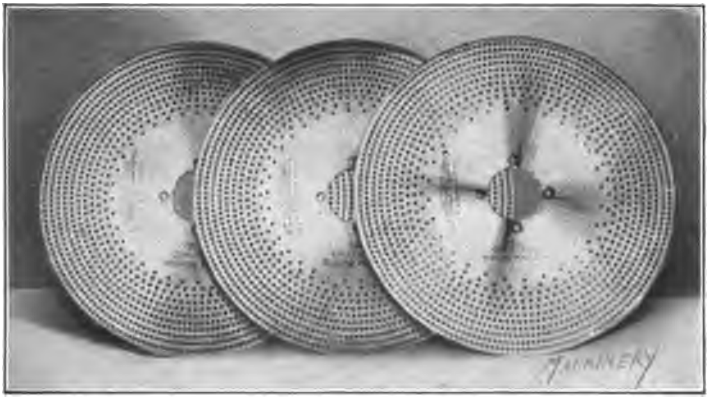

Fig. 5. Index Plates for obtaining a Large Number of Divisions by Simple Indexing

The following example is given to illustrate the method of determining the index movements and change gears to use for differential indexing: Suppose 59 divisions were required, what circle of holes and gears should be used? First assume that we are to index for 60 divisions by the simple method, which would require a $\frac{2}{3}$ movement of the crank. Now, if the crank is indexed $\frac{2}{3}$ of a revolution, 59 times, it will rotate in all, $59 \times \frac{2}{3}$ or 39 1/3 revolutions, which is $\frac{2}{3}$ of a revolution less than the 40 required for one complete revolution of the work. Therefore, the index plate must be geared so that it will move forward $\frac{2}{3}$ of a turn, while the work is revolving once. Hence, the ratio of the gearing must be $\frac{2}{3}$ to 1. Gears are next selected from those provided with the machine, which will give this ratio, as for example, gears having 32 and 48 teeth, respectively. The small gear is placed on the spindle, in this case, because the index plate is to make only $\frac{2}{3}$ of a turn, while the spindle makes one complete revolution. One idler gear is also interposed between the gears, because it is necessary for the plate to gain $\frac{2}{3}$ of a turn with respect to the crank; therefore, the movements of the index plate and crank must be in the same direction.

The differential method cannot be used for helical or spiral milling, because the spiral-head is then geared to the lead-screw of the machine, as explained in Chapter III.

High-number, Reversible Index Plates

The dividing heads furnished with Cincinnati milling machines, are equipped with comparatively large index plates. This increase in diameter gives room for more circles and a larger number of holes than the smaller plates, and the range is further increased by making the plate reversible, each side having different series of holes. Therefore, the number of divisions that can be obtained directly from one of these plates is greatly increased. The standard plate regularly supplied can be used for indexing all numbers up to 60; all even numbers and those divisible by 5 up to 120, and many other divisions between 120 and 400. If it should be necessary to index high numbers not obtainable with the standard plate, a high number indexing attachment can be supplied. This consists of three special plates (see Fig. 5), which have large numbers of holes and different series on each side. They can be used for indexing all numbers up to and including 200; all even numbers and those divisible by 5 up to and including 400. Owing to the range of the standard plate, the high-number attachment is only needed in rare instances, for ordinary milling machine work.

CHAPTER II

CUTTING SPUR GEARS IN A MILLING MACHINE

Spur gears are ordinarily cut in special gear-cutting machines, but the milling machine is often used in shops not equipped with special machines, or for cutting gears of odd sizes, especially when only a small number are required. Fig. 6 illustrates how a small spur gear is cut in the milling machine. The gear blank is first bored and turned to the correct outside diameter and then it is mounted on an arbor which is placed between the centers of the dividing head. An arbor having a taper shank which fits the dividing-head spindle, is a good form to use for gear work. If an ordinary arbor with centers in both ends is employed, all play between the driving dog and faceplate should be taken up to insure accurate indexing.

Cutter for Spur Gears

The type of cutter that is used for milling the teeth of spur gears, is shown in Fig. 7. This style of cutter is manufactured in various sizes for gears of different pitch. The teeth of these cutters have the same shape or profile as the tooth spaces of a gear of corresponding pitch; therefore, the cutter to use depends upon the pitch of the gear to be cut. The number of teeth in the gear must also be considered, because the shape or profile of the teeth of a small gear is not exactly the same as that of the teeth of a large gear of corresponding pitch.

The cutters manufactured by the Brown & Sharpe Mfg. Co. for cutting gears according to the involute system, are made in eight different sizes for each pitch. These cutters are numbered from 1 to 8 and the different numbers are adapted for gears of the following sizes. Cutter No. 1, for gears having teeth varying from 135 to a rack; No. 2, gears with from 55 to 134 teeth; No. 3, from 35 to 54 teeth; No. 4, from 26 to 34 teeth; No. 5, from 21 to 25 teeth; No. 6, from 17 to 20 teeth; No. 7, from 14 to 16 teeth; and No. 8, from 12 to 13 teeth.

If we assume that the diametral pitch of the gear illustrated in Fig. 6 is 12 and the required number of teeth, 90, a No. 2 cutter of 12 diametral pitch would be used, the No. 2 shape being selected because it is intended for all gears having teeth varying from 55 to 134.

Setting the Cutter Central

After the cutter is mounted on an arbor, it must be set over the center of the gear blank, as otherwise the teeth will not be milled to the correct form. One method of centering the cutter is illustrated by the diagram, Fig. 8. A true arbor is placed between the dividing head and foot-stock centers, and the table of the machine is first adjusted to locate the arbor in any convenient position outside of and somewhat below the cutter as at *A*. The graduated dial of the cross-feed screw is next set to zero. The arbor is then moved to position *B* and it is adjusted to barely touch or pinch a thin tissue paper "feeler" *f* held between the arbor and the corner of the cutter. The dial of the elevating screw is now set at zero, and the horizontal distance between positions *A* and *B* should be noted by referring to the cross-feed dial. For convenience, this will be called dimension No. 1, as indicated by the illustration. The arbor is next lowered and returned to position *A*, horizontally, the vertical position not being particular. The arbor is then raised until the elevating screw dial is again at zero, after

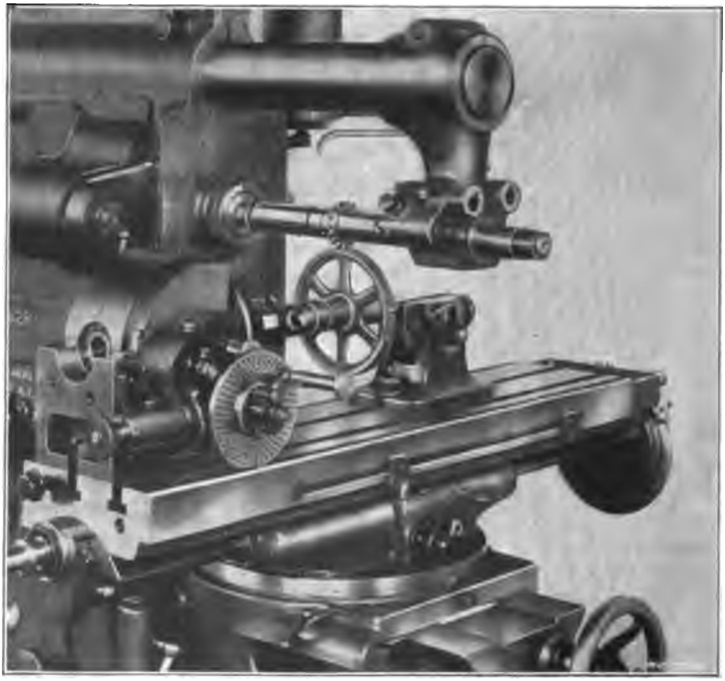

Fig. 6. Cutting the Teeth of a Spur Gear in a Universal Milling Machine

which it is moved to position *C*, or until it just touches a tissue paper "feeler" as before. The horizontal dimension No. 2 is next noted by referring to the cross-feed dial; this is added to dimension No. 1 and the sum is divided by 2 to get dimension No. 3. The arbor is then returned to position *A* (as far as the horizontal location is concerned) after which it is lowered far enough to clear the cutter and then moved inward a distance equal to dimension No. 3, which is the central position. This operation can be performed more quickly than described. When making the adjustments, all dial readings should be taken at the end of the inward or upward movements, to avoid errors due to backlash or lost motion in the elevating or feed screws.

A method of testing the location of a gear cutter, when considerable accuracy is required, is as follows: First mill a tooth space in a trial blank having the same diameter as the gear blank, and then, without changing the position of the cutter, remove the blank from the work arbor and turn it end for end. The blank should be loose on the arbor to permit feeding it back so that the cutter will enter the tooth space previously milled. The cutter is then revolved slowly by hand, in order to mark its position in the slot. If it is set exactly central, the second cut will follow the first, but if it is not central, some metal will be removed from the top of the space on one side and the bottom on the other. In order to center the cutter, it should be moved laterally toward that side of the tooth from which stock was milled at the top. Another trial cut is then taken and the test repeated.

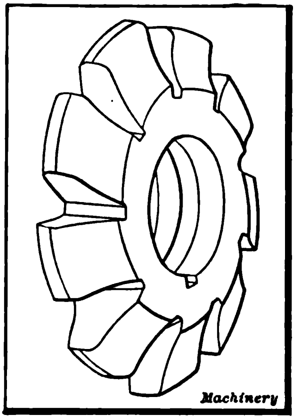

Fig. 7. Cutter for Milling the Teeth of Spur Gears

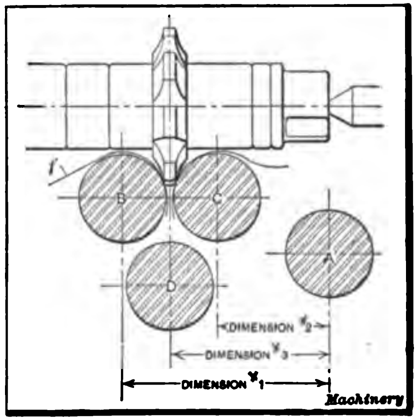

Fig. 8. Method of setting Cutter Central with Arbor

When the cutter is centrally located, the saddle should be clamped to the knee to hold it rigidly in position.

Setting the Cutter to Depth—Milling the Teeth

The next step is to set the cutter for milling tooth spaces of the proper depth. If the outside diameter of the gear blank is accurate, this can be done by first adjusting the blank upward until the revolving cutter just grazes its surface. The dial of the elevating screw is then set at zero, after which the blank is moved horizontally, to clear the cutter, and then vertically the required amount, as shown by the micrometer dial. This vertical adjustment should equal the total depth of the tooth space, which can be found by dividing the constant 2.157 by the diametral pitch of the gear. For example, if the diametral pitch is 12, the depth of the tooth space $= \frac{2.157}{12} = 0.179$ inch. After the blank has been raised this amount, the gear teeth are formed by feeding the blank horizontally and indexing after each tooth space is milled. About one quarter of the teeth have been milled in the gear blank shown in Fig. 6. The accuracy of the gear, assuming that the cutter is properly made, will depend largely upon setting the cutter central and to the proper depth. When the depth is gaged from the outside of the blank, the diameter of the latter should be accurate, as otherwise the teeth will not have the correct thickness. This diameter can be found by adding 2 to the number of teeth and dividing by the diametral pitch. The special vernier, gear-tooth caliper shown in Fig. 9, is sometimes used for testing the thickness of the first tooth milled. This test is especially desirable if there is any doubt about the accuracy of the outside diameter. A trial cut is taken at one side of the blank and then the work is indexed for the next space, after

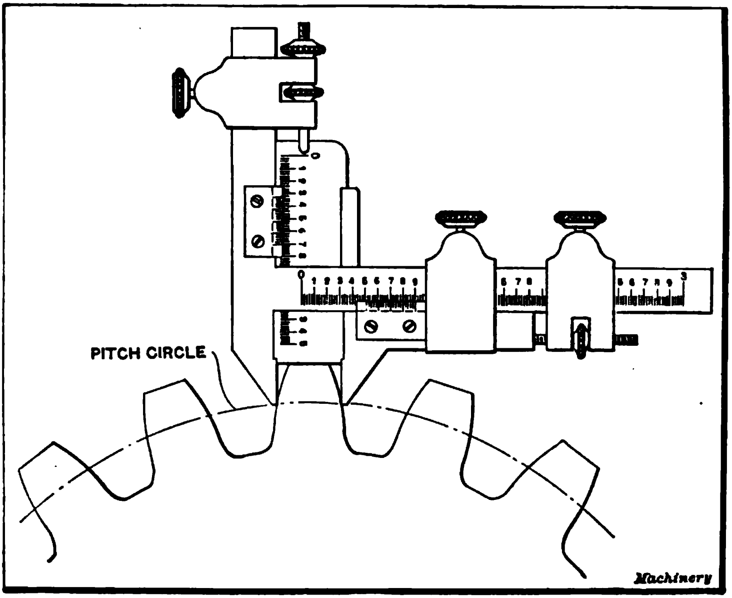

Fig. 9. Vernier Caliper for measuring the Thickness of Gear Tooth at the Pitch Circle

which another trial cut is taken part way across the gear. The vertical scale of the caliper is then set so that when it rests on top of the tooth (as shown in the illustration), the lower ends of the caliper jaws will be at the height of the pitch line. The horizontal scale then shows the thickness of the tooth at this point. The height from the top of the tooth to the pitch line equals the circular pitch multiplied by the constant 0.3183. The thickness of the tooth at the pitch line, for any gear, can be determined by dividing the circular pitch by 2, or the constant 1.57 by the diametral pitch. With a diametral pitch of 12, the thickness would equal $\frac{1.57}{12} = 0.131$ inch. The two trial cuts for determining the tooth thickness, should not extend across the blank, as it is better to simply gash one side; then if an adjustment is necessary, all the tooth spaces will be milled from the solid; whereas, if trial cuts were taken clear across the blank, very little metal would be removed from these spaces by the final cut and the thickness of the tooth between them would differ somewhat from the other teeth in the gear.

When a gear tooth is measured as shown in Fig. 9 it is the chordal thickness T (see Fig. 9a) that is obtained, instead of the thickness along the pitch circle; hence when measuring teeth of coarse pitch, especially if the diameter of the gear is quite small, dimension T should be obtained if accuracy is required. It is also necessary to find the height x of the arc and add it to the addendum H to get the corrected height H_1, in order to measure the chordal thickness T at the proper point on the sides of the tooth. To determine dimension T, multiply the pitch diameter of the gear by the sine of the angle a between the center and radial lines shown. Expressing this as a formula we have $T = D \sin a$, in which D equals the pitch diameter. To find angle a, divide 90 degrees by the number of teeth in the gear. The height x of the arc is found as follows: $x = R\ (1 - \cos a)$, in which R equals the pitch radius. That is, x equals 1 minus the cosine of angle a multiplied by the pitch radius of the gear. The corrected height H_1 is found by adding x to the distance H from the top of the tooth to the pitch circle. If much gear cutting is done, it is well to secure a table giving the chordal thickness T and the corrected height H_1, for various pitches and numbers of teeth.

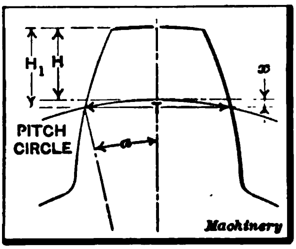

Fig. 9a. When measuring Large Gear Teeth, the Chordal Thickness T should be determined

When milling the teeth, a space is cut by feeding the blank in such a direction that it moves against the rotation of the cutter. After a space is milled, the cutter is returned to its starting point and the blank is indexed $\frac{1}{90}$ of a revolution (as the gear is to have 90 teeth) for milling the next space. This operation is repeated until all the teeth are milled.

When milling gear teeth that are coarser than 6 or 7 diametral pitch, it is advisable to first rough mill all the teeth and then take finishing cuts. Special "stocking" cutters are often used for rough milling very coarse gears, preparatory to finishing by a regular cutter. The speed for cutting gear teeth depends on the pitch of the teeth, the kind of material being milled, and the rigidity of the work and machine.

When the diameter of a gear is referred to, it is understood to mean the pitch diameter or diameter of the pitch circle, and not the outside diameter. The diametral pitch is the number of teeth to each inch of pitch diameter, and the circular pitch is the distance from the center of one tooth to the center of the next, measured along the pitch line.

CHAPTER III

HELICAL OR SPIRAL MILLING

The spiral head is not only used for indexing or dividing, but also in connection with the milling of spiral grooves. When a spiral is being milled, the work is turned slowly by the dividing head as the table of the machine feeds lengthwise. As the result of these combined movements, a spiral groove is generated by the milling cutter. The principle of spiral milling, is illustrated by the diagrams shown in Fig. 10. If a cylindrical part mounted between centers, as at *A*, is rotated and, at the same time, moved longitudinally at a constant rate, past a revolving cutter *c*, a helical or spiral groove will be milled as indicated by the curved line. Strictly speaking, a curve generated in this way upon a cylindrical surface, is a helix and not a spiral, although such curves will be referred to as spirals in this treatise, because of the universal use of this term at the present time.

Evidently, the lead *l* or distance that this spiral advances in one revolution, will depend upon the ratio between the speed of rotation and the longitudinal feeding movement. If the speed of rotation is increased, the lead of the spiral will be diminished, and *vice versa*, provided the rate of the lengthwise travel remains the same. If the cylinder traverses a distance equal to its length while making one revolution, the dimension *l* (sketch *A*) would equal the lead of the spiral generated, but, if the speed of rotation were doubled, the lead *l*, (sketch *B*), would be reduced one-half (assuming that the rate of lengthwise movement is the same in each case), because the cylinder would then make two revolutions while traversing a distance equal to its length.

Change Gears for Spiral Milling

The method of varying the speed of rotation on a milling machine, for obtaining spirals of different leads, will be seen by referring to Fig. 11 which shows an end and side view of a spiral head mounted on the table of the machine and arranged for spiral milling. The rotary movement of the spindle *S* and the work, is obtained from the feed-screw *L*, which also moves the table longitudinally. This feed-screw is connected to shaft *W* by a compound train of gears; *a*, *b*, *c* and *d*, and the movement is transmitted from shaft *W* to the worm-shaft (which carries the indexing crank) through the spiral gears *e*, *f*. and spur gearing (not shown) which drives the index plate, crank, and worm-shaft. When a spiral is to be milled, the work is usually placed between the centers of the spiral head and foot stock, and change gears *a*, *b*, *c* and *d* are selected to rotate the work at whatever speed is needed to produce a spiral of the required lead. The proper gears to use for obtaining a spiral of given lead, are ordinarily determined by referring to a table which accompanies the machine, although the gear sizes can easily be calculated, as will be explained later.

As an example of spiral milling, suppose we have a cylindrical cutter blank 3¼ inches in diameter in which right-hand spiral teeth are to be milled, as indicated in Fig. 12, which shows the cutter after the teeth have been milled. The blank is first mounted on an arbor which is placed between the centers with a driving dog attached. The arbor should fit tightly into the hole of the blank so that both will rotate as one piece, and it is also necessary to take up all play between the driving dog and faceplate. The spiral head is next geared to the feed-screw. If a table of change gears is available, it will show what gears

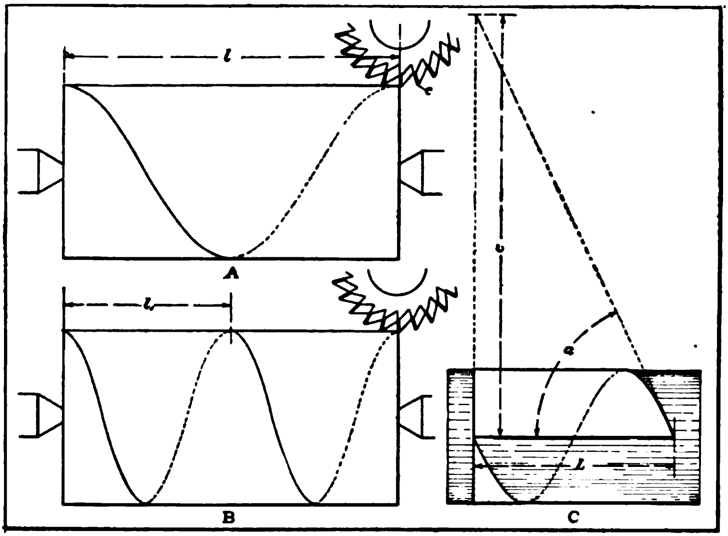

Fig. 10. Diagrams illustrating the Principle of Helical or Spiral Milling

are needed, provided the lead of the spiral is known. A small section of one of these tables is reproduced herewith (see Fig. 13) to illustrate the arrangement. Suppose the lead given on the drawing is 48 inches; then this figure (or the nearest one to it) is found in the column headed, "Lead in Inches," and the four numbers to the right of and in line with 48, indicate the number of teeth in the four gears to be used. The numbers opposite 48 are 72, 24, 64 and 40, respectively, and the position for each of these gears is shown by the headings above the columns. As 72 is in the column headed "Gear on Worm," a gear *d* (see also Fig. 11) of this size is placed on shaft *W*. The latter is referred to as the "worm-shaft," although, strictly speaking, the worm-shaft W_1 is the one which carries the indexing crank and worm. The first gear *c* placed on the stud *E*, has 24 teeth, as shown by the table, and the second gear *b* on the same stud has 64 teeth, whereas gear *a* on the screw has 40 teeth.

After these gears are placed in their respective positions, the first

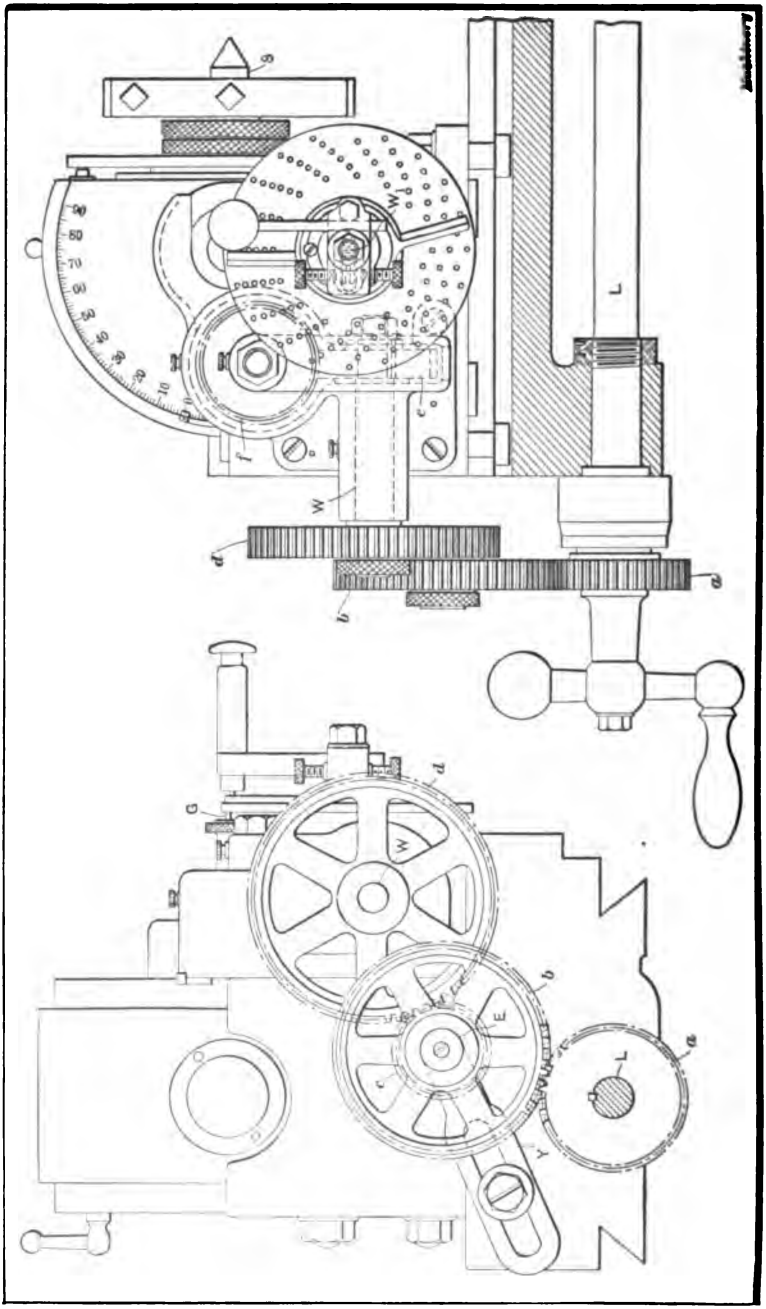

Fig. 11. The Indexing or Spiral Head of a Universal Milling Machine

and second gears c and b on stud E are adjusted to mesh properly with gears a and d by changing the position of the supporting yoke Y. As a right-hand spiral is to be milled, which means that it advances by twisting or turning to the right, an idler gear is not used with the design of spiral head shown. When milling a left-hand spiral, it is necessary to insert an idler gear in the train of gears (as at j in Fig. 17) in order to rotate the work in a reverse direction; this idler has no effect, however, on the ratio of the gearing. When the change gears are in place, evidently any longitudinal movement of the table effected by turning feed-screw L, will be accompanied by a rotary movement of the spiral head spindle. As connection is made with the worm-shaft W_1, Fig. 11, through the index plate and crank, the stop-pin G at the rear must be withdrawn for spiral milling, so that the index plate will be free to turn.

Form of Cutter Used and its Position

The next thing to consider is the kind of cutter to use. If we assume that the grooves are to have an angle of 60 degrees, evidently the cutter must have teeth which conform to this angle. The type used for forming teeth of spiral mills, is shown at A in Fig. 14. The teeth have an inclination with the axis, of 48 degrees on one side and 12 degrees on the other, thus giving an included angle of 60 degrees for the tooth spaces. This form of cutter is used in preference to the single-angle type shown at B, for milling spiral teeth, because the 12-degree side will clear the radial faces of the teeth and produce a smooth surface. The single-angle cutter B is used for milling grooves that are parallel with the axis. The cutter is mounted on an arbor, and it is set in such a position that when the groove is cut to the required depth, the 12-degree side will be on a radial line, as shown by the sketch; in other words, it should be set so that the front faces of the teeth to be milled, will be radial.

Setting the Cutter

A method of setting a double-angle cutter, for milling the teeth in spiral mills, which is simple and does not require any calculations, is, as follows: The pointer of a surface gage is first set to the height of the index head center and then the work is placed in the machine. The cutter is next centered with the blank, laterally, which can be done with a fair degree of accuracy by setting the knee to the lowest position at which the cutter will just graze the blank. The blank is then adjusted endwise until the axis of the cutter is in line with the end of the work, as shown by the side and plan views at A, Fig. 15. One method of locating the cutter in this position (after it has been set approximately) is to scribe a line on the blank, a distance from the end equal to the radius of the cutter. The blade of a square is then set to this line, and the table is adjusted lengthwise until the cutter just touches the edge of the blade. The cutter can also be centered with end (after it is set laterally) by first moving the blank endwise from beneath the cutter, and then feeding it back slowly until a tissue paper "feeler" shows that it just touches the corner of the blank. The relation between the cutter and blank will then be as shown at *A*.

The table is next set to the angle of the spiral (as explained later) but its lengthwise position should not be changed. The surface gage, set as previously described, is then used to scribe lines which represent one of the tooth spaces on the end of the blank where the cut is to start. This is done by first drawing a horizontal line as at *B*. This line is then indexed downward an amount equal to one of the tooth

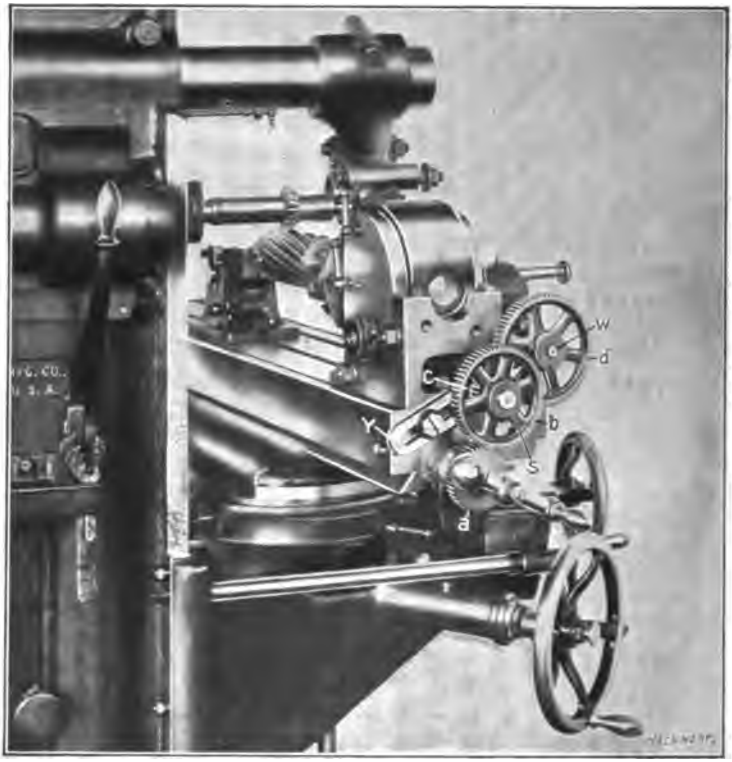

Fig. 12. Universal Machine arranged for Spiral Milling

spaces, and another horizontal line is drawn as at *C*. The last line scribed is then indexed 90 + 12 degrees, which locates it parallel with the 12-degree side of the cutter, as at *D*. The work is then adjusted laterally, and vertically by elevating the knee, until the cutter is so located that the 12-degree side cuts close to the scribed line, and, at the same time, the required width of land *w* (see sketch *E*) is left between the top edge of the groove and the line representing the front face of the next tooth. After the cutter is centered, as at *A*, the longitudinal position of the blank should not be changed until the cutter is set as at *E*, because any lengthwise adjustment of the work would be accompanied by a rotary movement (as the spiral head is geared to the table feed-screw) and the position of the lines on the end would be changed.

Setting the Table to Angle of Spiral and Milling the Grooves

The table of the machine must also be set to the same angle that the spiral grooves will make with the axis of the work. This is done by loosening the bolts which normally hold the saddle to the clamp-bed, and swinging the table around to the right position, as shown by the degree graduations on the base of the saddle. The reason for setting the work to this angle is to locate the cutter in line with the spiral grooves which are to be milled by it. If the cutter were not in line with the spiral, the shape of the grooves would not correspond with

	Driven	Driver	Driven	Driver		Driven	Driver	Driven	Driver		Driven	Driver	Driven	Driver
Lead in Inches	Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches	Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw	Lead in Inches	Gear on Worm	1st Gear on Stud	2nd Gear on Stud	Gear on Screw
42.00	72	24	56	40	48.00	72	24	64	40	56.31	86	24	44	28
					48.38	86	32	72	40	57.14	100	28	64	40
42.23	86	28	44	32	48.61	100	24	56	48	57.30	100	24	44	32
42.66	100	28	86	72	48.61	100	24	28	24	57.33	86	24	64	40
42.78	56	24	44	24	48.86	100	40	86	44	58.33	100	24	56	40
42.86	100	28	48	40	48.89	64	24	44	24	58.44	100	28	72	44
42.86	72	24	40	28	49.11	100	28	44	32	58.64	86	24	72	44
43.00	86	32	64	40	49.14	86	28	64	40	59.53	100	24	40	28
43.00	86	28	56	40	49.27	86	24	44	32	59.72	86	24	40	24
43.00	86	24	48	40	49.77	100	24	86	72	60.00	72	24	64	32
43.64	72	24	64	44	50.00	100	28	56	40	60.00	72	24	56	28
43.75	100	32	56	40	50.00	100	24	48	40	60.00	72	24	48	24
43.98	86	32	72	44	50.00	72	24	40	24	60.61	100	24	64	44
44.44	64	24	40	24	50.00	100	32	64	40	61.08	100	32	86	44
44.64	100	28	40	32	50.17	86	24	56	40	61.43	86	28	64	32
44.68	86	28	64	44	50.26	86	28	72	44	61.43	86	24	48	28

Fig. 18. Part of Table showing Gear Combinations to use for obtaining Spirals of Different Lead

the shape of the cutter. The angle to which the table should be set, or the spiral angle, varies according to the diameter of the work and lead of the spiral. As the diameter, in this case, is 3¼ inches and the lead of the spiral is 48 inches, the angle is 12 degrees. The direction in which the table is turned, depends upon whether the spiral is right- or left-hand. For a right-hand spiral the right-hand end of the table should be moved toward the rear, whereas if the spiral is left-hand, the left-hand end of the table is moved toward the rear.

After the table of the machine is set to the required angle and the saddle is clamped in position, the work is ready to be milled. The actual milling of the spiral grooves is practically the same as though they were straight or parallel to the axis. When a groove is milled, it is well to either lower the table slightly or turn the cutter to such a position that the teeth will not drag over the work, when returning for another cut, to prevent scoring or marring the finished groove. If the work-table is lowered, it is returned to its original position by referring to the dial on the elevating screw. After each successive groove is cut, the work is indexed by turning the indexing crank in the regular way. This operation of milling a groove and indexing, is repeated until all the teeth are finished. It should be mentioned that the differential method of indexing cannot be employed in connection with spiral work, because with this system of indexing, the worm-shaft of the spiral head is geared to the spindle. When milling spiral grooves, the position of the cutter with relation to the work, should be such that the rotary movement for producing the spiral, will be toward that side of the cutter which has the greater angle. To illustrate, the blank *A*, Fig. 14, should turn (as shown by the arrow) toward the 48-degree side of the cutter, as this tends to produce a smoother groove.

Calculating Change-gears for Spiral Milling

As was explained in connection with Fig. 10, the lead of a spiral cut in a milling machine depends on the relation between the rotary speed

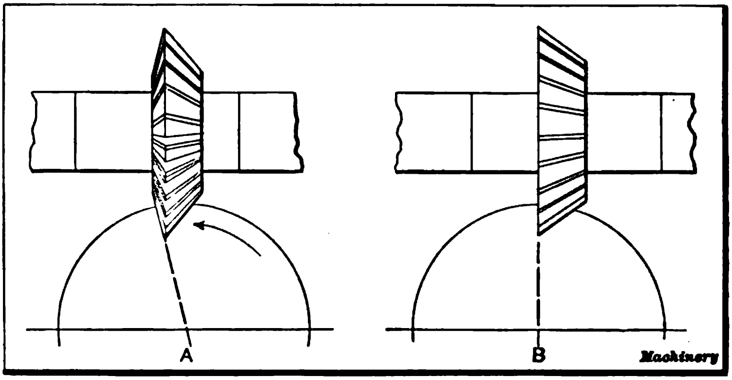

Fig. 14. Double- and Single-angle Cutters

of the work and its longitudinal movement, and these relative speeds are controlled by the change-gears *a*, *b*, *c* and *d*, Fig. 11, which connect the table feed-screw *L* with shaft *W*. If the combination of change-gears is such that 20 turns of screw *L* are required for one revolution of spindle *S*, and the screw has four threads per inch, the table will advance a distance equal to $20 \div 4 = 5$ inches, which is the lead of the spiral obtained with that particular gearing. Now the proper gears to use for producing a spiral of any given lead, can easily be determined if we know what lead will be obtained when change-gears of equal diameter are used. Suppose gears of the same size are employed, so that feed-screw *L* and shaft *W* rotate at the same speed; then the feed-screw and worm-shaft W_1 will also rotate at the same speed, if the gearing which forms a part of the spiral head and connects shafts *W* and W_1 is in the ratio of one to one, which is the usual construction. As will be recalled, 40 turns of the worm-shaft are required for each revolution of spindle *S*; therefore with change-gears of the same diameter, the feed-screw will also make 40 turns, and assuming that it has four threads per inch, the table movement will equal $40 \div 4 = 10$ inches. This movement, then, of 10 inches, equals the lead of the spiral that would be obtained by using change-gears of the same size, and it is known as the *lead of the machine.*

If we wanted to mill a spiral having a lead of 12 inches and the lead of the machine is 10, the compound ratio of the gears required would be $\frac{12}{10}$ or $\frac{\text{lead of spiral}}{\text{lead of machine}}$. The compound ratio, then, may be represented by a fraction having the lead of the required spiral as its numerator and the lead of the machine or 10 as its denominator. In

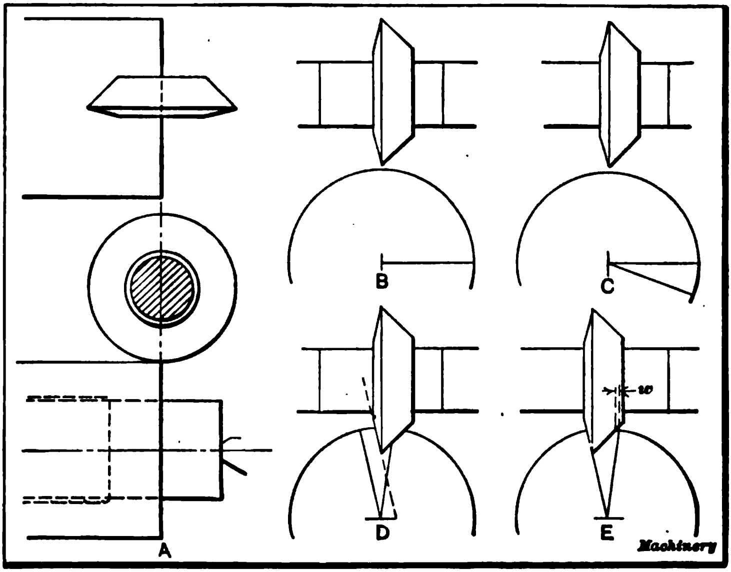

Fig. 15. Setting a Double-angle Cutter for Milling Teeth of a Spiral Mill

order to find what size gears to use, this ratio is revolved into two factors as follows:

$$\frac{12}{10} = \frac{3}{2} \times \frac{4}{5}$$

Each factor is then multiplied by some number which will give a numerator and denominator that corresponds to numbers of teeth on change-gears furnished with the machine. Suppose both terms of the first factor are multiplied by 24; we would then have,

$$\frac{3}{2} \times \frac{24}{24} = \frac{72}{48}$$

The second factor is also raised to higher terms in the same way; that is by using some multiplier which will give a new fraction, the numerator and denominator of which equals the numbers of teeth in available gears. Suppose 8 is chosen for the second multiplier; we then have,

$$\frac{4}{5} \times \frac{8}{8} = \frac{32}{40}$$

The set of fractions obtained in this way, that is $\frac{72}{48}$ and $\frac{32}{40}$, represent the gears to use for milling a spiral having a lead of 12 inches. The numerators equal the number of teeth in the driven gears, and the denominators the number of teeth in the driving gears. If numbers occurred in either fraction which did not correspond with the number of teeth in any of the change-gears available, the fraction should be multiplied by some other trial number until the desired result is obtained.

Relative Positions of the Change-gears

When the gears for cutting a given spiral are known, it remains to place them in the proper place on the machine, and in order to do this, the distinction between *driving* and *driven* gears should be understood. The gear *a* (Fig. 11) on the feed-screw is a driver and gear *b*, which is rotated by it, is driven. Similarly, gear *c* is a driver and gear *d* is driven. As the numerators of the fractions represent driven gears, one having either 72 or 32 teeth (in this instance) should be placed on shaft *W*. Then a driving gear with either 40 or 48 teeth is placed on stud *E* and the remaining driven gear is afterwards mounted on the same stud. The other driving gear is next placed on the screw *L* and yoke *Y* is adjusted until the gears mesh properly. The spiral head will then be geared for a lead of 12 inches, the gear on the worm having 72 teeth, the first gear on the stud having 40 teeth, the second gear having 32 teeth, and the gear on the screw having 48 teeth. Either the driving or driven gears could be transposed without changing the lead of the spiral. For example, the driven gear with 32 teeth could be placed on shaft *W* and the one having 72 teeth could be used as a second gear on the stud, if such an arrangement were more convenient. As previously stated, a reverse or idler gear is inserted in the train when cutting left-hand spirals, but it does not affect the ratio of the gearing.

Determining the Angle of the Helix or Spiral

When the change-gears for a given spiral have been selected, the next step is to determine the angle to which the table of the machine must be set in order to bring the milling cutter in line with the spiral. This angle equals the angle that the spiral makes with its axis and it depends upon the lead of the spiral and the diameter of the cylindrical part to be milled. The angle of a spiral can be determined graphically by drawing a right-angle triangle as shown by sketch *C*, Fig. 10. If the length *e* of one side equals the circumference of the cylinder on which the spiral is to be generated, and the base *L* equals the lead, the angle *a* will be the spiral angle. If such a triangle is wrapped around the cylinder, the hypothenuse will follow a helical curve, as the illustration indicates.

Another way of determining the angle of a spiral is to first get the tangent of the angle by dividing the circumference of the work by the lead of the spiral. When the tangent is known, the corresponding angle is found by referring to a table of natural tangents. For example, if the circumference e is 12 inches, and the lead L is 48 inches, the tangent equals $\frac{12}{48} = 0.25$ and the angle a corresponding to this tangent is about 14 degrees. Evidently, if the circumference is increased or

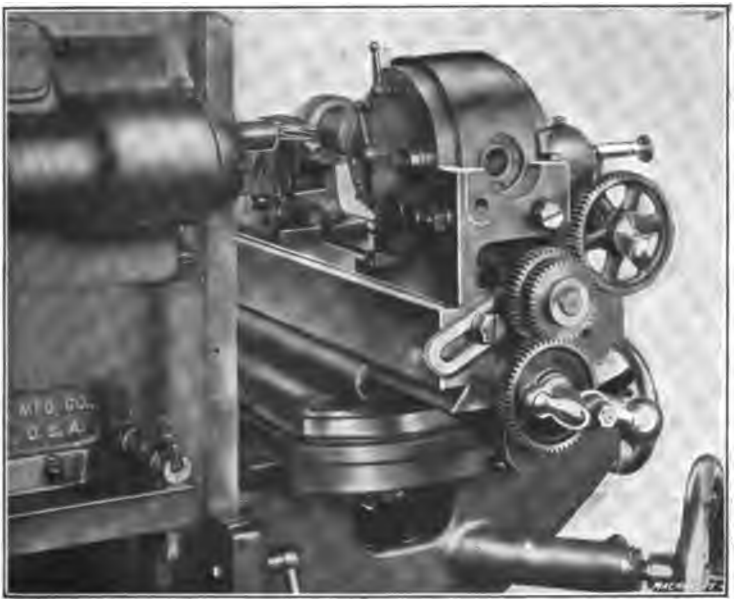

Fig. 16. Milling a Spiral Groove with an End Mill

diminished, there will be a corresponding change in angle a provided the lead L remains the same. For that reason, the outer circumference is not always taken when calculating the spiral angle. The angle for setting the table when cutting spiral gears in a milling machine, is determined by taking the diameter either at the pitch circle, or at some point between the pitch circle and the bottoms of the teeth, rather than the outside diameter, in order to secure teeth of the proper shape.

Cutting Spiral Grooves with an End Mill

When a spiral groove having parallel sides is required it should be cut with an end mill as illustrated in Fig. 16. If an attempt were made to mill a groove of this kind by using a side mill mounted on an arbor, the groove would not have parallel sides, because the side teeth of the mill would not clear the groove; in other words, they would cut away the sides owing to the rotary movement of the work and form a groove having a greater width at the top than at the bottom. This can be overcome, however, by using an end mill. The machine is geared for the required lead of spiral, as previously explained, and the work is adjusted vertically until its axis is in the same horizontal plane as the center of the end mill. With the machine illustrated, this vertical adjustment can be obtained by moving the knee up until its top surface coincides

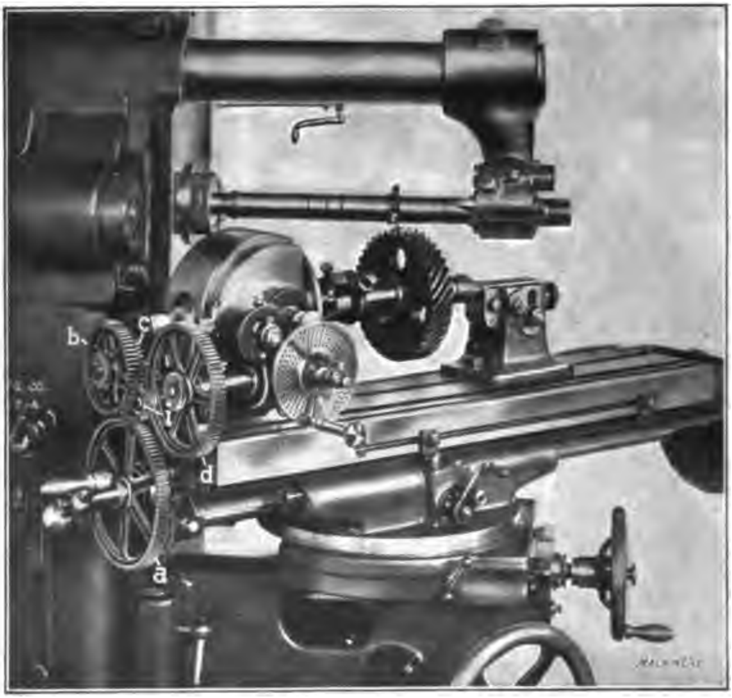

Fig. 17. Cutting the Teeth of a Spiral Gear in a Universal Milling Machine

with a line on the column marked *center*; the index head centers will then be at the same height as the axis of the machine spindle.

Cutting a Spiral Gear in a Universal Milling Machine

The teeth of spiral gears are often cut in universal milling machines, as indicated in Fig. 17, although special gear-cutting machines are used ordinarily where spiral gears are constantly being made, because the special machines are more efficient. As the teeth of a spiral gear are inclined to the axis and follow helical or "spiral" curves, they are formed by milling equally-spaced spiral grooves around the periphery of the blank, the number of the grooves corresponding, of course, to the number of teeth in the gear. From this it will be seen that a spiral gear is similar to a multiple-threaded screw, except that the teeth do not correspond in shape to screw threads; in fact, this type of gearing is sometimes referred to as screw gearing.

Cutter to Use for Spiral Gears

Because of the inclination of the teeth, the cutting of spiral gears is quite different from the method followed for spur gears, as far as the arrangement of the machine and the selection of the cutter is concerned. The spiral head must be connected to the table feed-screw by change gears that will give a spiral of the required lead, and the proper cutter to use depends upon the number of teeth in the gear, their pitch and the spiral angle. Just why the inclination of the teeth to the axis of the gear is considered when selecting a cutter will be more clearly understood by referring to the diagrammatical view of a spiral gear shown in Fig. 18. The circular pitch of the teeth is the distance *c* measured along the pitch circle at one end of the gear, or in a plane at right angles to the axis.

As will be seen, the circular pitch in the case of a spiral gear is not the shortest distance between the adjacent teeth, as this minimum distance *n* is along a line at right angles to the teeth. Hence, if a cutter is used having a thickness at the pitch line equal to one-half the circular pitch, as for spur gearing, the spaces between the teeth would be cut too wide and the teeth would be too thin. The distance *n* is referred to as the normal circular pitch, and the thickness of the cutter at the pitch line should equal one-half this pitch. Now, the normal pitch varies with the angle of the spiral, which is equal to angle *a;* consequently, the spiral angle must be considered when selecting a cutter.

If a gear has thirty teeth and a pitch diameter of 6 inches, what is sometimes referred to as the *real* diametral pitch is 5 $(30 \div 6 = 5)$ and in the case of a spur gear, a cutter corresponding to this pitch would be used; but if a 5-pitch cutter were used for a spiral gear, the tooth spaces would be cut too wide. In order to secure teeth of the proper shape when milling spiral gears, it is necessary to use a cutter of the same pitch as the normal diametral pitch.

The normal diametral pitch can be found by dividing the real diametral pitch by the cosine of the spiral angle. To illustrate, if the pitch diameter of the gear shown in Fig. 17 is 6.718 and there are 38 teeth having a spiral angle of 45 degrees, the real diametral pitch equals $38 \div 6.718 = 5.656$; then the normal diametral pitch equals 5.656 divided by the cosine of 45 degrees, or $5.656 \div 0.707 = 8$. A cutter, then, of 8-diametral pitch is the one to use for this particular gear.

This same result could also be obtained as follows: If the circular pitch *c* is 0.5554 inch, the normal circular pitch *n* can be found by multiplying the circular pitch by the cosine of the spiral angle. For example, $0.5554 \times 0.707 = 0.3927$. The normal diametral pitch is next found by dividing 3.1416 by the normal circular pitch To illustrate,

$$\frac{3.1416}{0.8927} = 8,$$ which is the diametral pitch of the cutter.

Of course, in actual practice, it is not generally necessary to make such calculations, as the pitch of the gear, the lead and angle of the spiral, etc., is given on the drawing, and the work of the machinist is confined to setting up the machine and cutting the gear according to specifications. It is much easier, however, to do work of this kind when the fundamental principles are understood.

As previously explained in Chap. II, the proper cutter to use for spur gears depends not only upon the pitch of the teeth, but also upon the number of teeth in a gear, because the teeth of a small gear do not have the same shape as those of a much larger size of the same pitch. Therefore, according to the Brown & Sharpe system for spur gears having involute teeth, eight different shapes of cutters (marked by numbers) are used for cutting all sizes of gears of any one pitch from a 12-tooth pinion to a rack. The same style of cutter can be used

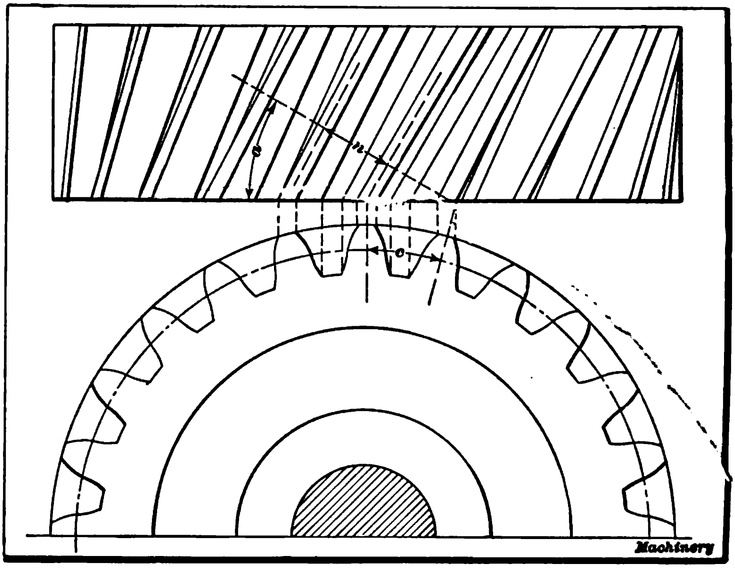

Fig. 18. The Circular Pitch of a Spiral Gear is the Distance o and the Normal Pitch, Distance n

for spiral gearing, but the cutter is not selected with reference to the actual number of teeth in the gear, as with spur gearing.

By referring to the list of cutters given on page 11, Chapter II, it will be seen that a No. 3 would be used for a spur gear having 38 teeth. A spiral gear with 38 teeth, however, might require a cutter of some other number, because of the angular position of the teeth. If the actual number of teeth in a spiral gear is divided by the cube of the cosine of the tooth angle, the quotient will represent the number of teeth for which the cutter should be selected, according to the system for spur gears. If we assume that a gear is to have 38 teeth cut at an angle of 45 degrees, then the cutter to use would be determined as follows: The cosine of 45 degrees is 0.7071 and $38 \div 0.7071^3 = \frac{38}{0.3535} = 107$. The list of cutters previously referred to calls for a No. 2 cutter for spur gears having any number of teeth between 55 and

134; hence, that is the cutter to use for a spiral gear having 38 teeth and a tooth angle of 45 degrees. It will be understood that this number has nothing to do with the pitch of the cutter, which is determined as previously explained; it is simply that one of the eight cutters (according to the B. & S. system) which is made for milling gears having numbers of teeth between 55 and 134.

The number obtained by the foregoing rule is much larger than the actual number of teeth in the spiral gear. This is because a line at right-angles to the teeth, along which the normal pitch is measured, has a larger radius of curvature than the pitch circle of the gear (although, strictly speaking, the term radius is incorrectly used, as this line is a helix and not a circle) and the curvature increases or diminishes for corresponding changes in the spiral angle. Therefore, the number of teeth for which the cutter is selected depends upon the angle of the spiral, as well as the actual number of teeth in the gear. As the angle becomes smaller, the difference between the normal and circular pitches also diminishes until, in the case of spur gears, the normal and circular pitches are equal.

Gearing Machine—Position of Table

The change gears *a*, *b*, *c* and *d*, Fig. 17, connect the spiral head and table feed-screw and rotate the gear blank as the table feeds lengthwise, in order to produce the spiral teeth. The relative sizes of these gears depend upon the lead of the spiral or the distance that any one tooth would advance if it made a complete turn around the gear. When calculating the sizes of spiral gears, the diameter and angle of the teeth is usually made to suit conditions; consequently, the lead of the spiral is sometimes an odd dimension that cannot be obtained exactly with any available combination of change gears, although some combination of the gears furnished with a universal milling machine will generally give a lead which is close enough for all practical purposes.

The gear shown in Fig. 17 has left-hand spiral teeth. Therefore it is necessary to place an idler gear *I* in the train of gears in order to reverse the rotation of the gear blank. Without this idler, the rotation would be in the opposite direction and a right-hand spiral would be milled.

Before the teeth of a spiral gear can be milled the table of the machine must be set to the spiral angle. This is done so that the cutter will produce grooves and teeth of the proper shape. As previously explained. the angle of a spiral depends upon the lead *L* (see Fig 10), and the circumference *e* of the cylindrical surface (which may be either real or imaginary) around which the spiral is formed. The smaller the circumference, the smaller the angle *a*, assuming that the lead *L* remains the same. The angle, then, that the teeth of a spiral gear make with the axis, gradually diminishes from the tops to the bottoms of the teeth, and if it were possible to cut a groove right down to the center or axis, its angle would become zero. Hence, if the table of the machine is set to the angle at the top of a tooth, the cutter will not be in line with the bottom of the groove, and, consequenly, the teeth will not be milled to the correct shape. It is a common practice to set the table to the angle at the pitch line, which is nearly halfway between the top and bottom of the tooth, although some contend that if the angle near the bottom of the groove is taken, teeth of better shape will be obtained.

Whatever the practice may be the angle is determined by first getting the tangent and then the corresponding angle from a table of tangents. For example, if the pitch diameter of the gear is 4.46 and the lead of the spiral is 20 inches, the tangent will equal $\frac{4.46 \times 3.1416}{20}$ $= 0.700$, and 0.700 is the tangent of 35 degrees, which is the angle to which the table is set from the normal position at right angles to the spindle.

The table is adjusted by loosening the bolts which ordinarily hold it to the clamp-bed and swiveling it around until the 35-degree graduation on the circular base coincides with the stationary zero mark. Before setting the table to the spiral angle, the cutter should be located directly over the center of the gear blank. An accurate method of centering a cutter of this kind was described in connection with Fig. 8, Chapter II.

Milling the Spiral Teeth

The teeth of a spiral gear are proportioned from the normal pitch and not the circular pitch. The whole depth of the tooth, that is the depth of each cut, can be found by dividing the constant 2.157 by the normal diametral pitch of the gear; the latter, as will be recalled, corresponds to the pitch of the cutter. The thickness of the gear at the pitch line equals 1.571 divided by the normal diametral pitch. After a cut is completed the cutter should be prevented from dragging over the teeth when being returned for another cut. This can be done by lowering the blank slightly or by stopping the machine and turning the cutter to such a position that the teeth will not touch the work. If the gear has teeth coarser than 10 or 12 diametral pitch, it is well to cut twice around; that is, take a roughing and a finishing cut.

When pressing a spiral gear blank on the arbor, it should be remembered that spiral gears are more likely to slip when being cut than spur gears. This is because the tooth grooves are at an angle and the pressure of the cut tends to rotate the blank on the arbor.

CHAPTER IV

THE VERTICAL MILLING MACHINE

When an end mill is driven directly by inserting it in the spindle of a milling machine of the horizontal type it is often difficult to do satisfactory work, especially if much hand manipulation is required, because the mill operates on the rear side where it cannot readily be seen when one is in the required position for controlling the machine. Moreover, it is frequently necessary to clamp the work against an angle-plate to locate it in a vertical position or at right-angles to the end mill, when the latter is driven by a horizontal spindle. In order to overcome these objectionable features special vertical milling attachments are used to convert a horizontal machine temporarily into a vertical type. These vertical attachments are very useful, especially when the shop equipment is comparatively small and a horizontal machine must be employed for milling a great many different parts, but where there is a great deal of work that requires end milling, it is better to use a machine having a vertical spindle.

A vertical milling machine is shown in Fig. 19. The part to be milled is attached to table *T* and the cutter is driven by the vertical spindle *S*, so that it is always in plain view. This is particularly desirable when milling an irregular outline, or any part that requires close attention.

The table of this machine has longitudinal, crosswise, and vertical movements, all of which can be effected either by hand or by the automatic power feeds. The spindle and the slide which supports the lower end can also be fed vertically, within certain limits, by hand or power. It should be mentioned that milling machines of this type do not always have vertical movements for both the spindle and table. In some designs the table, instead of being carried by a sliding knee *K*, is mounted on a fixed part of the base which extends forward beneath it; whereas other machines have a table that can be moved vertically, but a spindle that remains fixed, as far as vertical movement is concerned.

The particular machine shown in Fig. 19 is driven by a belt pulley *P*, which transmits power through gears and shafts to spindle *S*. This belt pulley is connected or disconnected with the driving shaft by vertical lever *M*, which serves to start and stop the machine. The speed of the spindle is varied by levers *A*, *B*, *C*, and *D*. Levers *A* and *B* operate a tumbler-gear through which four speeds are obtained. This number is doubled by lever *C*, and lever *D* doubles it again, thus giving a total of sixteen speeds. The direction of rotation is reversed by lever *H*.

The power feeds for the table are varied by the levers seen attached to the feed-box *F*. The feed motion is transmitted to a reversing box on the side of the knee, by a telescoping shaft, the same as with a horizontal machine. Lever *R* may be used to start, stop or reverse the automatic table feeds; lever *V* controls the vertical movement of the knee and table; and lever *N* the cross-movement. The table is reversed by lever *L* at the front, the reversing lever *R* not being used for this

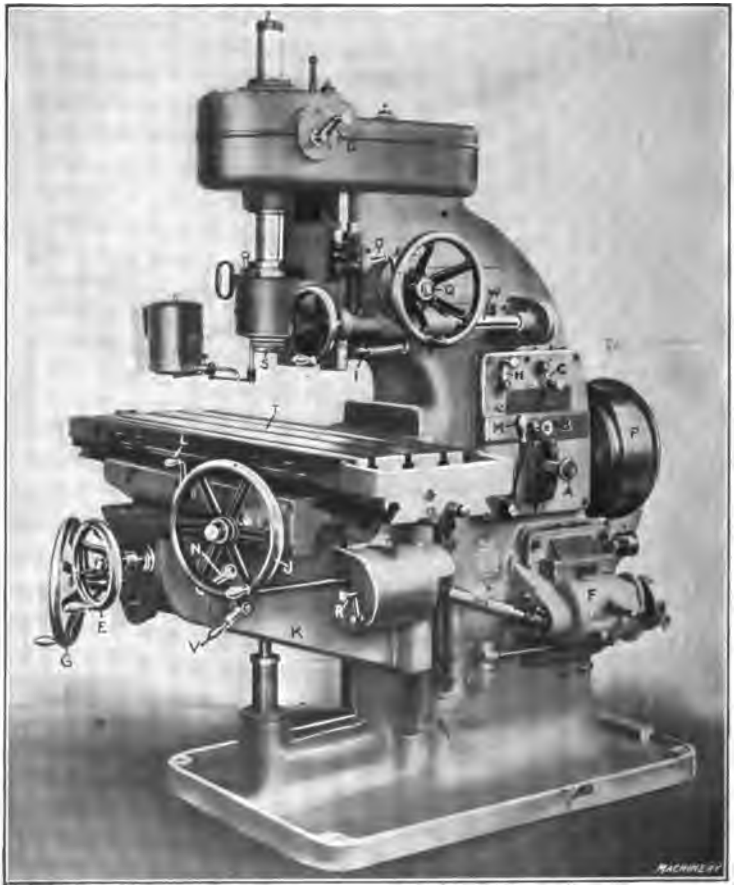

Fig. 19. Brown & Sharpe Vertical-spindle Milling Machine

purpose. The handwheel *G* is for raising and lowering the table, and the smaller wheel *E* is for the transverse adjustment. By means of handwheel *J* the table can be given a fast or slow movement, or the wheel can be disconnected entirely, a clutch in the center of the hub being used to make these changes. The handwheels *E* and *G* can also be disengaged from their shafts by knobs in the center of each wheel. This is done to prevent the table from being shifted after an adjustment is made, in case the workman should accidentally turn one of the wheels.

The vertical feed for the spindle head is also varied by the mechanism at *F*, the required motion being transmitted to the top of the machine by a chain and sprockets which drive worm-shaft *W*. This worm-shaft is connected with the upper sprocket through a clutch controlled by lever *I*. This same clutch is also operated by adjustable stops clamped into T-slots in the side of the spindle-head, for automatically disengaging the vertical feed at any predetermined point. Shaft *W* transmits the feeding movement to the spindle, through worm gearing, and a pinion shaft *Q*, and lever *O* engages or disengages the worm-wheel with this pinion shaft. When the worm-wheel is disengaged, the large handwheel at the side of the column may be used to raise or lower the spindle rapidly, and, at other times, the small hand-wheel at the front gives a slow feeding movement.

Circular Milling Attachment

The vertical milling machine is often used for milling circular surfaces or slots. In order to do this it is necessary to impart a rotary movement to the piece being milled. This is done by means of a circular milling attachment which is bolted to the main table of the machine, as shown in Fig. 21. The table of the attachment can be revolved by handwheel *A* or automatically. The power feed is derived from the splined shaft which drives the longitudinal feed-screw of the table, this shaft being connected by a chain and sprockets to shaft *B* which transmits the movement to the attachment. When the attachment is in use the table feed-screw is disconnected from the splined shaft, so that the feeding movement is transmitted to the circular table only. For adjusting the longitudinal table, when using the circular attachment, a crank is applied to the squared end of the screw at the left end of the table. The circular attachment has automatic stops for disengaging the feed at any point, which are held in a circular T-slot cut in the periphery of the table. The circumference of the table is also graduated in degrees, so that angular adjustments can be made when necessary.

Vertical Milling Operations

The vertical milling machine illustrated in Fig. 19 is shown at work in Fig. 20. The casting *C*, which is being milled, is the saddle of a milling machine, and the operation is that of finishing the dovetail ways for the table. The ways on the under side have already been milled and this finished part is placed against a plate or fixture *F*, having a slide similar to the knee upon which the saddle will be mounted when assembled.

The cutter used for this job has radial end teeth for milling the flat or bottom surfaces, and angular teeth for finishing the dovetail. The cutter revolves in a fixed position, and the slide is milled by feeding the table endwise after it is adjusted to the proper vertical and crosswise positions. The fixture is made in two parts, and the top section can be swiveled slightly so that the dovetail can be milled tapering on one side for the gib which is afterward inserted. The top part of the fixture is located in the proper position when milling either the straight or taper side, by a pin which passes through the upper and lower plates.

Milling a Circular T-slot

The operation illustrated in Fig. 21, as previously intimated, requires the use of a circular attachment, as it is necessary to mill a circular T-slot. The casting in which this slot is being cut, is the wheel-stand slide of a cylindrical grinder and the slot receives the

Fig. 20. Example of Milling on Vertical Milling Machine

heads of clamping bolts. As the T-slot must be concentric with a hole previously bored in the casting, it is necessary to locate this hole in the center of the circular table. This is done by placing an arbor in the central hole of the table, having a bushing which just fits the hole in the casting. The latter is held to the circular table by a clamp and the bolts shown.

The T-slot is formed by two operations: A plain, rectangular slot is cut first by using an ordinary end-mill, and then the enlarged T-section at the bottom is milled by a special T-slot cutter. This particular view was taken after the T-slot cutter had completed about one-quarter of the groove. The cutter rotates in one position and the circular groove is milled as the casting is slowly fed around by the circular attachment. The shape of the finished slot is clearly shown to the left, and the plain rectangular slot cut by the first operation is shown to the right.

Examples of End and Edge Milling

Fig. 22 shows how a vertical machine is used for milling the bearing brasses of an engine connecting-rod. These brasses are cast with

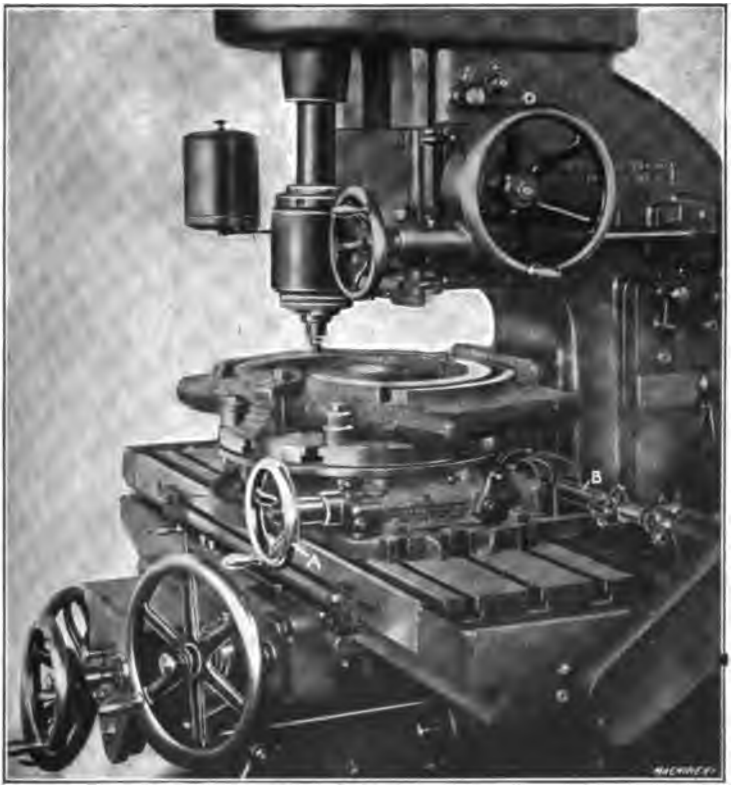

Fig. 21. Milling a Circular T-slot on a Vertical Machine

flanged sides which must be finished to fit the strap which holds the brasses in position on the rod. An end-mill is used for this work. The end or radial teeth finish the bottom of the groove, while the cylindrical part of the mill finishes the groove to the required width. The brasses are clamped to a special box-shaped angle-plate, and four sets are milled at one passage of the tool. For finishing the opposite sides, the milled surfaces are "bedded" on a cylindrical rod to align them with the table. In this way both sides are finished parallel.

Work of this kind is often done in the shaper, but these small brasses can be finished more rapidly by milling, as the bottom of the grooves and the sides of the flanges are milled simultaneously, whereas, with the shaper it would be necessary (with a single-pointed tool) to cut down each side and plane the horizontal surface at the bottom of the groove, separately. Furthermore, it is easier to mill these brasses to a uniform size than to plane them in a shaper. When milling, the width between the flanges is governed by the diameter of the cutter, but if a shaper were used, this width would depend on the adjustment of the tool, which might not always be set in exactly the

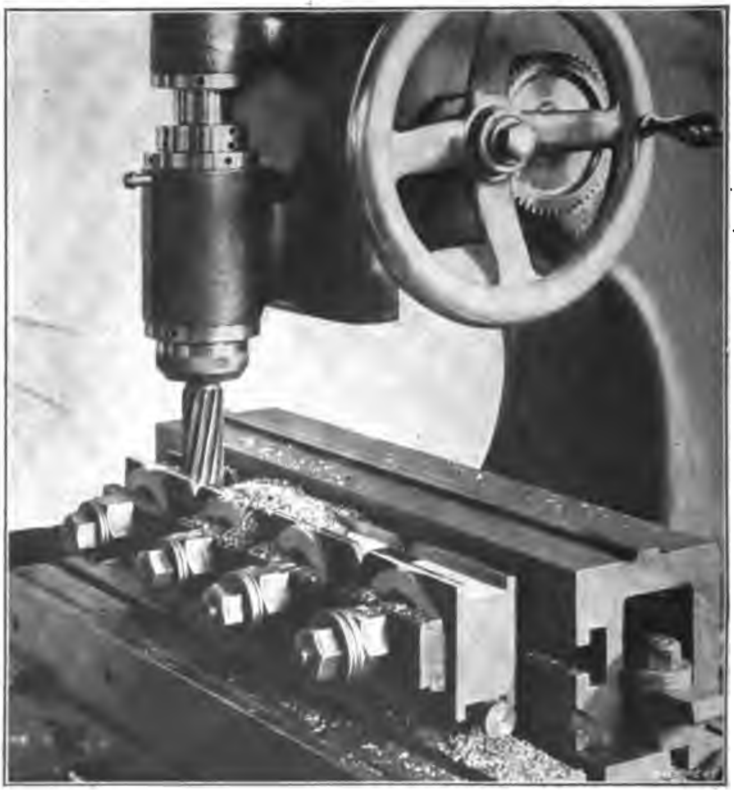

Fig. 22. Milling Connecting-rod Bearing Brasses on Becker Vertical Machine

same position. The vertical milling machine used for this operation, is not the same as the one previously illustrated, although its construction is very similar and it is used for the same class of work.

The vertical milling machine is often used for finishing the edges of straight or circular parts, and irregular shapes can also be worked out by using the longitudinal and cross feeds alternately, as may be required. Of course, if an irregular outline is to be followed, the machine is fed by hand. At *A*, Fig. 23, is shown an odd-shaped steel forging, the rough end and sides of which are finished by milling, as indicated at *B*. The straight sides and part of the circular hub are first milled as shown in this illustration. As the hole through the hub has already been bored, this is used for locating the forging in a central position, the bored hub being placed over a close-fitting cylindrical piece that is clamped to the table as shown. The work is held by a bolt and heavy washer at the top, and it is kept from turning by a small angle-plate which is set against the flanged end.

As the illustration shows, the edge is finished by a spirally-fluted end-

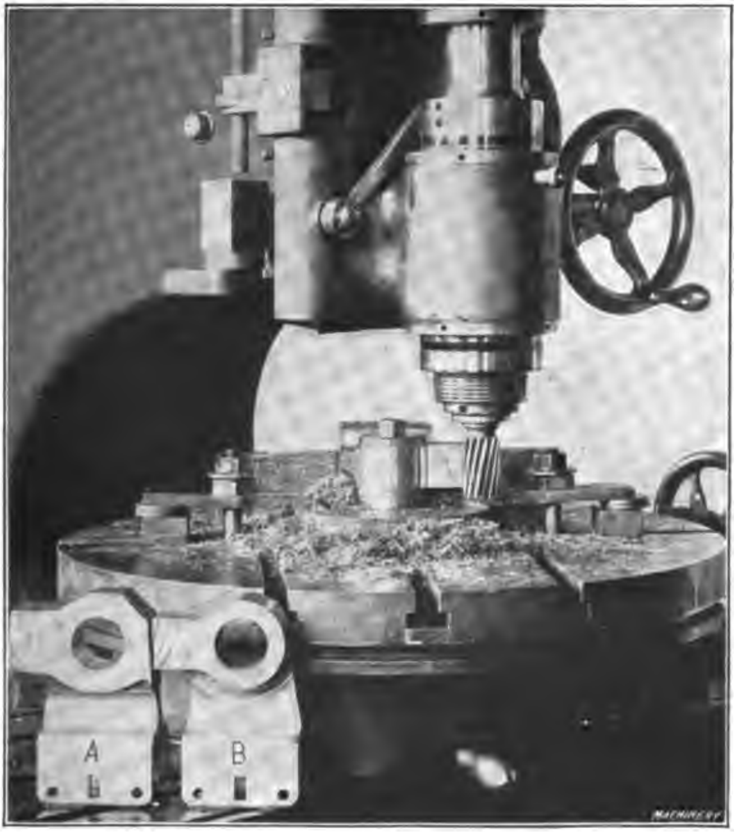

Fig. 23. Milling the Edge of a Steel Forging

mill. The table of the machine is fed longitudinally for milling the straight part, and then the circular attachment is used for finishing the circular hub, around as far as the projecting flanged end will permit. The circular end of the hub is then completed (as shown in Fig. 24) by using a different type of cutter which rounds that part of the hub next to the projecting end and gives a finished appearance to the work. This cutter, which is called a "rose mill," has a spherical end that forms a fillet as it feeds around.

This particular forging may require a little handwork for finishing one or two rough, uneven spots left by milling, but this is very slight at the most. Without a milling machine, however, it would be necessary to trim up this part by hand, and to make a neat job of it would require considerable time. In fact, before the milling machine came into use, vise or handwork was done on a much more extensive scale than at the present time, and, incidentally, the amount of handwork in connection with the fitting and erecting of machinery, is gradually

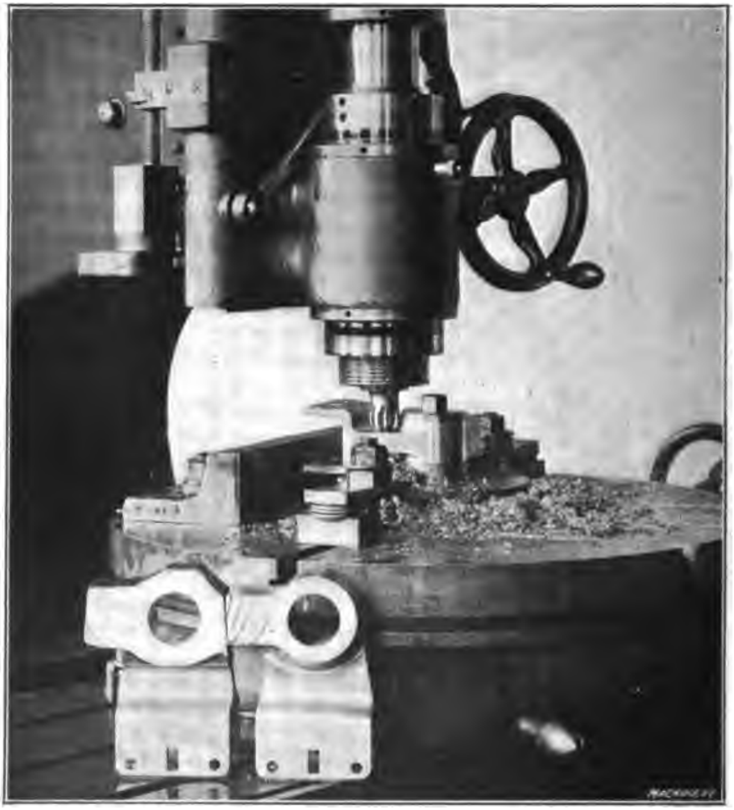

Fig. 24. Finishing a Circular Fillet with a Rose Milling Cutter

diminishing, owing to the high degree of accuracy with which parts can be finished, not only by milling but by modern machines and methods generally.

When milling edges in the vertical machine, the depth of the cut is sometimes limited by the spring of the cutter arbor, although when quite wide edges have to be milled, the arbor is sometimes supported at the lower end by a bracket which is attached to the column of the machine. This prevents the cutter from springing away from the work, and enables fairly heavy cuts to be taken.

Surface Milling in the Vertical Machine

While the vertical milling machine is especially adapted for milling straight or curved edges or surfaces of irregular shape, it is also very efficient for finishing plain, flat surfaces on certain classes of work. Frequently the top of a casting or forging and its sides or edges, can be milled at one setting, which not only saves time but insures accuracy. When a flat, horizontal surface is milled in a vertical machine,

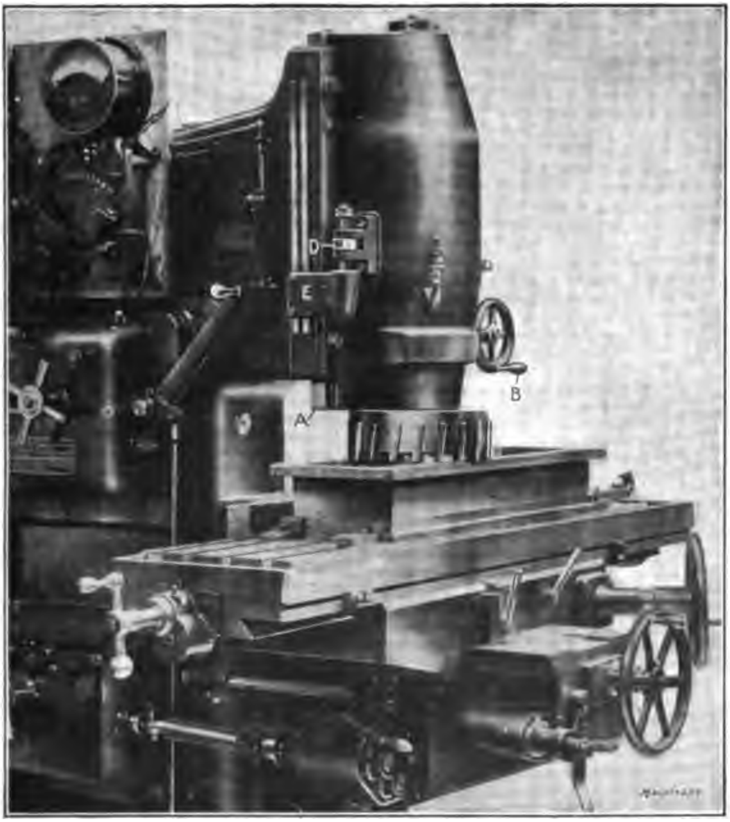

Fig. 25. Finishing Top Surface of a Casting on a Cincinnati Vertical Machine

a face cutter is used, as shown in Fig. 25. This cutter, which is over 12 inches in diameter, is screwed to the end of the spindle and the flange around the casting *C* is milled by the ends of the inserted teeth or blades. This cutter is large enough to mill both sides of the casting in one cut. The over-all dimensions of this part are 12 by 36 inches, and the width of the flanges on each side is 2 inches.

The machine shown in this illustration is a powerful, rigid design especially adapted for work of this kind. It is similar in many respects to the plain horizontal machine described in Chapter I, Part I, of this treatise, excepting, of course, the changes necessary on account of the vertical location of the spindle. The part to be milled is bolted directly to the table, and, before milling the first casting, the knee is elevated, so that the spindle slide *A* will not need to extend much below its bearing when the cutter is at work. The spindle and cutter are then lowered for the right depth of cut by using the fine hand-feed which is operated by the small wheel *B* at the right of the spindle. After rough milling the surface by traversing the table longitudinally, the feed is reversed and a finishing cut 0.010 of an inch deep is taken, as the table feeds in the opposite direction.

Fig. 26. Machine equipped with Two Work-holding Fixtures so that One Casting can be chucked while the Other is being Milled

The micrometer stop *D* which engages an arm *E* bolted to the side of the column, makes it possible to set the cutter to the same vertical position, when milling a number of castings of the same height. This same casting can also be milled by using a smaller cutter which covers a flange on one side only, instead of the entire casting. When the smaller cutter is employed, it is made to follow the rectangular flange by using the longitudinal and cross feeds, alternately.

The example of vertical face milling shown in Fig. 26 illustrates a modern method of chucking castings and operating the machine, when large numbers of duplicate parts have to be milled. There are two independent work-holding fixtures mounted on the table, and the cutter moves from one casting to another. First a roughing cut is taken about 3/16 inch deep, with the table feeding 7¾ inches per minute. When the working side of the cutter reaches the end of the casting, the feed is reversed and increased to 20 inches per minute for the return or finishing cut. Meanwhile, another casting is placed in the other fixture, and when the cutter reaches it, the feed is reduced to 7¾ inches. While this roughing cut is being taken, a new piece is chucked in the other fixture, and so on, one casting being chucked while the other is being milled, so that the milling operation is practically continuous. Of course, this method of handling the work, cannot be employed unless it is possible to clamp the part in the proper position in a comparatively short time. The fixtures shown in this illustration are made like milling machine vises and have special jaws

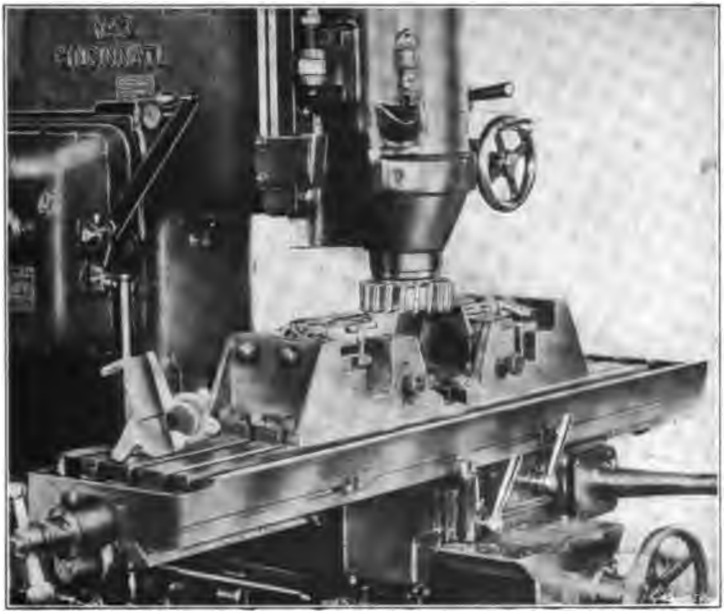

Fig. 27. Another Milling Operation Employing Two Fixtures

with angular faces which hold a casting firmly against the base of the vise.

Fig. 27 shows a continuous milling operation similar to the one just referred to, as far as the method of chucking the work is concerned. There are two independent fixtures, as before, and the castings are inserted in each fixture alternately; that is, one is being chucked while the other is being milled. The machine is fitted with an automatic reverse, and the table travels back and forth without stopping. Two cuts are taken across each piece; first a roughing cut and then a finishing cut on the return movement of the table. One of the finished castings is shown on the left end of the table. The material is malleable iron and the milled surface has an over-all dimension of 6 by 7 inches. From 1/16 to 3/32 inch metal is removed, and the table feeds 12½ inches per minute.

Continuous Circular Milling

The continuous method of face milling is also done in connection with a circular attachment. The parts to be milled are held in a fixture near the edge of the table, and, as the latter revolves, one casting after another is fed beneath the revolving cutter. An example of continuous circular milling is shown in Fig. 28. The operation is that of milling sad-irons These are held in a fixture having a capacity for fourteen castings. The table makes one revolution in from three to four minutes when doing this particular work. As the finished cast-

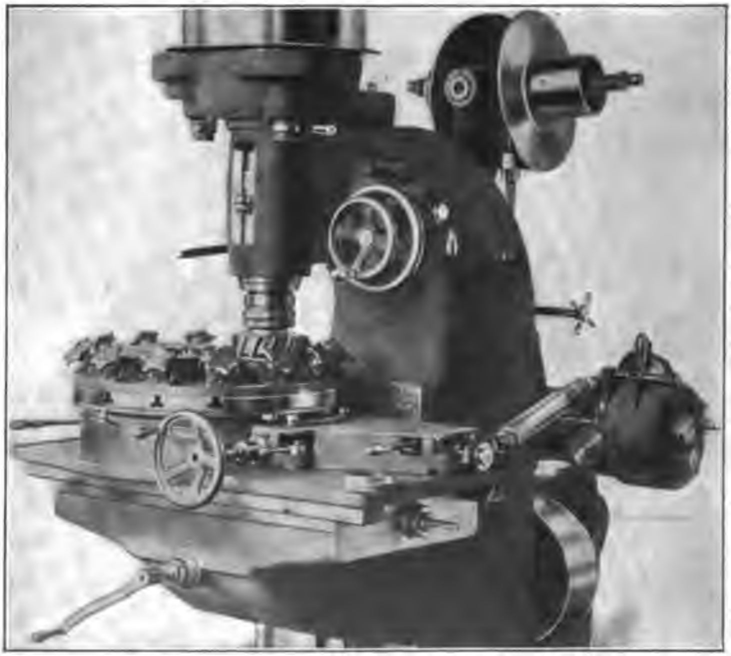

Fig. 28. Becker Vertical-spindle Machine for Continuous Circular Milling

ings come around to the front they are removed and replaced by rough ones, without stopping the machine so that the milling operation is continuous. From two thousand to three thousand castings can be milled per day by this method, the number depending on the kind of material. The fixture has star-shaped clamping nuts which make it possible to quickly release a finished casting or clamp a rough one in position. This machine is not a regular vertical milling machine of the standard type, but is especially designed for continuous circular milling. The table is without cross adjustment but can be fed longitudinally for straight surface milling. Continuous circular milling is also done on standard vertical machines by using the circular milling attachment, as previously mentioned.

CHAPTER V

LINCOLN AND PLANER-TYPE MILLING MACHINES

The milling machine shown in Fig. 29 is intended especially for manufacturing; that is, it is not adapted to a great variety of milling operations but is designed for machining large numbers of duplicate parts. The construction is very rigid but comparatively simple, and,

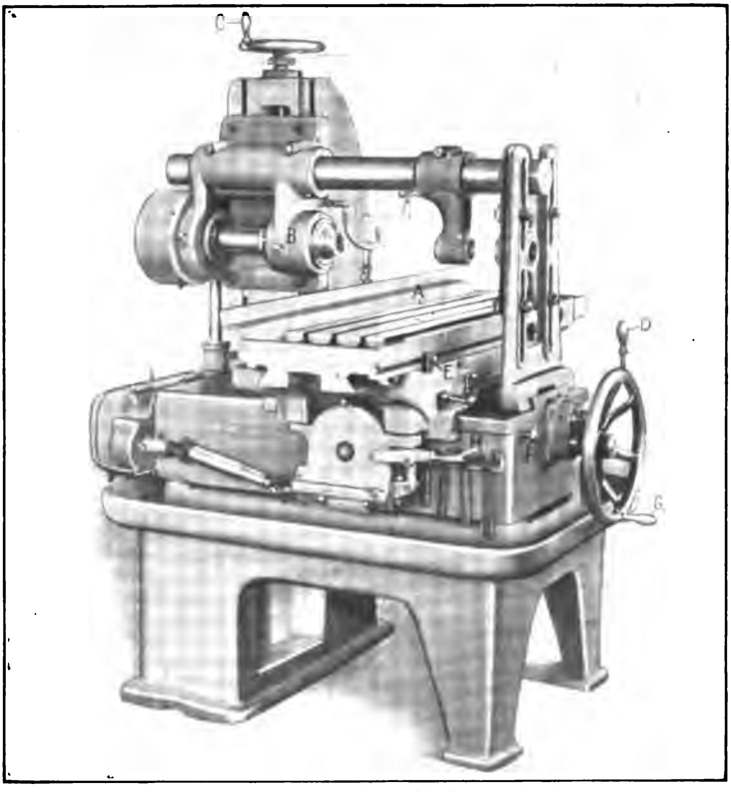

Fig. 29. Brown & Sharpe Plain Milling Machine of the Lincoln Type

therefore, this style of machine is preferable to the more complicated designs for work within its range. Milling machines having the same general construction as the one illustrated, are often referred to as the Lincoln type. As will be noted, the work-table *A*, instead of being carried by an adjustable knee, is mounted on the solid bed of the machine and the outer arbor-support is also bolted directly to the bed. This connection gives a very rigid support both for the work and cutter. The work is usually held in a fixture or vise attached to the table, and the milling is done as the table feeds longitudinally.

The table is not adjustable vertically, but the spindle-head *B* with the spindle, can be raised or lowered as may be required. This vertical adjustment of the spindle-head is effected by turning handwheel *C* which has a graduated collar reading to thousandths of an inch. After the spindle has been adjusted vertically, the head is clamped to the upright by the four bolts shown. The spindle is driven from a pulley at the rear which transmits the motion through shafting and gearing.

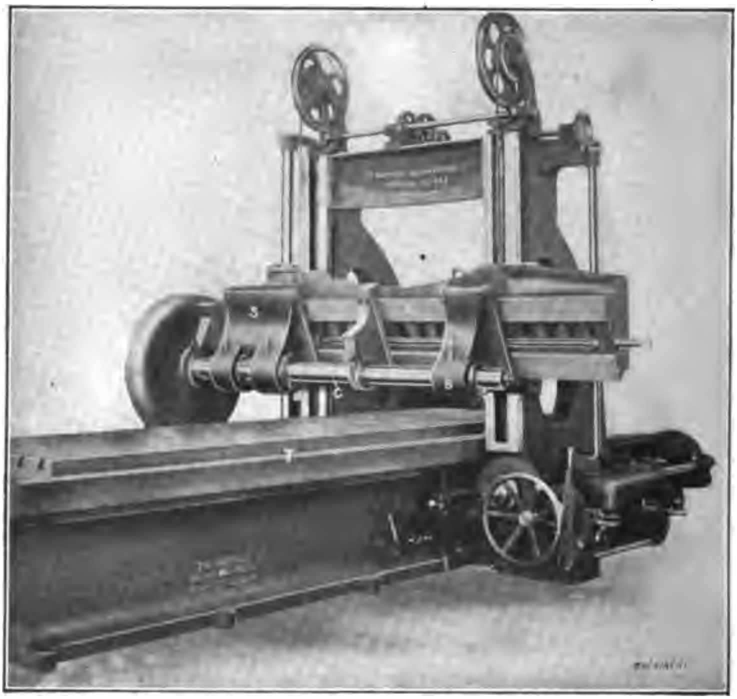

Fig. 30. Ingersoll Horizontal or Planer-type Milling Machine

A friction clutch is located in this driving pulley and provides means for starting and stopping the machine. This clutch is operated by the hand-lever *D*.

The table has a longitudinal power feed in either direction, which can be varied to suit requirements. This power feed can be automatically disengaged at any point by setting the adjustable stops *E* in the proper position. The direction of the feed can also be reversed by operating reverse-rod *F*. The large handwheel *G* can be used for adjusting the table lengthwise or crosswise. Normally this handwheel is in position for traversing the table lengthwise. When a transverse movement is required in order to locate the work with reference to the cutter, the handwheel is pushed inward, which engages it with the cross-feed screw. Before using the hand traverse, the worm-gearing of the power feed mechanism should be disengaged by operating lever *H*. The variations in both spindle speeds and table feeds are obtained, on this particular machine, by means of change gears. As machines of this kind are frequently used for a long time on one class of work, it is not necessary to make speed or feed changes very often.

This machine has a maximum longitudinal feed for the table of 34 inches; a transverse adjustment of 6 inches, and a vertical adjustment for the spindle of 12 inches. The variety of milling that can be done on a machine of this type is small as compared with the column-and-knee machines, but it is intended for milling operations that are of the

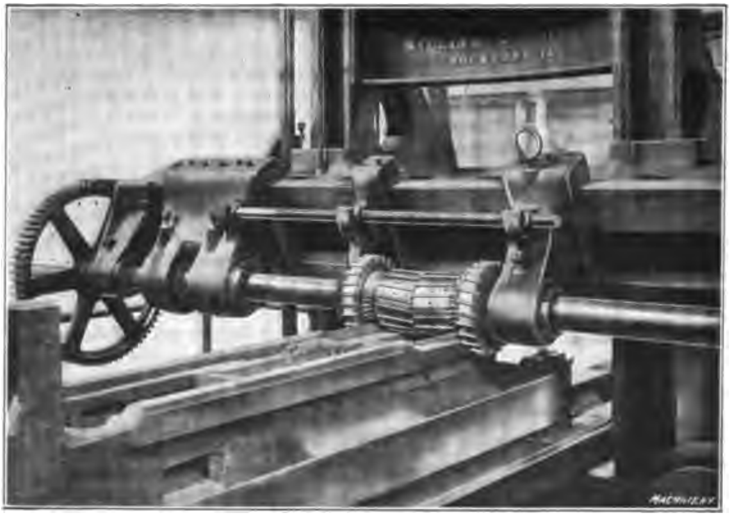

Fig. 31. Milling the Ways of a Turret Lathe Bed on a Horizontal Machine

same general character, so that a great capacity or "range" is not needed. The Lincoln type is used very effectively in connection with the manufacture of firearms, sewing machines, electrical instruments and many other kinds of machinery.

Horizontal Milling Machines of the Planer Type

The machine illustrated in Fig. 30 is designed for heavy milling operations. This style of milling machine is sometimes referred to as a planer or slab type; as the illustration shows, it is built somewhat like a planer. The work-table *T* is mounted on a long bed, and the cutter arbor *C* is carried by a cross-rail *A* which, in turn, is attached to vertical housings. The cutter arbor is driven by gearing at the left end, and it can be adjusted longitudinally by traversing the main saddle *S* along the cross-rail. The outer end of the arbor is supported by a bearing *B*, and there is also an intermediate support. The work-table has an automatic feeding movement along the bed, and it can be traversed rapidly by power, in either direction, when the position needs to be changed considerably. The power feed can be automatically disengaged at the end of the cut by a tappet which is shifted along the side of the bed to the required position. The cross-rail can be raised or lowered to locate the cutter at the required height, and

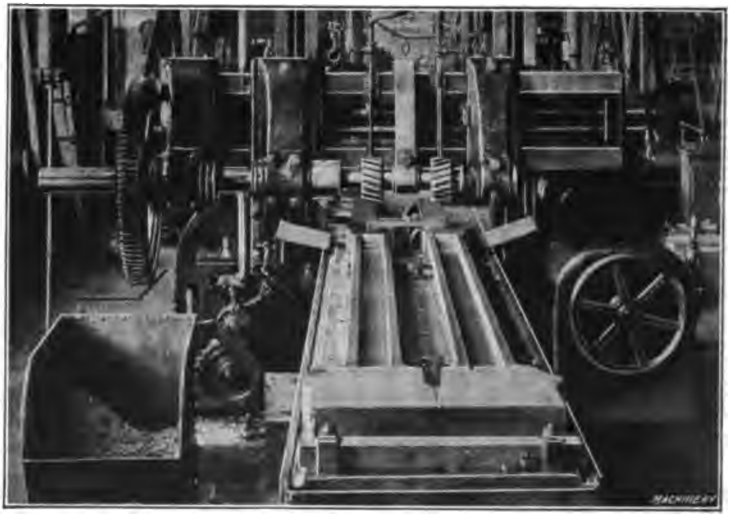

Fig. 32. Channeling the Sides of Locomotive Main-rods on Horizontal Machine

it is counterbalanced by weights attached to wire ropes that pass over the pulleys at the top of the housings.

Fig. 31 shows how a horizontal machine of this kind is used for milling a large casting. The particular part illustrated is the bed of a turret lathe, and the operation is that of milling the V-shaped ways,

Fig. 33. Cutters used for Channeling Main-rods

the flat surfaces inside these ways and the outer sides or edges. The arrangement of the gang of eight cutters is clearly shown by the illustration. The bed has been moved away from the cutters somewhat, in order to show the shape of the milled surfaces. The V-shaped ways are milled by angular cutters and the flat inner surfaces by cylindrical cutters, while the edges are trued by large side mills. This gang of cutters rotates to the right, as viewed from the operating side of the machine, and the table feeds toward the rear or against the cutter rotation.

The great advantage of machining a casting in this way is that all the surfaces are milled to shape at one passage of the work. This same casting could be machined in a planer, which is true of practically all work done on large horizontal milling machines, but whether a planer or a milling machine should be used is a question that is often difficult to decide. The number of parts to be milled and the general character of the work, must be considered. To illustrate, it

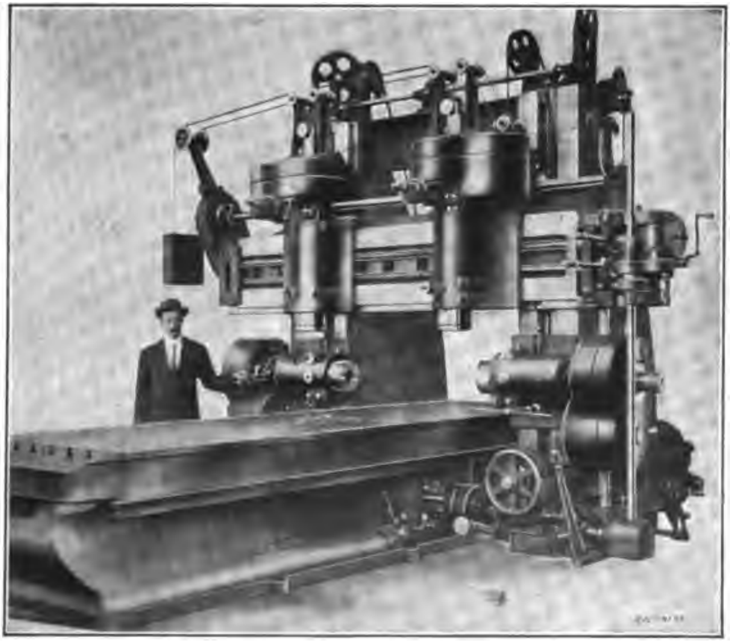

Fig. 34. Ingersoll Four-head Milling Machine

might be possible to finish a casting by milling much more rapidly than by planing. It does not necessarily follow, however, that milling will be more economical than planing. In the first place, milling cutters are much more expensive than the single-pointed planer tools which can be forged to shape by a blacksmith or toolsmith, and more time is also required to set up a milling machine than a planer, especially when a gang of cutters must be arranged for milling several surfaces simultaneously. Hence, if only a few parts are required and the necessary milling cutters are not in stock, the cost of the cutters, and the time for arranging the machine, might much more than offset the time gained by the milling process. On the other hand, when a large number of duplicate parts are required, milling is often much more economical than planing. It must not be inferred from this that the planer should always be used for small quantities of work, and the milling machine when there is a large number of parts, although the quantity of work to be done, frequently decides the question. Sometimes planing is preferred to milling, because the surface left by a planing tool is more desirable, in certain cases, than a milled surface.

When castings or forgings are quite long and narrow, two parts are sometimes clamped side by side on the bed and milled at the same time by separate cutters. Fig. 32 illustrates a job of this kind. The two steel forgings on the machine are the main rods of a locomotive, the sides of which have been channeled or grooved to form an I-beam section. This lightens the rod considerabbly but leaves it strong enough to resist the various stresses to which it is subjected. This view was taken after the channels on one side were milled. These channels are milled from the solid, and the cutters used for this work are shown on an enlarged scale in Fig. 33. They have inserted spiral teeth which incline in opposite directions to neutralize the endwise thrust. They are 8¼ inches in diameter and their width is 4½ inches, which corresponds to the width of the channel. When milling, these cutters revolve 36 revolutions per minute, giving a peripheral speed of 82 feet per minute. The channel or groove is 1¾ inches deep, and it is milled in two cuts, each having a depth of ⅞ inch. A constant stream of lubricant pours on each cutter through the hose and vertical pipes seen attached to the cross-rail. When setting up work for an operation of this kind, it must be held securely against endwise movement, because the pressure of such heavy milling cuts is very great. In this case, the rods rest against a heavy steel block which is fastened across the end of the table to resist the endwise thrust of the cut.

Multiple-head Milling Machine

Horizontal machines are built in many different designs which are modified to suit different classes of work. Fig. 34 shows a machine which, instead of having a single cutter-arbor, is equipped with four heads. Two of these heads are carried by the cross-rail and the other two are attached to the right and left housings. The cross-rail heads have vertical spindles and the side-heads, horizontal spindles, so that the sides and top surfaces of castings can be milled simultaneously. The side-heads can be adjusted vertically on the housings, and the vertical heads laterally along the cross-rail. This particular machine will drive face mills up to 20 inches in diameter.

Machines of the same general design are also built with three heads, one being on the cross-rail and two on the housings, and there are various other modifications. With the multiple-spindle machines, the number of spindles used at one time depends, of course, on the nature of the work. For some jobs it is necessary to use the horizontal spindles, whereas other parts are milled by using the horizontal and vertical spindles in combination. This type of machine is very efficient for certain kinds of milling.

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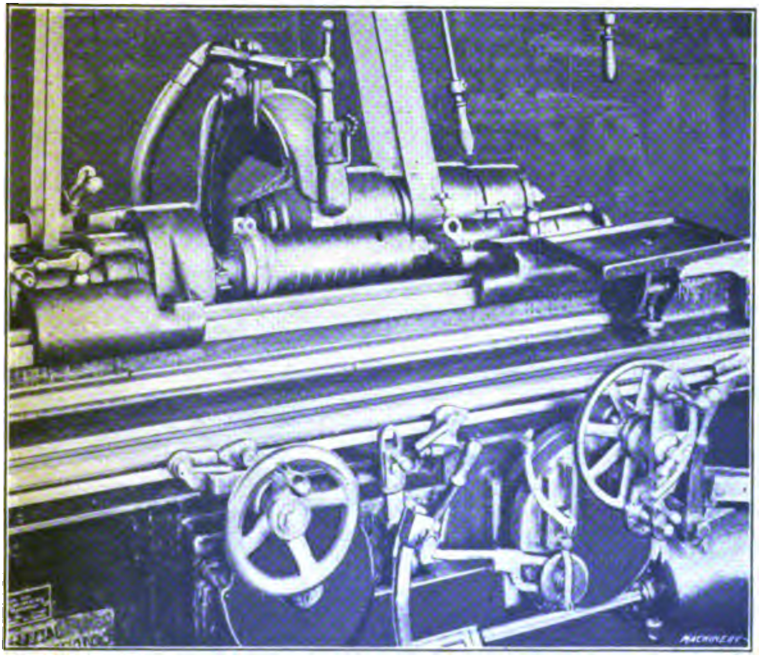

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GRINDING AND GRINDING MACHINES

CONTENTS

CHAPTER I

CYLINDRICAL GRINDING MACHINES

Grinding machines were originally used almost exclusively for truing tool steel parts which had been distorted by hardening, and they are still indispensable for work of this class. The great improvements which have been made, both in grinding machines and abrasive wheels, however, have resulted in the application of the grinding process to the finishing of a great many unhardened parts. In either case, the work, as a rule, is first reduced to within a few thousandths inch of the required size by turning in some form of lathe, and then it is ground to the finished dimension. After a part has been hardened, grinding is the only practicable method of truing it. On the other hand, unhardened pieces can be finished by other means, but grinding is preferable for most cylindrical work, because it enables parts to be finished accurately to a given diameter, in less time than would be required by any other known method.

Several different types of grinding machines have been developed for handling the various kinds of work to which the grinding process is applicable. The machines used for grinding cylindrical parts such as shafts, piston-rods, etc., are called cylindrical grinders whereas the type used for grinding holes in bushings, gears, milling cutters, etc., are known as internal grinders. There are also surface grinders for finishing flat or plane surfaces. and, in addition, types that are specially designed for sharpening cutters, reamers, etc. As cylindrical grinders are the type most commonly used, they will be considered first.

When grinding a cylindrical part such as a rod or shaft, it is mounted between the conical centers of the grinder (as shown by the diagrams, Fig. 1), just as it would be placed between the centers of a lathe for turning; in fact, the same center holes upon which the shaft was rough turned are used when grinding. The work is rotated rather slowly upon these centers c and c_1 by a driving dog d, which engages a pin in the driver plate at the left, and the surface is ground cylindrical by a disk-shaped wheel g. This wheel rotates rapidly (a 14-inch wheel would run about 1600 revolutions per minute), and the grinding is done either by traversing the rotating part past the face of the wheel or by traversing the wheel along the work. Some cylindrical grinders operate in one way, and some the other. The diagram A, Fig. 1, illustrates the method of grinding by traversing the work, the reciprocating movement past the wheel face being indicated by the full and dotted lines which show the position of the shaft at each end of the stroke. The revolving wheel g is fed inward a slight amount at each end of the work and the latter is accurately ground to the required diameter. The wheel can be fed by hand or automatically, the latter method being generally employed, except when adjusting the wheel or starting a cut. The amount that the shaft moves endwise while making one revolution, is always somewhat less than the full width of the grinding wheel face in order to secure a smooth surface free from ridges. This side traverse, as well as the rotative speed of the work, is varied to suit conditions. The operation of a machine having a traversing wheel is shown by diagram *B*. In this case, the work, instead of moving back and forth past the wheel, rotates in one position while the grinding wheel, which is mounted on a suitable carriage, moves from one end to the other, as indicated by the full and dotted lines.

The grinding wheels are composed of innumerable grains of some hard abrasive material which is held together by an adhesive bond. These grains or cutters, as they might properly be called, have sharp

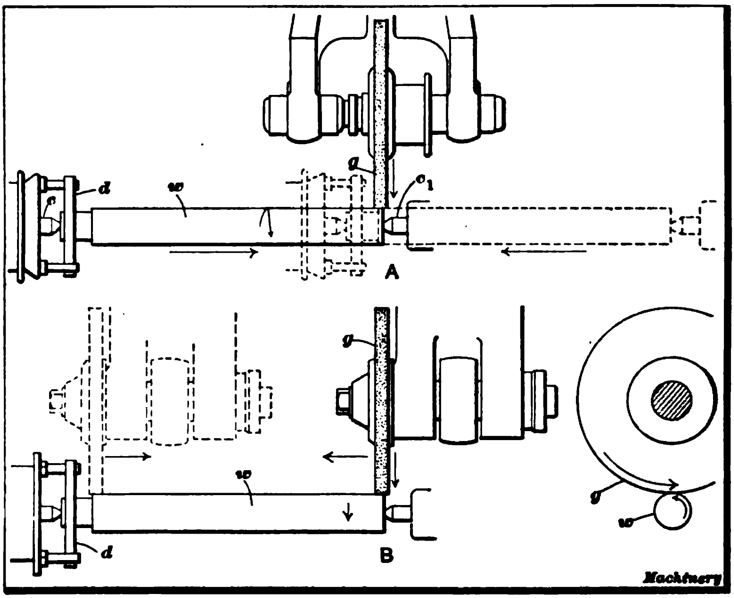

Fig. 1. (A) Diagram illustrating Method of Grinding by traversing Work past Face of Grinding Wheel. (B) Grinding by Traversing the Wheel

corners or edges which cut away the metal as the work traverses past the wheel face, or *vice versa*. The relative rotation of the wheel and the part being ground should always be as shown by the end view (diagram *B*), for cylindrical grinding. As the arrows indicate, the grinding side of the wheel *g* moves downward, and that side of the work *w* being ground, moves upward or in the opposite direction.

From the foregoing, it will be seen that a cylindrical grinding machine must be arranged to rotate both the grinding wheel and work. In addition, either the work or the wheel must be traversed longitudinally. The wheel must also be fed in automatically for taking successive cuts, and provision must be made for varying the traversing movement and the rotative speed of the work to suit different conditions. The way these various movements and adjustments are obtained with the type of cylindrical grinder illustrated in Fig. 2, will be explained. It should be understood, however, that the mechanical details vary with grinders of different makes, although all cylindrical grinding machines operate on the same general principle.

Cylindrical Grinding Machine of the Universal Type

The machine shown in Fig. 2 operates by traversing the work past the grinding wheel *G*, as illustrated by the diagram *A*, Fig. 1. The grinding wheel is revolved by a belt that passes over a pulley at the side of the wheel and connects with an overhead countershaft. The table *A*, which moves back and forth when the machine is in operation. carries a headstock *H* and a footstock *F* in which conical centers *C* and

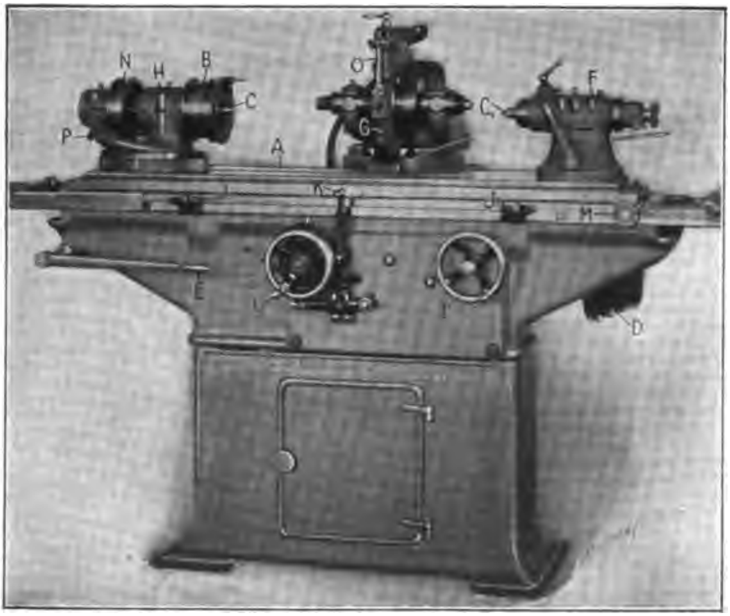

Fig. 2. Brown & Sharpe Universal Cylindrical Grinding Machine

C_1 are inserted. When a cylindrical part such as a shaft or rod is to be ground, it is placed between these centers and is rotated upon them by a belt passing over pulley *B* and connecting with a long cylindrical drum, which forms part of the overhead works for driving the machine. This long drum is used instead of a narrow pulley, so that the belt can shift along as the table moves to and fro.

The power for moving the table along the ways of the bed is obtained from a belt connecting with cone-pulley *D* which transmits motion to the table through suitable shafts and gearing located inside the bed. The traverse of the table and rotation of the work-spindle, can be started or stopped by lever *E* to the left. The wheel *I* to the right is used for moving the table by hand. When operating the table in this way, the knob in the center of this wheel is pushed inward, and when the table is to be traversed automatically, this knob is pulled out. The travel of the table or the length of its stroke is controlled by the position of the adjustable dogs *J* and J_1 which operate the reversing lever *K*. Lever *K* connects with a clutch inside the base and this clutch, through gearing, reverses the movement of the table whenever lever *K* is thrown to the right or left. The length of the stroke is changed by varying the distance between dogs *J*. These dogs slide upon a rack attached to the front of the table and are held in position by a spring-latch that engages the rack teeth.

The Automatic Cross Feed

The grinding wheel can be moved to or from the work by rotating handwheel *L*, and it is fed inward automatically by the mechanism

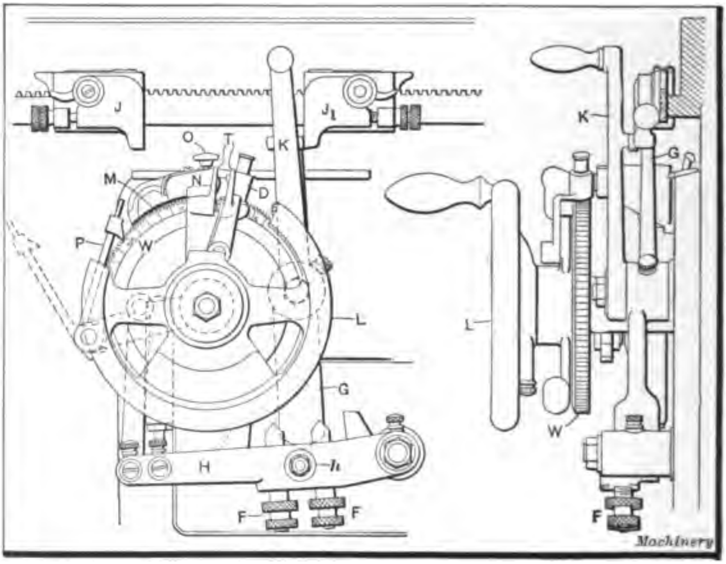

Fig. 3. Mechanism which feeds the Grinding Wheel forward at each Reversal of the Work and automatically disengages the Feed when a Predetermined Amount has been ground away

located just back of this wheel. This mechanism is so arranged that it can be set to stop the feed when the diameter has been ground to a predetermined size. The way in which this automatic feed operates will be more clearly understood by referring to the detail drawing, Fig. 3. When the dogs *J* strike lever *K*, thus reversing the table movement, the lever *G* is also actuated, and it has a V-shaped end which engages roll *h*, and operates lever *H* and pawl *P*. If this pawl is in mesh with the ratchet wheel *W*, the grinding wheel will be fed forward an amount depending upon the position of the screws *F*, which come against a surface on lever *G*, thus regulating the upward movement of lever *H* and, consequently, the movement of the pawl at the end of each stroke. The automatic feed will continue at each reversal until the shield *M* (which is attached to head *N*) intercepts pawl *P* and prevents it from engaging the ratchet wheel *W*. The feed then stops automatically.

The amount that the grinding wheel moves inward before the feed is automatically disengaged, depends upon the distance between the end of shield *M* and the tooth of pawl *P*. Each time the table reverses, this pawl rotates ratchet *W* one or more teeth and this feeding movement continues until shield *M* moves around and disengages the pawl, as previously mentioned. As a movement of one tooth represents a reduction in the diameter of the work of 0.00025 inch, the automatic feed can be set for grinding very close to a given size by varying the distance between the disengaging shield and the pawl. The feed can be set to give the full amount at each end of the stroke or any part of the full amount at either end, by adjusting the regulating screws *F*. The feed on this particular machine can be varied from 0.00025 inch to 0.004 inch at each reversal of the table. These feeds seem like very small amounts, especially when compared with the cuts taken on turning or planing machines, but the grinder is a precision machine used for producing fine, accurate surfaces and it is not adapted to taking deep cuts. With a modern high-power machine, however, metal can be removed with considerable rapidity.

The automatic cross feed is a great advantage, especially when grinding a large number of duplicate parts, as it prevents grinding them too small, and makes it unnecessary for the operator to be continually measuring the diameter of the work. The automatic feed is also desirable because it moves the wheel inward an unvarying amount at each reversal. This regularity of the feeding movement increases the "sizing power" of the grinding wheel. In other words, the wheel maintains its size for a longer period and the wear is more uniform. Of course, all grinding operations are accompanied by more or less wheel wear which has to be compensated for (as will be described later), although the amount of wear is surprisingly small when the wheel and work rotate at the proper speeds.

Miscellaneous Features

The headstock *H* (Fig. 2) is held to the table by bolts which slide in a T-slot, and the footstock *F* is clamped by the lever shown, so that the distance between the centers can be varied to suit the length of the work. The spindle and upper part of the headstock can be swiveled about a vertical axis for grinding flat disks or taper work, and the angular position is shown by degree graduations on the circular base. The spindle of the footstock is not screwed rigidly against the end of the work, as in the case of a lathe, but it is held in position by a strong spring. By means of this spring, a firm, even pressure is applied to the center, and, in case the work expands from the heat developed in grinding, the center yields and the part being ground is not distorted.

The usual method of grinding a cylindrical part is to rotate it on two "dead centers," both centers remaining stationary. The object of grinding work while it revolves on stationary centers is to secure accuracy, for then any slight error which may be in the spindle bearings is not reproduced in the work. If center *C* were rotated with the work, as in the case of a lathe, any eccentricity of the center would result in inaccurate grinding. Therefore, when grinding cylindrical parts on centers, the spindle is locked by a pin *P* which engages a hole in the flange of pulley *N*. Pulley *B*, which rotates freely around the spindle, carries a driving dog and rotates the work. For some classes of grinding, as, for example, when grinding parts held in a chuck attached to the spindle, it is necessary to rotate the spindle. Lock-pin *P* is then withdrawn and a belt from the overhead driving drum is connected with pulley *N*.

The upper part of the work-table can be set at an angle for taper grinding. This upper swiveling table is normally held to the lower member by bolts at each end. When these are loosened, the table can be turned a limited extent about a central stud, by means of adjusting

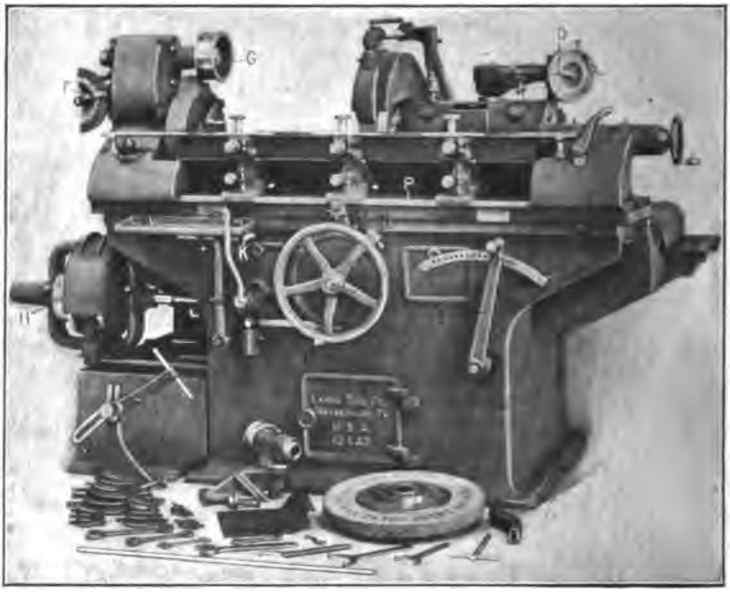

Fig. 4. Landis Plain Grinding Machine

screw *M*. There are two sets of graduations on the end of the swiveling table, one reading to degrees and the other giving the taper in inches per foot. When the swivel table is set at an angle, the headstock and footstock centers remain in line but are at an angle with the ways of the bed or the line of motion. For ordinary cylindrical grinding, the wheel-stand slide is set at right angles to the ways. On a grinder of this type, the wheel slide can also be set at an angle when necessary for grinding parts having a steep or abrupt taper.

Another feature of the cylindrical grinder which should be referred to is the provision made for supplying cooling water to the wheel when grinding. At the point where the wheel is in contact with the work there is considerable heat generated; consequently a cooling medium is very essential when grinding parts which revolve upon the centers, in order to maintain an even temperature. When water is not used, the part being ground tends to bend towards the wheel owing to the higher degree of heat and resulting elongation on the grinding side; in other words, its axis will be continually changing, and, obviously, inaccuracy will be the result. The apparatus for supplying the water consists of a small pump of the fan type which operates in a tank at the rear. The water is conveyed to the grinding wheel through a hose and pipe *O*, and plays on that part of the work being ground.

Cylindrical Grinding Machine of the Plain Type

Cylindrical grinding machines, like milling machines, are divided into two general classes, known as plain and universal grinders. The first type is used for grinding work in large quantities, which varies comparatively little in form, which means that it is essentially a machine for manufacturing purposes. The general construction of the universal grinder is similar to that of the plain grinder, but it differs

Fig. 5. End View of Landis Grinder, showing Automatic Cross-feed Mechanism

from the latter in having certain special features and auxiliary attachments which adapt it to a more general or universal class of work. The principal difference between the universal and plain types, as far as the construction of the machine itself is concerned, is as follows: The wheel slide of a universal machine can be swiveled with relation to the travel of the table; the headstock can also be set at an angle, and provision is made for revolving the spindle for grinding parts that are held in a chuck or otherwise. With a plain machine the wheel slide is permanently set at right angles to the table travel and the headstock cannot be swiveled. The machine shown in Fig. 2 is a universal type, whereas a plain grinder is shown in Fig. 4. These machines differ considerably in their construction because they are different makes. Plain and universal machines of the same make, however, are practically the same except for the changes referred to, unless one is much larger than the other.

The machine illustrated in Fig. 4 operates by traversing the grinding wheel along the work which rotates in a fixed position, as indicated by the diagram *B*, Fig. 1. The travel of the wheel carriage is regulated,

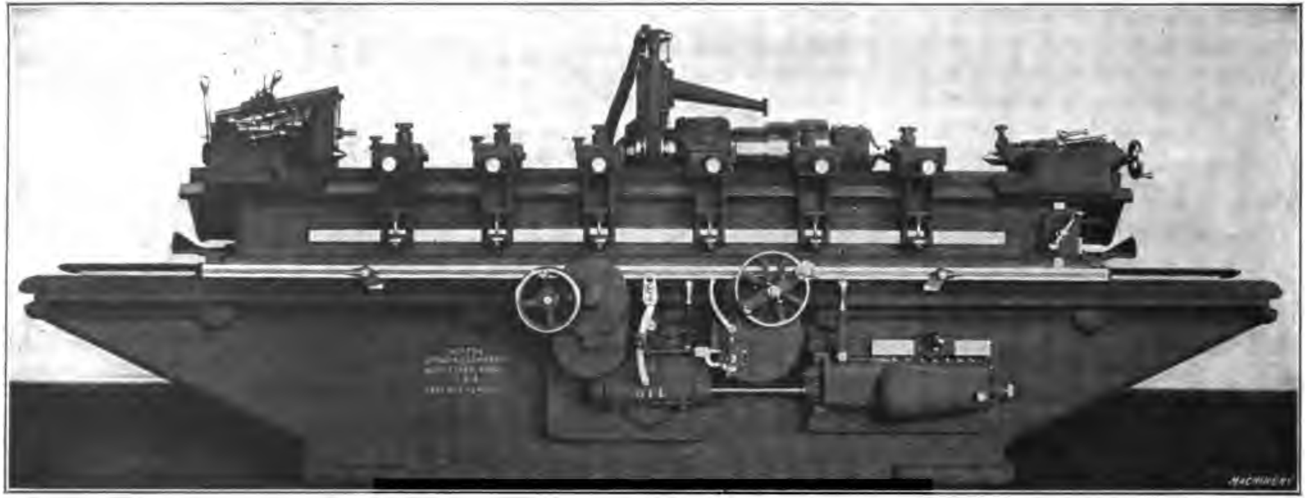

Fig. 6. Norton Cylindrical Grinding Machine of the Plain Type

for work of different lengths, by varying the position of the dogs *N*, which are mounted on a wheel or circular rack. On the periphery of this wheel worm-teeth are cut, and the dogs are held in any desired position by worms which may be lifted out of engagement when the dogs are to be moved a considerable distance. The tappet *O* against which these dogs strike, thus reversing the movement of the carriage, can be swung out of the way when it is desired to let the wheel travel beyond the reversing points. The amount that the wheel carriage moves longitudinally per revolution of the work, or its side traverse, is regulated by changing the position of lever *I*. The lever *J* is used for reversing the carriage travel at any point, by hand, while the traverse movement is started or stopped by lever *K*. When it is desired to move the carriage longitudinally by hand, the wheel *L* is used. The platen *P* can be swiveled for grinding taper work, the same as with a universal machine. The power for traversing the wheel carriage is obtained from a belt operating on pulley *H*, and the work is rotated by a belt connecting with pulley *G*. The work speeds are varied by shifting lever *F*.

The grinding wheel is moved to or from the work by the handwheel *D*. In conjunction with this handwheel there is an automatic cross feed which may be set to advance the wheel at each reversal of the carriage on which the wheel is mounted. This feed is effected by the pawl *A* (Fig. 5) which meshes with ratchet teeth in the periphery of the wheel *D*. Provision is made for automatically disengaging this feed when the wheel has ground any predetermined amount from the work. This is accomplished by a movable ring *B*, mounted on the handwheel and having a knock-out cam *C*, which engages a pin on the feed pawl *A*. When setting this feed to grind a given amount, the wheel is first brought into contact with the work, by turning the handwheel *D*; the ring *B* is then moved around until the cam *C* is against the pin on pawl *A*. When the machine makes its first stroke, the pawl is disengaged from the ratchet. The wheel should then be allowed to pass over the work until it has practically ceased cutting, when the traverse should be stopped, say at the footstock end. The diameter of the work is next measured carefully with a micrometer. The thumb-latch *E* is then pressed against its stop four times for each 0.001 inch reduction in diameter required. As this thumb-latch has attached to it a spring pawl engaging the ratchet teeth on the wheel *D*, the ring *B*, with its knock-out cam, is moved away from the feed pawl *A* an amount equivalent to one ratchet tooth each time the latch is pressed. When the grinding is continued, the cam gradually moves backward and finally disengages the feed pawl. The amount of feed is regulated by adjusting screw *F*.

Large Grinding Machine of the Plain Type

Fig. 6 shows a large grinding machine of the plain type which will grind work up to 96 inches in length. This machine has a moving work-table and the grinding wheel revolves in a fixed position, except for the crosswise feeding movement at each end of the stroke. The wheels used in this machine are 24 inches in diameter and have a width of 2 inches. The wheel slide is fed forward either by a handwheel or automatically, and the automatic feed can be set for grinding a given amount. The rotative speed of the work can be changed by shifting the belt on the driving cone pulley of the headstock. The rate of table traverse can also be regulated to give a coarse feed for removing stock rapidly or a finer feed for finishing. The mechanism seen at the front of the machine includes the automatic cross feed, and the table speed-changing mechanism. There are also hand-wheels for adjusting the table longitudinally and the grinding wheel in a crosswise direction. The particular machine illustrated is equipped with six steadyrests which are used for supporting the work and to prevent vibration. The number of rests used in any case depends upon the length of the part being ground.

CHAPTER II

CYLINDRICAL GRINDING OPERATIONS

As an example of grinding, suppose a rather short shaft is to be ground cylindrical and to a diameter somewhere between 2.050 and 2.0495 inches, there being an allowable variation in size of 0.0005 inch. Before beginning to grind, a wheel should be selected that is suitable for the part to be ground. When grinding, the work must also be rotated at the proper speed in order to minimize the wheel wear and secure a well finished surface. The points to be considered when selecting the wheel and adjusting the work speed, have been referred to separately in Chapter III, to avoid confusion. We shall assume that a wheel of the proper grade and grain has been mounted on the spindle of the grinder and that a machine similar to the one shown in Fig. 2 is to be used. We shall also assume that the work has been rough turned in a lathe to within about 0.010 inch of the required size.

The headstock *H* and footstock *F* are first set the required distance apart and then the work is placed between the centers with a driving dog attached to the headstock end, as illustrated in Fig. 7. The same center holes upon which the part was turned, are also used when grinding, and they should be carefully cleaned before placing the shaft in the machine. The centers should also be oiled, because, as previously mentioned, work of this kind rotates upon the "dead" centers of the machine, which remain stationary in order to secure greater accuracy. When the shaft is in place, the reversing dogs *J* and J_1 are set to give the table the right length of stroke. The travel should be reversed when a small part of the wheel face has passed the end of the piece being ground. If the stroke is too long, more time will be required for taking a cut than is necessary.

As the part is to be ground cylindrical or straight, the swivel table *A* should be set to the zero position. The headstock *H* must also be set to zero, as otherwise the centers will not be in alignment. It should be remembered that the graduations are only intended to give an approximate setting, and when accuracy is required, it is necessary to test the work by using a micrometer or gages. This test is made by first taking a trial cut and then measuring the diameter of the work at each end. If there is any variation, the table is turned slightly in whatever direction may be required to produce a cylindrical surface, by using the fine adjusting screw *M*, Fig. 2.

Setting the Automatic Feed

When starting a cut and setting the automatic feed, the grinding wheel is moved in by hand until it is almost in contact with the work. The stroke of the table is then stopped by pushing in knob *Q*, (with this particular machine) and pawl *P* is placed into engagement with the

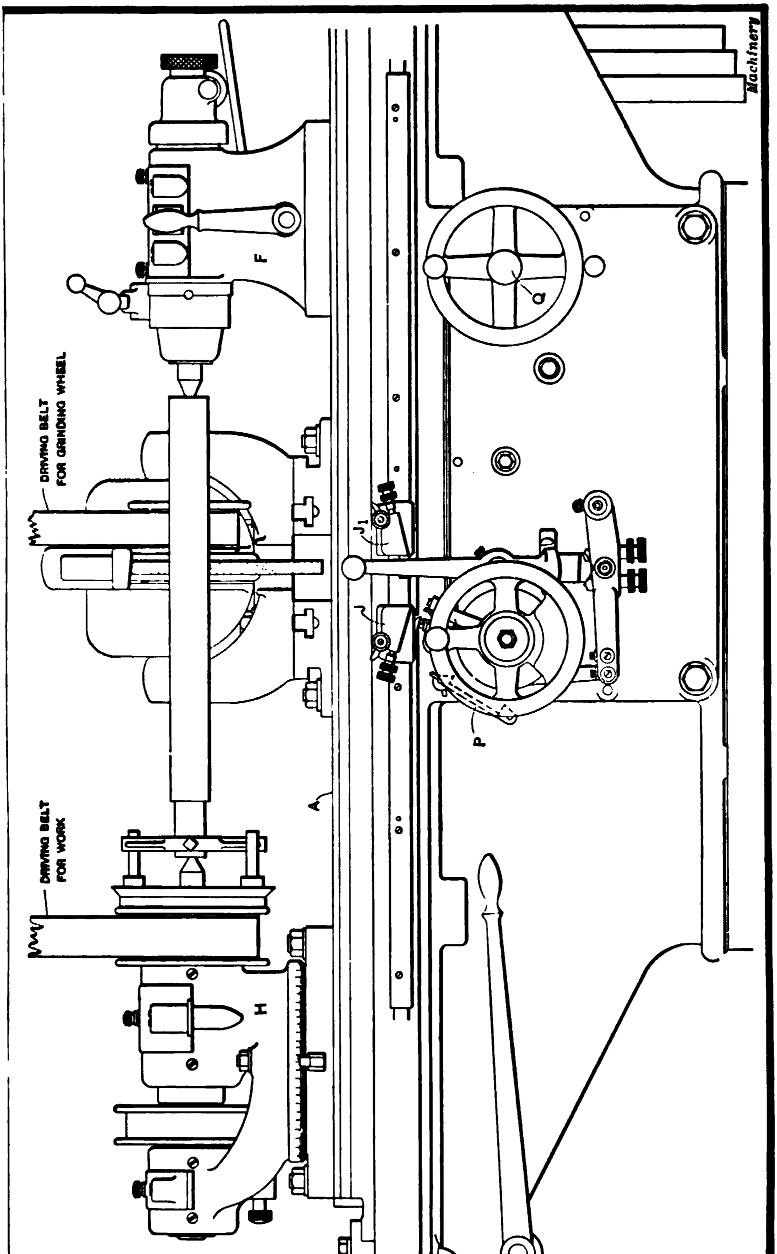

Fig. 7. Type of Machine illustrated in Fig. 2, arranged for Grinding a Cylindrical Shaft

ratchet wheel. The latch *O* (see Fig. 3) is then raised and the head *N* moved around the periphery of the ratchet wheel until the point of shield *M* has just passed the tooth occupied by the pawl, so that the latter rests upon the shield. After the table stroke is again started, thumb-latch *T* is pressed until the grinding wheel begins to cut. When the surface is ground true, the table is stopped when the grinding wheel is at the footstock end, and the diameter of the part ground is measured with a micrometer. The thumb latch *T* of the automatic feed is then pressed once for each quarter of a thousandth to be removed. To illustrate, suppose the diameter, after the surface has been trued, is 2.057 inch. Then there would be 0.007 inch stock to remove (2.057 — 2.050 = 0.007; hence, the latch would be pressed twenty-eight times, thus moving shield *M* far enough away from the feed pawl to allow the latter to continue feeding until 0.007 inch has been ground away.

When the feed has been set, the table traverse is again started and the grinding continued until the feed is disengaged. The wheel should then be stopped at the footstock end, as before, when the density of the sparks thrown off by the wheel have diminished somewhat and are about the same as for the final cut taken prior to the first measurement. If a suitable wheel has been used and the work rotated at the proper speed, the diameter should be very close to 2.050 inch, because, in this case, a comparatively small amount has been ground away, and, consequently, the wheel wear would be almost negligible. On the other hand, where it is necessary to remove considerable stock, the diameter of the work might be somewhat above the size for which the automatic feed was set, owing to the wear of the grinding wheel. After the amount of wheel wear for removing a given amount of stock is determined, the automatic feed can be set to compensate for this wear, when grinding a duplicate part. For example, if the diameter of the work were 0.001 inch over size, the latch *P* would be pressed four times or once for each quarter thousandth reduction required, and the grinding continued until the feed was again automatically disengaged. After this disengagement takes place, the traversing movement of the work should be continued until the wheel has practically ceased cutting, as shown by the decrease in the shower of sparks.

By noting the sparks and then stopping the machine when the volume or density is practically the same for the final cut, duplicate parts can be ground to a given diameter within close limit; in fact the shower of sparks thrown off by the grinding wheel is a very convenient and sensitive indication of the depth of the cut, and, with a little practice, it is possible to gage the cut to within very close limits by this method. An interesting experiment was made to determine what the depth of a cut would be when the sparks were just visible. A hardened steel gage was ground very carefully and, when taking the final cut, the work was traversed past the wheel until no sparks were visible. The exact diameter of the gage was then found by using a measuring machine, after which the gage was again placed in the grinder and the wheel was fed forward very slowly until sparks were just visible. The gage was then traversed past the wheel, as before, until all the sparks had disappeared. Then by again measuring the diameter, it was found that a reduction of 0.00001 inch had been made.

One not experienced in grinding machine operation should become familiar with the relation between the shower of sparks thrown off by the wheel and the depth of the cut, so that a given amount of stock can be ground away without wasting too much time in measuring. It is well for the inexperienced operator to note the density of the sparks when cuts of a known depth are being taken. With a little practice, one can judge the depth of a cut by this method with considerable accuracy.

When one shaft is ground and another is to be inserted in the machine, pawl *P* is disengaged and handwheel *L* is turned to the right about one revolution (without changing the position of shield *M*) in order to move the wheel away from the work. The latter is then removed and replaced by a rough shaft. When the new blank is in position, wheel *L* is turned to the left until the grinding wheel begins to cut. Then pawl *P* is again placed in mesh with the ratchet wheel, which causes the automatic feed to operate as previously described.

While the automatic feed will enable parts to be ground to a given diameter within close limits, this diameter should, of course, always be measured either with a micrometer or by the use of a fixed gage. As previously intimated, the accuracy of the automatic feed for grinding to the diameter for which it is set, depends upon the amount the wheel wears, and the wheel wear, in turn, is governed by the "grade" of the wheel and the surface speed of the work. When a wheel of the proper grade is used and surface speeds of the wheel and work are correct, the wear is surprisingly small and, in some instances, quite a number of duplicate parts can be ground without compensating for the wheel wear.

Taking Roughing and Finishing Cuts

The exact method of procedure when grinding cylindrical parts often depends on the number of pieces to be ground and their shape. A single shaft having a diameter of, say, 2 inches and a length of 12 inches, could be ground by simply placing it between the centers with a dog attached and proceeding as described in the foregoing. On the other hand, if the shaft were long and flexible, it would have to be supported by work-rests to prevent deflection and vibration. A single shaft might also be finished by taking a number of light cuts which would be, practically, a succession of finishing cuts, whereas a number of pieces would be first "rough" ground and then finished.

The difference between roughing and finishing in the grinder is as follows: For roughing, a fast side traversing movement is used that is almost equal to the face width of the wheel, and comparatively deep cuts are taken, whereas, for finishing, the side feed and depth of cut are reduced in order to obtain a fine, smooth finish. The rotative speed of the work is also changed for finishing; in some shops the speed is increased, whereas in others it is diminished. This variation in practice is doubtless due to the use of different machines and grinding wheels. The method commonly employed for ordinary machine grinding is to use a coarse, free-cutting wheel and a work speed that is fast enough to keep the wheel "sharp" and permit rapid grinding. The same wheel is then used for finishing after it has been trued with the diamond, and the work speed is reduced to get a finer finish than would be possible with the higher speed used for roughing. The advantage of rough grinding and then finishing by a separate operation, is that the stock can be removed more rapidly by the roughing operation. It is necessary, however, to true the wheel face before taking the finishing cut and when grinding a single part, it might be better to simply take a number of light cuts in order to keep the face of the wheel true.

The following example will serve to illustrate one method of handling a grinding machine when the parts are first rough ground close to size and then finished by light cuts. Suppose there are a number of cylin-

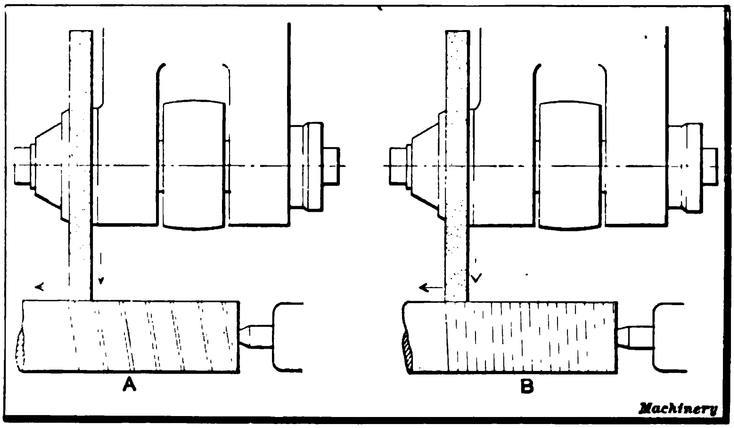

Fig. 8. (A) Wheel with Excessive Side Traverse or Feed. (B) Wheel feeding laterally a Fraction of its Width for each Revolution of the Work

drical rods which have been rough turned in the lathe to within 0.020 inch of the finish size, and are to be ground to a diameter of 2 inches and be given a good finish. Before beginning to grind, a number of steadyrests should be clamped to the table of the machine and adjusted against the work to prevent the latter from springing and vibrating. These rests are made in several different styles and the number that should be used depends on the length of the work. This matter of supporting the work is very important, and will be referred to subsequently. The grinder is next set to the right length of stroke, and the feed of the table (or side traverse of the wheel) as well as the work speed, should also be properly adjusted.

The wear of a grinding wheel, as previously mentioned, depends very much on the surface speed of the work, the wear increasing as the work speed is increased. Hence it is the modern practice to use a comparatively slow work speed in conjunction with a coarse side feed of the wheel when it is important to grind rapidly; that is, instead of feeding the wheel a distance equal to only 1/8 or 1/4 its width per revolution of the work, it is given a side feed that is only a little less than the full width of the wheel face. Comparatively wide wheels are also used in modern machines, so that the surface being ground is covered quite rapidly.

Suppose the work is rotated fast enough to give a surface speed of 25 feet per minute and the fastest side feed is engaged in order to determine by trial what combination will give the best results. When the wheel is brought into contact with the work, if it leaves coarse, spiral feed lines (as shown at *A*, Fig. 8) having a greater pitch than the width of the wheel, the side feed should be reduced until the wheel does not leave any unground surface. In other words, the side feed should be somewhat less than the wheel width in order to grind a

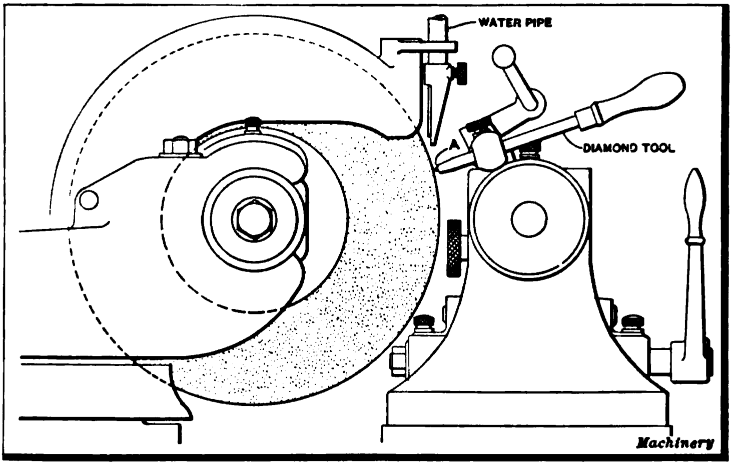

Fig. 9. Truing Face of Grinding Wheel by use of Diamond Tool

smooth surface, free from ridges. On the contrary, if the fastest side feed only moves the wheel laterally a fraction of its full width (as indicated by the narrow feed lines at *B*) the work speed should be reduced until the side feed is nearly equal to the wheel width. Owing to the rapid side feed, the wheel will pass over the surface being ground in a comparatively short time, and by using a rather slow work speed, the wear of the wheel is minimized. This method of grinding is employed when using large machines, which have sufficient driving power to enable such broad cuts to be taken and are rigid enough to prevent excessive vibration. When a small light grinder is employed, it is not always feasible to take such wide cuts, owing to the lack of rigidity and driving power. The depth of the cut or the amount that the wheel feeds inward at each reversal, is also controlled by the power and rigidity of the machine used.

After the stroke, side feed and work speed have been properly adjusted, the feed mechanism is set to give the desired depth of cut. We shall assume that in this case a cut of 0.001 inch is to be taken at each reversal, which would reduce the diameter 0.002 inch for each passage of the wheel. As soon as the rough turned surface has been ground true, the wheel should be allowed to pass across the work without feeding it inward, until the sparks diminish somewhat thus showing that the wheel has practically ceased cutting. The diameter is then measured to find out how much stock must be removed by roughing. Suppose the diameter is 2.016 inch and we want to rough grind to within about 0.002 inch of the finish size or to a diameter of 2.002 inches; there would then be 0.014 inch to be removed by rough grinding, and the automatic feed would be set for this amount. The machine is then started and the grinding continued until the feed is disengaged and the wheel has practically ceased cutting as before. The diameter is then

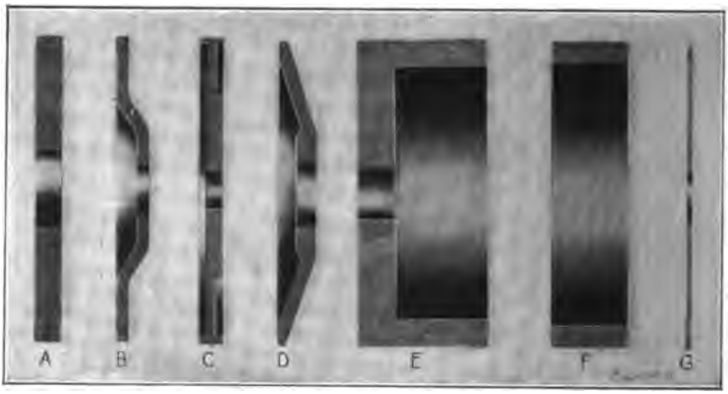

Fig. 10. Grinding Wheels of Different Shape

again measured and the difference between this measurement and 2.002 inch will show how much the wheel has worn. If the wheel wear should be excessive, it would be well to try a finer feed when grinding the next piece.

We shall assume that the rods are to be rough ground to a diameter somewhere between the limits of 2.0015 and 2.0025 inch, and that the diameter of the first piece was 0.002 or 0.003 inch over the maximum size when the automatic feed tripped. This stock should first be removed by putting on additional feed and then another blank should be placed in the machine and the roughing operation repeated, but with a reduced feed in order to diminish the wheel wear. By a little experimenting we should be able to find what combination would give the best results. All parts are then rough ground, and whenever the wheel has worn to such an extent that the diameter is greater than the maximum limit of 2.0025 inches, enough additional feed is "put on" to grind the next blank to the minimum roughing limit of 2.0015 inches. After all of the pieces have been roughed out, in this way, the wheel should be trued for finishing, as explained in the next paragraph. The finishing cuts are then taken after the side feed of the wheel and the surface speed of the work have been reduced, to obtain a smoother finish.

As little stock is removed when finishing, it should be possible to grind a number of parts without compensating for wheel wear.

Truing a Grinding Wheel

The grinding wheel should never be used unless it runs true and has an even bearing on the surface of the work. In other words, the face of the wheel should be parallel with the surface being ground, and it is especially important to have a true, even wheel face when taking a finishing cut. The only satisfactory method of truing a wheel is by the use of a diamond tool. This tool is clamped to the footstock of the machine (as shown in Fig. 9), or in a special holder attached to the table, and the stroke is adjusted so that the diamond point *A* will just clear the wheel face on each side. The wheel, which should revolve at the speed required for grinding, is then trued by bringing it into contact with the diamond as the latter travels back and forth. Very light cuts should be taken and water used to keep the diamond cool. The diamond tool should be held with the point quite close to the clamp or point of support in order to reduce vibration and give a smooth accurate wheel surface. Diamond tools usually have round shanks to permit clamping them in different positions so that the wear on the diamond will not be confined to one to two points. When truing the wheel, light cuts should be taken and the diamond traversed across the face with a uniform speed. The number of times that the wheel has to be trued depends upon the character of the work and the kind of wheel used. If it is necessary to remove considerable stock, the wheel may have to be trued before taking each finishing cut, provivded the roughing and finishing operations are performed successively. When a number of duplicate parts are ground, this is avovided by first rough grinding them all and then truing the wheel once for finishing the entire lot, or as many parts as the wheel will grind satisfactorily.

Shapes of Grinding Wheels

Grinding wheels are made in a great many different shapes and sizes for use in different types of grinding machines, and on different classes of work. A plain disk-shaped wheel *A*, Fig. 10, is used for most cylindrical grinding. The diameter and width of the wheel, for ordinary work, depends, principally, upon the size and power of the machine. The type of wheel shown at *B* is intended for grinding up to a large shoulder. It is mounted on the end of the spindle and is dished at the center, so that the retaining nut on the spindle will not project beyond the side of the wheel and strike the shoulder. Wheel *C* is especially adapted for facing the ends of bushings or small shoulders. When the wheel is used for end facing, the grinding is done by the side, which is recessed to reduce the contact area. The saucer-shaped wheel *D* is extensively used for grinding formed milling cutters, etc., especially on regular tool- and cutter-grinding machines. The cup wheel *E* is used for grinding flat surfaces by traversing the work past the end or face of the wheel. The cylindrical or ring-wheel *F* is also used for producing flat surfaces and grinds on the end or face. The cup wheel is attached directly to the spindle but the ring-wheel is held in a special chuck.

Thin wheels *G* are used for sharpening cutters, reamers, etc., or for cutting off stock. Grinding wheels are made in many other shapes, but most of them are modifications of the few styles referred to.

Rests or Supports for the Work

Practically all parts that are ground on centers should be supported by suitable work-rests or "steadies," as their use will permit taking deeper cuts with coarser feeds and also increase the "sizing power" of the wheel. When grinding long and slender parts, such supports are indispensable, and even for work which is short and rigid, rests are desirable to prevent vibration, which increases wheel wear and affects the quality of the ground surface. These rests or supports are fastened to the table of the machine and are equipped with shoes of hard

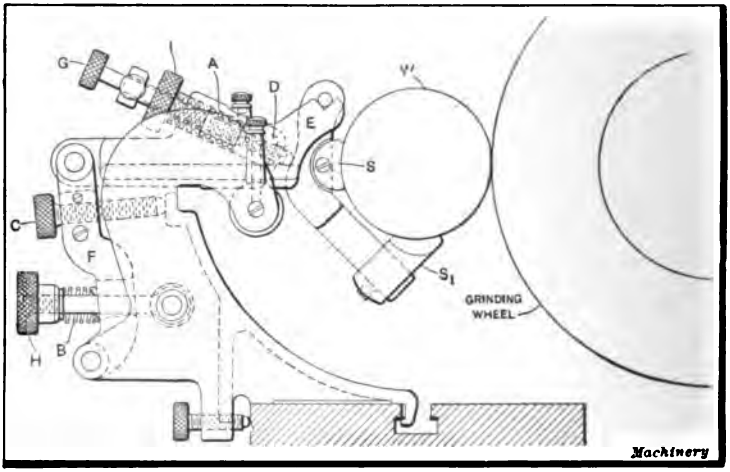

Fig. 11. Universal Back-rest for Supporting Work being Ground

wood or soft metal which bear against the piece being ground. The number of rests used, depends on the form and diameter of the work. According to a commonly accepted rule, the distance between each rest should be from six to ten times the diameter of the part being ground.

Work-rests are made in several different styles, and they may be divided into two general classes which differ in that one type is rigid and the other flexible. The rigid rest gives a positive unyielding support, whereas the flexible rest, as the name implies, can yield more or less, the supporting shoe being held against the work by springs. Most rigid rests must be readjusted by hand as the diameter of the work is reduced by grinding, whereas the shoes of the flexible type adjust themselves automatically after the rest is properly set. Then there is another form of rest which has spring tension but can be made rigid when desirable, and still another type is so designed, that the supporting shoes are adjusted automatically but the support is unyielding.

A design of work-rest that has been extensively used, is shown in Fig. 11. This is a spring or flexible type and is called a universal back-rest. The work *W* is supported by the shoes *S* and S_1 which are held yieldingly but quite firmly in position, by means of springs located at *A* and *B*. Adjustable stops *C* and *D* are provided to prevent the springs from forcing the work against the wheel after the part has been ground to the required diameter. When these stops are correctly set, no pressure is exerted by the springs upon the shoe after the work has been reduced to the finished size. Provision is also made for regulating the pressure of the springs to adapt the rest to either light or heavy work. After the stops are once set, duplicate parts can be ground to the same diameter without readjusting the rests.

Fig. 12 shows how four of these back-rests are used for supporting a long shaft which is being ground. After they are clamped to the table

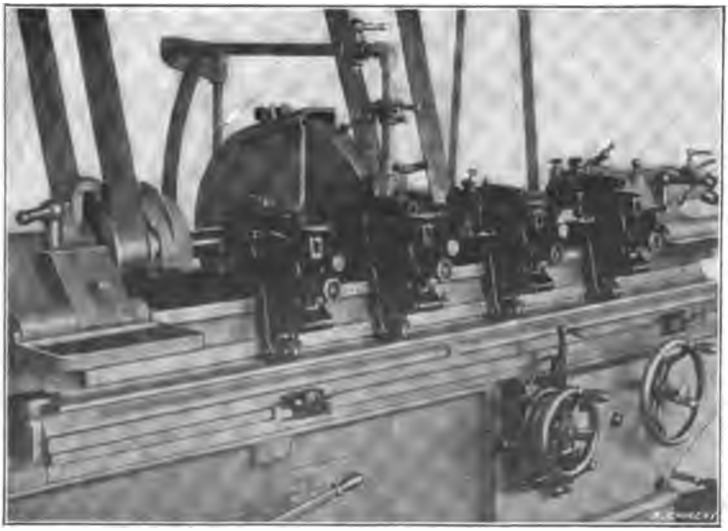

Fig. 12. Grinding Machine equipped with Four Universal Back-rests

of the machine, the shoes of each rest are adjusted, independently, to bear properly against the shaft. The way this adjustment is made will be more clearly understood by again referring to Fig. 11. The holder for the shoes has trunnions at the top which rest in V-shaped notches formed at the front end of frame *E*. The latter is connected at the rear with a link *F* which is pivoted at its lower end. Spring *B* tends to push frame *E* forward, and the extent of this forward movement is regulated by stop-screw *C*. In addition to this motion, the shoe holder can also be swiveled about its supporting trunnions by spring *A*. This spring forces screw *G* against the holder, and the movement of the screw is regulated by stop *D*. From the foregoing, it will be seen that spring *B* forces shoe *S* against the rear side of the work, whereas spring *A* forces shoe S_1 in an upward direction. Moreover, the pressure of the shoes can be arrested (after the work has been ground to a given diameter) by setting stops *C* and *D* in the proper position.

In adjusting a back rest, screw *G* is turned out far enough to allow the shoe to clear the work, and nut *H* is loosened to entirely relieve the tension of spring *B*. Stop screw *C* is also turned back, and nut *I* is screwed in to slightly compress spring *A*. Screw *G* is next turned forward to bring the shoes into contact with the work. The shoes are then held lightly in position and screw *C* is turned until the end just touches its stop or seat. With screw *C* in this position, both shoes should bear evenly against the work. Spring *B* is next compressed somewhat by turning nut *H*. The combined pressure of screws *A* and *B* should be only sufficient to resist the wheel pressure when taking the final cut, and also to prevent vibration.

When grinding the trial piece for adjusting the work-rests, the screws *G* on the different rests are used to keep the shoes in contact with the

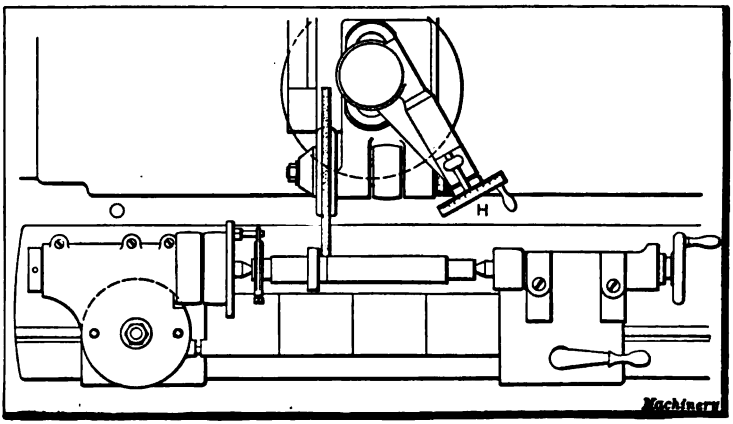

Fig. 18. Grinding Close to a Shoulder—Plan View

work, and the diameter at various points is regulated by adjusting stop-screws *C*. When the rests are correctly set, screws *G* are only adjusted to compensate for the wear of the shoes, and screws *C* are used for the delicate diameter adjustments. When short stiff pieces are being ground, the cylindrical form is obtained from the machine centers, but when the work is long and flexible, the control of the cenetrs is limited and they only steady the ends; consequently, in order to grind a slender shaft or rod cylindrical from one end to the other, it is necessary to rely on the adjustment of the work-rests.

Before adjusting the rests it is the practice in some shops to grind true "spots" for each of the supporting shoes. In order to do this, the rests are first placed in their respective positions and then the machine table is moved by hand until one of the rests is opposite the grinding wheel. The work is next "spotted" or trued by feeding the wheel in against the revolving work, while the table remains stationary. The diameter of the surface ground in this way should be within, say 0.002 inch of the finished size, although a larger allowance may be needed in certain cases. This "spotting" operation is repeated by successively placing each work-rest in front of the grinding wheel and proceeding as described. When spotting a very flexible shaft, it is well to first grind a spot for the work-rest nearest the footstock and then place this rest in position. The rest nearest the headstock is then located in the same manner and in this way a support is provided for the work, while spotting for the rests in the center of the shaft. The practice of grinding spots is not to be recommended for ordinary work, and, in many shops, parts are never "spotted" prior to grinding, even when they are ground from the rough.

There is a difference of opinion among grinding machine operators and manufacturers regarding the relative merits of the rigid work-rest and the flexible or spring type. Some advise the use of spring-rests for supporting light slender work, and the fixed or rigid form when grinding heavy stiff parts, whereas others advocate the use of rigid rests for

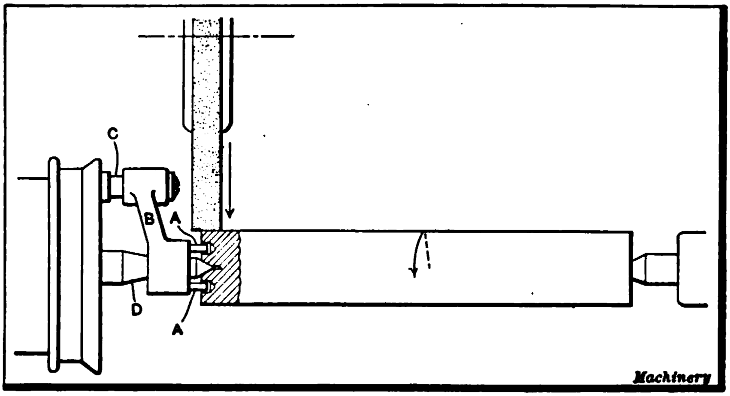

Fig. 14. Special End-driving Dog applied to Shaft for Grinding entire Length in One Operation

light as well as heavy work. It is also the practice in some shops to use spring-rests almost exclusively. Satisfactory results can doubtless be obtained with each type, under favorable conditions. When the work is light and flexible, spring-rests are often used in preference to the fixed form. On the other hand, when a heavy rigid piece is being ground, solid unyielding rests are commonly employed to provide as solid a support as possible in order to absorb vibration and prevent chattering.

When chattering is caused by vibration of the work, owing to improper supports, the surface left by the grinding wheel has minute, parallel ridges which spoil the finish; moreover the vibration which produces the chatter marks causes excessive wheel wear and greatly affects the efficiency of the grinding operation. Chatter marks are also caused by defects in the machine itself, in which case they have a spiral form. Sometimes the wheel spindle vibrates either because it is too light or the bearings are too loosely adjusted. Chattering is also produced by an unbalanced or improperly trued wheel, and the jar from a large stiff belt-joint will also set up vibrations that are copied on the work in the form of chatter marks. In some instances, chattering can be eliminated by a slight change in the work speed or by using a wheel of different grade; but, in other cases, the remedy is not so simple, especially when the trouble is caused by the design, construction or mounting of the machine.

Grinding Close to a Shoulder

Occasionally it is necessary to grind close to a shoulder, as indicated in the plan view, Fig. 13. This can be done by setting the wheel close to the shoulder with the hand adjustment and then feeding it straight in until the diameter next to the shoulder is reduced to the finished size or slightly above it; the remaining surface between the shoulder and the end of the work is then ground by using the power traverse movement in the usual way. The object in first grinding close to the shoulder is to provide a clearance space so that the wheel does not have

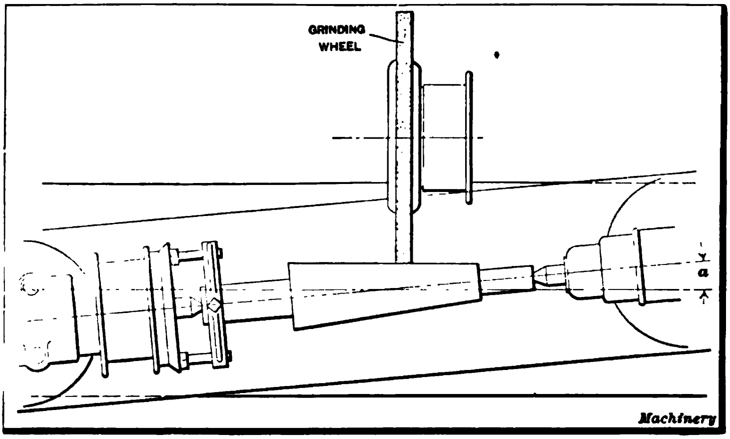

Fig. 15. Taper Grinding by Swiveling Platen to Required Angle

to travel close up to the shoulder. It is also possible to grind close to a shoulder without providing a clearance space, by carefully adjusting the stroke dogs to reverse the table when the wheel is almost against the shoulder. When this method is employed, the dog which controls the reversal at the shoulder end of the travel, must be accurately located to prevent the wheel from striking, and it may be necessary to adjust this dog for each piece ground, because the center holes usually vary more or less in depth and any such variation would change the position of the shoulder with relation to the wheel. The result is that considerable time is wasted in adjusting the stroke, and for that reason the first method referred to is preferable. With the second method, the surface next to a shoulder is also likely to be left a little large unless the wheel is allowed to dwell for a short time at the extreme end of the stroke. With the machine illustrated in Fig. 2 this dwell can be obtained by pushing in the knob located in the center of the handwheel *I*. The table traverse is again started by pulling out this knob. The machine shown in Fig. 13 is similar to the one shown in Fig. 4, but differs in that it is a universal type.

Special End-driving Dog

Sometimes it is desirable to grind a straight cylindrical shaft from one end to the other at one setting. Of course this cannot be done when a regular driving dog is used, because the latter will interfere with the movement of the grinding wheel. Fig. 14 illustrates a special end-driving dog which is sometimes used in cases of this kind. This dog has pins *A* which engage holes drilled in the end of the work. The arm *B* swings freely on pin *C* and has a hole which is larger than the machine

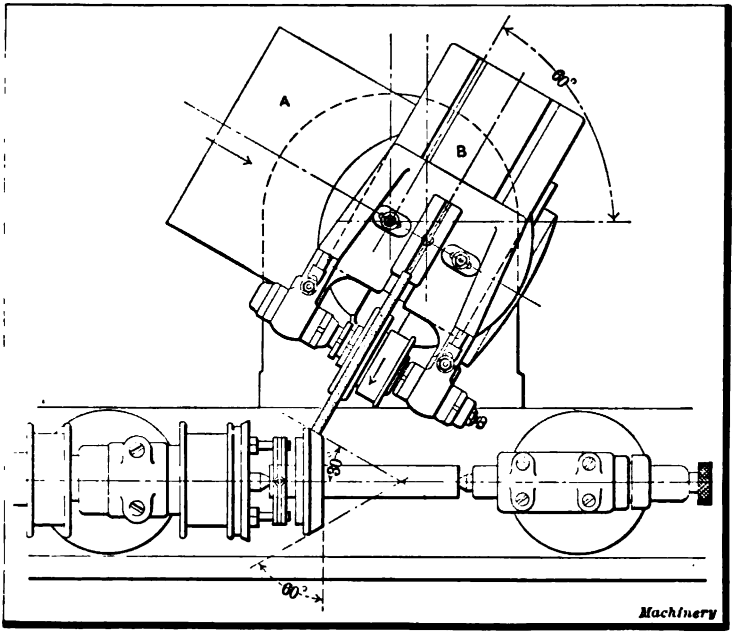

Fig. 16. Grinding Abrupt Taper by Setting Wheel-slide to Required Angle

center *D*, thus allowing it to turn on pin *C* until the driving pins *A* engage the holes on both sides. With this arrangement, the grinding wheel can move across the entire shaft, thus permitting the latter to be ground in one operation, instead of reversing it on the centers for grinding the driving or "dogged" end.

Taper Grinding

Taper parts are ground practically the same as those that are straight or cylindrical, provided the taper is not too steep or abrupt. The work is placed between the centers, as illustrated in Fig. 15, and the table is set to the required angle *a*, as shown by the graduations at one end. This adjustment locates the axis of the work at an angle with the table's line of motion; hence a taper is produced, the angle of which depends upon the amount that the swivel table is turned from its central or parallel position. There are usually two sets of graduations for the swivel table, one reading to degrees and the other giving the taper in inches per foot. The taper should be tested before the part is ground to the finished size, by using a gage or in any other available way.

The plan view, Fig. 16, shows how a taper surface is ground when the angle is beyond the range of the swivel table. The wheel slide *A* (which is normally at right angles to the table) is set to bring its line of motion parallel with the taper to be ground. The upper wheel stand *B* is also set at right angles to slide *A*, to locate the wheel face parallel with the taper surface. The table of the machine should be set in the zero position, so that the angular graduations on the wheel slide base will give correct readings with relation to the axis of the work. After adjusting

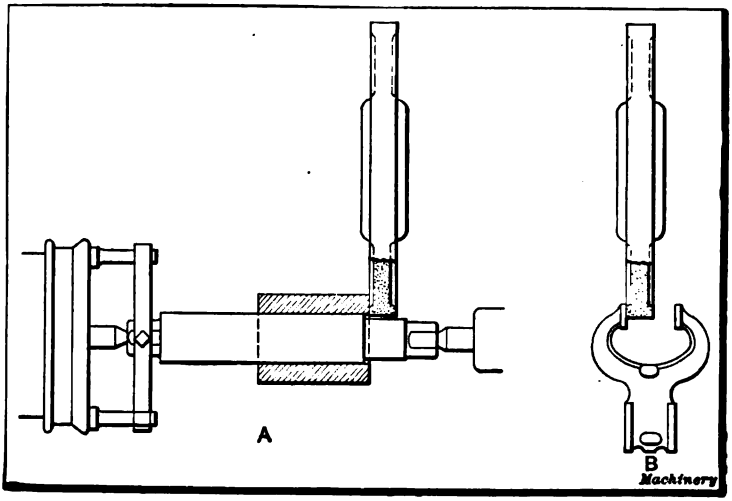

Fig. 17. Grinding with Side of a Recessed Wheel

the table to the proper longitudinal position, the grinding is done by moving the wheel across the taper surface by using the hand cross-feed. and the depth of each cut is regulated by slight longitudinal adjustments of the table. When the taper is tested, if any adjustment is necessary, this can be made by the table adjusting screw. Evidently an operation of this kind must be done on a universal machine, because the wheel slide of a plain type does not have the angular adjustment.

Parts having a double or compound taper can be ground at one setting. provided one taper is within the range of the swivel table. The latter is set for the smaller angle and the wheel slide for the greater angle, as indicated by the sketch *A*, Fig. 18. The wheel is set at right angles to the longest surface and one corner is beveled to suit the other surface. One part is then ground by traversing the table, and the other by moving the wheel slide. The wheel base, in this instance, should be set to an angle corresponding to the sum of the angles of both tapers, as measured from the axis. The sum of both angles, in the example illustrated, is 50 degrees.

Grinding with Side of Wheel

When it is necessary to grind bushings or sleeves, they are sometimes mounted on a mandrel as shown at *A*, Fig. 17. This view illustrates how the end of a bushing is finished by grinding with the side of the wheel. A wheel for end facing should be soft and porous and it should also be recessed on the sides (as shown by the sectional view) to reduce the working area. The grinding should be done by moving the work

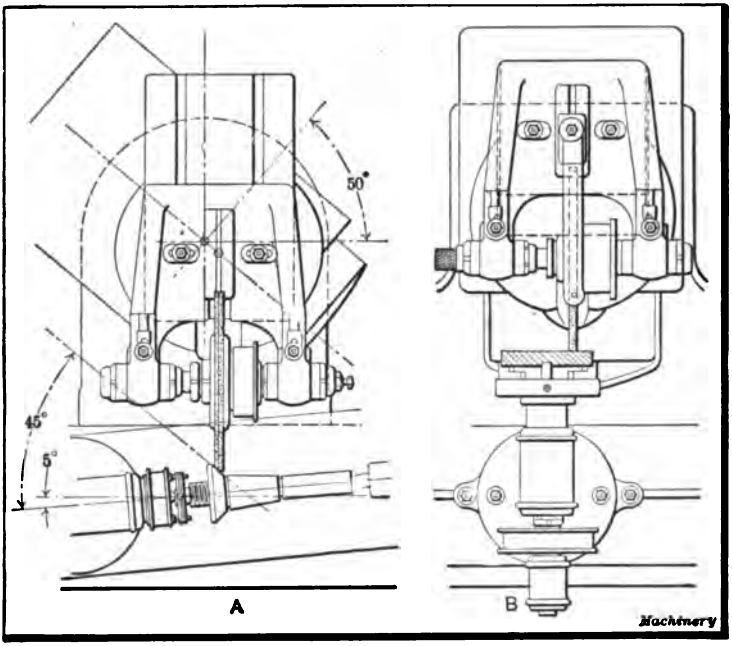

Fig. 18. (A) Grinding a Double Taper by Traversing both Platen and Wheel Slide. (B) Grinding the Side of a Disk

endwise against the side of the wheel, instead of traversing the wheel laterally. This method of facing the ends of cylindrical parts is only employed when the surfaces are quite narrow. Sketch *B* indicates how the jaws of a caliper gage are ground by the side of the wheel. The gage is held in a fixture attached to the table of the machine and the wheel is traversed across the face of the jaw being ground. It is necessary to traverse the wheel in this instance because the work is not revolving.

Use of the Universal Head

The headstock of the universal grinder is used for holding and revolving many parts, such as saws, milling cutters, and other pieces that cannot be revolved between the centers. Sometimes the work is held in an ordinary chuck screwed to the headstock spindle, and special collet chucks or fixtures are also employed, as well as magnetic chucks, where electric power is available. Sketch *B*, Fig. 18, illustrates how the side of a plain, flat disk is ground. The headstock spindle is set at right angles to the table, and the work, in this case, is held in a four-jawed chuck. When grinding, the wheel operates on only one side of the disk, and the automatic table traverse is used. If the surface must be flat it can be tested with a straightedge or by allowing the wheel to pass clear across the face and noting the density of the sparks on both sides. When the sparks show the same at all points the surface is flat within close limits. The fine adjusting screw for the table should be used for making adjustments. Obviously, concave or convex surfaces can be ground by setting the headstock to the required angle.

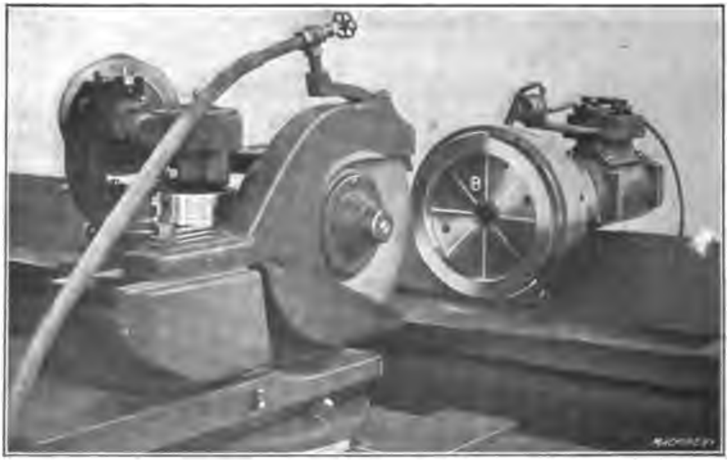

Fig. 19. Grinding Side of Steel Ring which is held by a Magnetic Chuck

Fig. 19 illustrates the use of a magnetic chuck attachment for face grinding. The operation is that of grinding the sides of a steel ring *A*. As these sides must be flat, the headstock spindle is set at right angles to the wheel spindle. The work is rotated by a belt (not in place) which passes over a pulley located just back of the magnetic chuck *B*. The current for magnetizing the chuck is conveyed through the wires and brushes shown. The wheels used for grinding flat surfaces should be of a softer grade than for cylindrical work, owing to the greater contact area.

Truing Grinding Machine Centers

Fig. 20 illustrates how a universal grinding machine is used to true its own centers. The headstock is set to an angle of 30 degrees, giving an included standard angle of 60 degrees, and the grinding is done by traversing the wheel across the conical surface. The tailstock center is ground first by inserting it in the headstock spindle, these centers being interchangeable. The table stroke should be adjusted so that the wheel overlaps the taper surface slightly on each side, and a copious supply of water should be used, when grinding, to prevent drawing the temper of the hardened centers. The centers of a plain grinder are inserted in a special fixture while being trued. This fixture is clamped to the table and holds the center at an angle of 30 degrees. It is very important to keep the centers in good condition, as otherwise parts ground upon them will not be accurate.

Preparation of Work for Grinding

The amount of stock that can economically be removed by grinding depends largely on the size and power of the grinding machine. The modern practice, when using heavy machines, is to reduce the work in a lathe to within somewhere between 0.015 and 0.030 inch of the required diameter and then finish by grinding. The lathe is simply used for roughing, and the stock is removed by taking one or more coarse

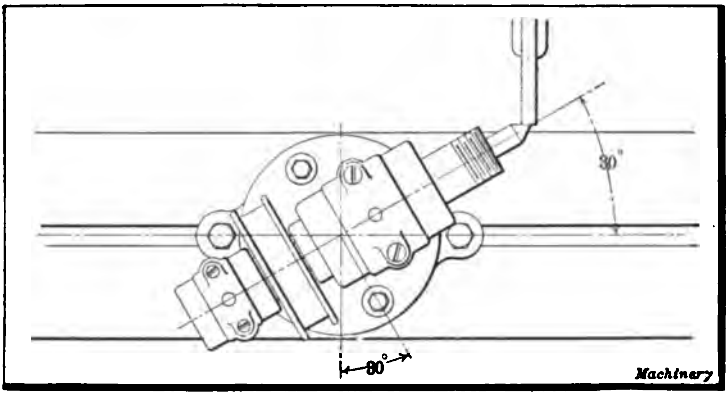

Fig. 20. Truing Conical Center of a Universal Grinder

cuts, leaving a rough surface on the work. When the diameter has been reduced to within say 0.025 inch of the finished size by turning, it is more economical to remove this stock by grinding than by taking a light finishing cut in the lathe. It is also practicable, in some cases, to grind bar stock from the rough without any preliminary turning operation, although most work is first turned. When using a light grinder the allowance for grinding must be comparatively small and is governed more or less, in any case, by the size and character of the work, as well as by the power and stock-removing capacity of the grinding machine.

Parts which have been hardened are occasionally so distorted by the hardening process that they cannot be finished to the required size. Straightening can then be resorted to, but this should not be done while the work is cold, as there is always a tendency for the piece to resume its original shape owing to internal strains, and even if properly heated, there is more or less danger of such distortion. When a hardened part must be straightened it should first be heated (though not enough to anneal it) and then straightened in a press. By proper annealing prior to the hardening process, this tendency to spring out of shape is often overcome. The annealing, which releases the internal strains incident to the rolling or forging operations, should take place after the outer surface has been removed in the lathe; then if the work runs practically true when tested, it can be machined to the grinding size, but if the piece is badly warped, it should be heated to a cherry red, straightened, and then annealed as before. Whenever possible, grinding should be done last, so that the work will not be marred or sprung out of true by other machining operations that may be performed later. Keyways in shafts, etc., should invariably be finished prior to grinding, as the removal of metal for the keyway from one side of the shaft will often distort the latter.

The machine itself should be carefully examined frequently, as its efficiency often depends upon a little intelligent care. The bearings, particularly of the wheel spindle, should be carefully adjusted to eliminate all lost motion, and the cross-slide for the grinding wheel should be thoroughly oiled so that it moves freely. The centers in the work should correspond to the angle of the machine centers and be carefully cleaned and oiled before the work is placed in position. When a grinding wheel is being mounted on the spindle, see that the central hole is a close but easy fit. If the diameter of the hole is about 0.005 inch large, the wheel will slide on without cramping, and it will not only have a good fit on the spindle, but an even bearing against the inside flange. Soft washers of blotter or rubber should be placed between the wheel and flanges on each side, as they compensate for any roughness in the wheel and distribute the clamping pressure evenly. The flanges should be tightened just enough to hold the wheel firmly, to avoid any unnecessary strain.

CHAPTER III

GRINDING WHEELS—WORK SPEEDS

If satisfactory work is to be done in the grinder it is absolutely essential that the grinding wheel be of a grade and grain which is adapted for the material to be ground. Grinding wheels are composed of a large number of grains or kernels of some suitable abrasive material, such as alundum, corundum or carborundum, which are held together by what is known as a bond. By varying the amount and composition of this bond, wheels of different grades are obtained. The term grade does not refer to the degree of hardness of the abrasive, but to the tenacity with which the bond holds the grit in place. A wheel from which the grit or cutting particles can easily be dislodged is called soft, and one which holds the particles securely is referred to as a hard wheel.

The degree of hardness or grade of a wheel is commonly denoted by the letters of the alphabet. According to one system the letter *M* represents a medium grade and the successive order of letters preceding and following *M* denote softer and harder wheels. For example, grade *E* is soft; grade *I*, medium soft; *M*, medium; *Q*, medium hard; *U*, hard; *Y*, extremely hard; whereas the intermediate letters indicate grades between those mentioned. Thus wheel *L* is one grade softer than *M*, and *N* one grade or degree harder. This method of grading wheels is not universal, as a standard system has never been adopted by the different manufacturers.

The grain or coarseness of a wheel is designated by numbers which indicate the number of meshes to the linear inch through which the kernels of grit will pass. To illustrate, a 36 grain means that the grains or cutting particles will pass through a sieve having 36 meshes to the linear inch. The combination of grade and grain is marked on the side of the wheel by using the letter for the grade and the number for the grain; thus a 36-M wheel is one having cutting material of No. 36 grain and a medium degree of hardness.

Selection of Wheel for Grinding

When selecting a grinding wheel there are several factors which must be considered. The grade and grain depend largely upon the character of the material to be ground and its degree of hardness. For example, machinery steel requires a harder wheel than hardened tool steel. The reason for this will perhaps be better understood if we think of a grinding wheel as a cutter having attached to its periphery an innumerable number of small teeth, for this is literally what the thousands of small grains of abrasive are. When the wheel is of the proper grade these small teeth or cutting particles are held in place by the bond until they become too dull to cut effectively, when they are torn out of place by the increased friction. Obviously these grains or cutters will become dulled sooner when grinding hard than when grinding soft steel; hence, as a general rule, the harder the material, the softer the wheel, and *vice versa.*

When a hard wheel is used for grinding hard material, the grit becomes dulled, but it is not dislodged as rapidly as it should be, with the result that the periphery of the wheel is worn smooth or glazed, so that grinding is impossible without excessive wheel pressure. Any undue pressure tends to distort the work, and this tendency is still further increased by the excessive heat generated. If the surface of the wheel becomes "loaded" with chips and burns the work, even when plenty of water is used, it is too hard.

Soft materials, such as brass, are ground with a soft wheel, which crumbles easily, thus preventing the wheel from becoming loaded or clogged with metal, as would be the case if a hard-bonded wheel were used. When a wheel is used which is too soft, the wear is, of course, greatly increased, as the particles of grit are dislodged too rapidly, and, consequently, the wheel is always "sharp." This means that the abrasive has not done sufficient work to become even slightly dulled, and the result is a rough surface on the work.

The area of the surface which is in contact with the wheel should also be considered when selecting the proper grade. For a given material the wheel should be softer as the area increases. To illustrate, a wheel of grade *N* might be suitable for grinding cylindrical pieces 2 inches in diameter, but not suitable for a diameter of 4 inches, because of the increased contact area, owing to the increase in diameter.

The grain or degree of coarseness of the wheel is another point to be considered when making a selection. Generally speaking, coarse wheels are better adapted to most work because the larger grains permit deeper cuts to be taken. When a very fine finish is required, particularly on a number of duplicate pieces, fine wheels are sometimes used for finishing, after the work has been ground to within, say, 0.002 inch of the required size with a coarse wheel. It is not necessary, however, to use a fine wheel in order to obtain a smooth surface, as a wheel of comparatively coarse grain will produce a finish fine enough for most purposes, if the work speed is reduced somewhat and the wheel is trued with a diamond just before taking the finishing cut; in fact, very fine surfaces can be obtained with a comparatively coarse wheel, provided there is tne proper relation between the surface speeds of the wheel and work. When roughing cuts are being taken, the cutting particles are constantly worn away or dislodged so that the face of the wheel is kept rough or "sharp," and the ground surface is also comparatively rough. After the wheel face has been trued with a diamond, however, light finishing cuts, in conjunction with a reduced work speed, will give a finish which is smooth enough for all practical purposes, even though a fairly coarse wheel is used.

Incidentally, it is not always the highly polished surface which represents the most accurate work, because this finish is sometimes obtained at the expense of accuracy, by using hard wheels that require so much pressure to make them grind that the work is distorted. In order to secure accuracy, the wheel must cut freely and without perceptible pressure. Sometimes a coarse wheel refuses to cut after a surface has been finished to a certain point, because the cutting particles wear off somewhat and the ends become too large and blunt to enter the smooth surface. If this occurs, the wheel should be trued with a diamond or be replaced with one of finer grain. When grinding brass or soft bronze the grain of the wheel must be as fine as the finish desired; in other words, it is not practicable to use a coarse wheel for finishing these metals.

Peripheral Speed of Work and Grinding Wheel

A wheel which is perfectly adapted to grinding a certain kind of material will not work satisfactorily if the relative surface speeds of the wheel and work are not approximately correct. The work speed affects the wear of the wheel, which, when excessive, also affects the finish of the surface being ground. The amount of stock that the wheel removes for a given amount of wear can be increased or diminished by varying the work speed, the wheel wear being excessive when the speed is too high. This close relation between the work speed and the wheel wear makes it possible to use a wheel which is somewhat harder than it should be for a given piece of work, by increasing the work speed, with the result that the grit is dislodged more easily, and, consequently, does not remain long enough to cause glazing, which would otherwise take place; this practice, however, is not to be recommended.

As there are a number of factors, such as kind of material, finish desired, etc., which determine the proper work speed, it is impractical to say just what this speed should be unless the conditions are known. A speed of twenty-five feet per minute might be correct for grinding a certain piece of steel, and not correct for another steel part having a different carbon content. The finish of a ground surface, as previously stated, is also affected by the work speed. It is possible to grind a very rough or smooth surface by simply varying the speed, depth of cut and side feed of wheel, the surface becoming smoother as these are diminished. For this reason the speed and feeds (when within, say, 0.002 inch of the finish size) are often reduced before taking the finishing cuts. The best method of ascertaining the proper speed for a given piece of work, and, incidentally, of determining the best wheel to use, is by experimenting until the desired results are obtained. This does not necessarily mean that whenever a new piece of work is to be ground considerable time must be wasted, as the speed adjustments are easily made, and besides, experience will soon teach what combinations of speed will give the best results.

The peripheral or surface speed of a grinding wheel is usually somewhere between 5500 and 6000 feet per minute, although speeds between 5000 and 6500 feet per minute are employed. As the wheel diminishes in size, it appears to get softer, even though the peripheral or surface speed is maintained. This increase in wear is due to the fact that the grit of a small wheel is in contact with the work oftener owing to the increased number of revolutions necessary for the same surface speed.

It should always be remembered that the thing to be sought after is maximum production. When choosing a grinding wheel, for example, if one too hard for the work is selected with the idea of reducing the wheel wear, the corresponding reduction in the output will much more than off-set the increased expense incurred by using a softer and more rapidly wearing wheel. The wheel wear, however, should be considered, and, as it is dependent upon the work speed, the vibration of the work, and depth of cut, these should receive careful attention. When certain combinations of speed, feed, etc., have been found correct for a certain kind and size of material, it is advisable to record this information for future reference, for while such data may not always be applicable, owing to a difference in the grade of the material, it will, in many instances, enable one to save considerable time.

Composition of Grinding Wheels

There are several kinds of abrasive materials used in the manufacture of grinding wheels, and the composition of the bond for holding the abrasive grains together in the form of a wheel is also varied to produce wheels adapted to different purposes. At one time practically all grinding wheels were made of emery, but other materials possessing superior cutting qualities are now largely employed for machine grinding. Three of the abrasives commonly used in modern grinding wheels are corundum carborundum and alundum. Both emery and corundum are natural abrasives, whereas the other materials mentioned are produced artificially. Corundum is much purer than emery and contains a much larger percentage of crystalline alumina, which is the element in both abrasives that does the cutting.

Carborundum, which is a trade name for carbide of silicon, is a product of the electric furnace. The principal materials used in the manufacture of carborundum are coke and sand. The coke is used to supply the carbon, and the sand the silicon. These elements are placed in an electric furnace, where they are subjected to a temperature ranging between 7000 and 7500 degrees F., for a period of thirty-six hours. In this terrific heat all impurities in the coke and sand are destroyed and the carbon and silicon unite to form masses of carborundum crystals. These crystals are only inferior to the diamond in hardness. After the furnace is cooled the masses of crystalline carborundum are crushed to grains which are subjected to various forms of treatment and are finely graded. Alundum is also made in the electric furnace by the fusion of a mineral called Bauxite, which was considered infusible until the invention of the electric process. The chemical composition of alundum is similar to the ruby and sapphire which are the hardest natural minerals, except the diamond.

In the manufacture of grinding wheels the abrasive grains are bound together by mixing them with an adhesive substance or "bond." which is usually composed either of clays and fluxes, silicate of soda, or shellac.

The Vitrified Process

When clays are used they are thoroughly mixed with the abrasive in large power-driven mixing kettles. This mixture is then drawn off into molds and dried. The wheels are then shaved off to the proper shape in a special machine, after which they are baked or burned continuously for a period of 100 hours or more, the time depending upon the size of the wheels. During this baking process the temperature is gradually raised until the clay is partially melted and vitrified. The wheels are then allowed to cool slowly for a week, and great care must be taken to maintain uniform temperatures and prevent sudden changes. As the cooling takes place the clay crystallizes and binds the abrasive grains firmly together. This is known as the vitrified process and is the method employed for making most grinding wheels.

The Silicate and Elastic Processes

There are two other common methods of making grinding wheels, one of which is known as the silicate, and the other as the elastic process. With the silicate process, silicate of soda is the principal ingredient of the bond. The abrasive grains are first mixed with the bond in special machines, and the mixture is then tamped into molds. After the wheels are molded they are dried and baked in special ovens. The temperature of these ovens is much lower than is requird in connection with the vitrified process.

Wheels made by the elastic process have shellac as the principal ingredient of the bond. They are also molded and then baked at a comparatively low temperature to set the shellac. Wheels made by this process have great tensile strength and also a certain amount of elasticity so that very thin wheels can be safely used; in fact elastic wheels only 1/32 inch thick are manufactured. Elastic wheels are also made by what is known as the Vulcanite process, in which case the bond is composed of vulcanized rubber. Tough, thin wheels can be produced by this method, but they are very expensive.

The vitrified wheel is generally considered superior for most grinding operations, as it is very porous and free cutting. It is adapted to cylindrical and surface grinding, and for a variety of other operations. Vitrified wheels are difficult to make in large sizes as they are liable to crank in the kiln, and the process requires about four weeks, which is sometimes a decided disadvantage. Silicate wheels are recommended for wet tool grinding, wet surface grinding (especially when cup wheels are used), and whenever accuracy of grading is required. Silicate wheels can be made in large sizes and the process only requires a few days, which is an advantage, particularly when special shapes are needed.

CHAPTER IV

INTERNAL GRINDING

The grinding of holes is known as internal grinding. This class of work is done on universal machines and also on special types designed exclusively for internal grinding. When a universal cylindrical grinder is employed for internal work it is equipped with an internal grinding attachment. Fig. 21 shows how an internal attachment is applied to a Landis machine. The regular wheel head is turned half way around on its slide, and the internal fixture *A* is bolted to the front of the slide after the wheel-guard has been removed. The spindle of the internal

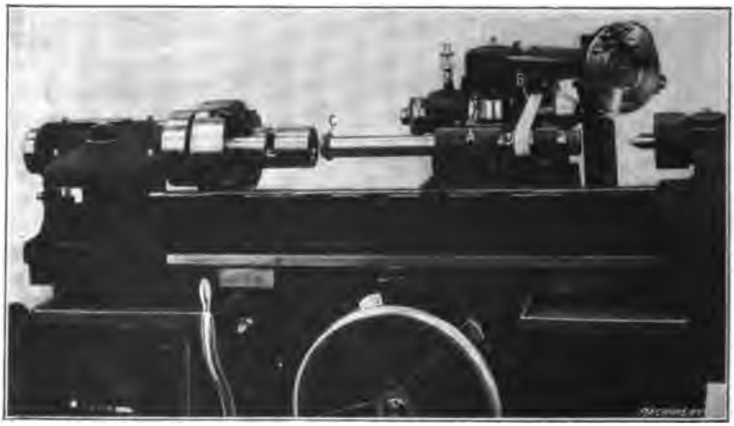

Fig. 21. Landis Universal Grinder equipped with Internal Grinding Attachment

fixture is driven by a short belt *B* connecting with a pulley which replaces the regular grinding wheel. The work is held in a chuck mounted on the headstock spindle, and the grinding is done by a wheel *C*. The wheel to use in any case must, of course, be somewhat smaller than the hole to be ground, and the grinding is done by traversing the wheel through the hole. The work is rotated rather slowly when grinding, and the wheel cuts along one side as it passes through.

The wheels used for internal grinding should generally be softer than those employed for other grinding operations, because the contact area between the wheel and work is comparatively large. The wheel spindle is also rather weak so that a soft wheel that will cut with little pressure, should be used to prevent springing the spindle. The grade of the wheel depends on the character of the work and the stiffness of the machine, and where a large variety of work is being ground, it may not be practicable to have an assortment of wheels adapted to all conditions. By adjusting the speed, however, a wheel not exactly suited to the work in hand can often be used. If the wheel wears too rapidly, it should be run faster, and if it tends to glaze, the speed should be diminished.

When adjusting the machine for grinding a hole, the length of the stroke should be regulated so that the wheel will only travel beyond the ends of the hole, one-fourth or one-half its width, because if it is allowed to pass clear through the hole, the spring of the spindle will cause the hole to be ground "bell-mouthed" or large at the ends.

When a hole is to be ground straight or cylindrical, the head can be accurately set by the following method: Before attaching the internal fixture a cylindrical piece is gripped in the chuck and ground

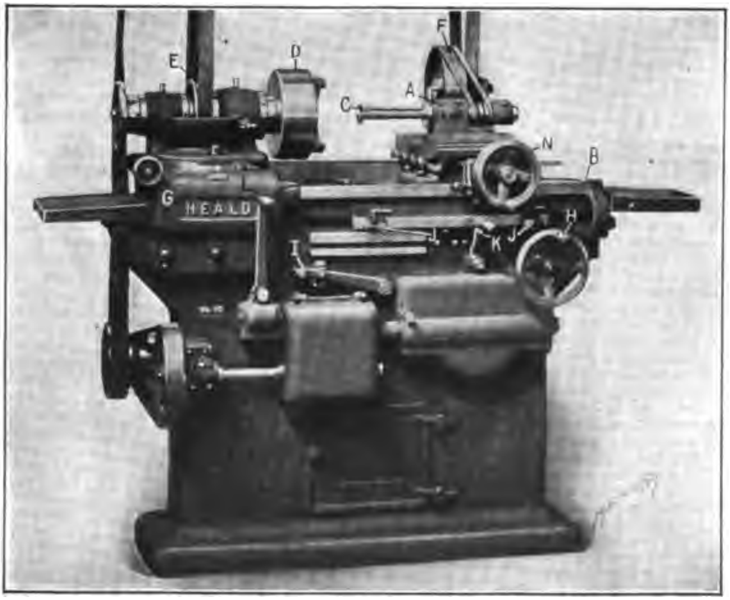

Fig. 22. Heald Internal Grinding Machine

externally with the regular wheel. When the head is adjusted so that this test piece is ground straight, then it is properly set for grinding a straight or cylindrical hole. The straightness of a hole can also be tested when grinding it, by the following method: First grind the hole true with the wheel operating in its normal position on the rear side; then bring the wheel into contact with the opposite side of the hole and, as it passes through, note the density of the sparks in order to determine whether the hole is straight or tapering. If the wheel cuts heavier as it approaches the back end of the hole the latter is smaller at that end, but if the density of the sparks becomes less, the hole is smaller in front. When the sparking is even on both sides the hole is straight or cylindrical.

The work shown in Fig. 21 is held in an ordinary three-jawed chuck, but draw-in collets and special fixtures are often used for internal grinding. When gripping frail parts in a chuck, care should be taken to prevent springing them out of shape. As the pressure of grinding is comparatively light, it is not necessary to clamp the work very tightly, although if a part is held insecurely, it may be shifted when testing the diameter of the hole with a plug gage, especially if the gage sticks in the hole. Therefore, a greater clamping pressure than is necessary for grinding is often required. In the case of thin bushings and similar work, this matter of distortion is very important; for work of this class, the Heald Machine Co. recommends the use of a special chuck which clamps endwise, thus avoiding all radial pressure and distortion.

Internal grinding is often done dry, although cooling water should be used whenever practicable, as it not only keeps the work cool but washes away the chips and abrasive. When a part that has been ground dry, is being measured with a plug gage, the latter may stick or "freeze" in the hole, unless the work is cooled somewhat before inserting the gage. This sticking is due to the fact that the hole being ground is expanded by the frictional heat of grinding and when the cold plug gage is inserted, the hole contracts and grips the gage. Internal grinding wheels should be kept true in order to secure smooth accurately finished holes. A diamond tool is preferable for truing the wheel face, although a piece of some hard abrasive such as carborundum can be substituted. The diamond tool or carborundum "rub," as the case may be, should be held in a fixed position when in use.

Heald Internal Grinder

A machine that is designed especially for internal grinding is shown in Fig. 22. The grinding wheel head *A* is mounted on a cross-slide which is carried by the table *B*. The latter has a reciprocating movement on the bed for traversing the grinding wheel *C* through the hole. The work is held in some form of chuck *D*, or in a special fixture, and it is rotated by a belt operating on pulley *E*. This belt connects with a pulley overhead, the speed of which can be varied by a change gear box forming part of the countershaft. This feature enables the work speed to be varied for grinding holes of different diameter. The pulley *F* for driving the wheel spindle, is driven by belt from an overhead drum which allows the table to move longitudinally. The headstock is mounted on a base *G* which forms a bridge over the table so that the latter can pass beneath it. The headstock can be set to an angle of 45 degrees either side of the center-line, for grinding taper holes. The table can be operated by handwheel *H* or by power. Lever *I* engages the power feed clutch, and the stroke of the table and grinding wheel is controlled by the position of dogs *J* which engage reverse lever *K*. The travel of the table per revolution of the work is controlled by lever *L*. By means of this lever three rates of feed are obtained for each work speed, a coarse feed being used for rough grinding and finer feeds for finishing. The cross feed for the wheel slide can be operated either by hand or automatically. The automatic feed mechanism is located just back of wheel *N* which is used for the hand movement.

CHAPTER V

SURFACE GRINDING

The grinding of plane or flat surfaces is called surface grinding. There are several different types of surface grinders, some of which are adapted principally to tool-room work, and others to general manufacturing. A common method of grinding a flat surface is indicated by the diagram *A*, Fig. 23. The work *w* is traversed to and fro beneath the grinding wheel *G* (as indicated by the dotted lines), and either the wheel or work is fed laterally (see end view) at each end of the stroke, so that the periphery of the wheel gradually grinds the entire surface. Another method of producing flat surfaces is illustrated at *B*. The wheel *g*, in this instance, is a cup type, and the vertical surface *a* is ground by being traversed past the face of the wheel; hence this is often called face grinding.

Diagram *C* illustrates the operation of a vertical surface grinder. The grinding is done by either a cup or ring wheel *g*, which revolves about a vertical axis. The work *w* is attached to a reciprocating table and is traversed beneath the grinding wheel. This type of machine is used quite extensively, at the present time, and it has proved very efficient for work within its range. Diagram *D* illustrates the operation of another vertical-spindle machine. In this case the work table has a rotary instead of a reciprocating movement. This type is especially adapted to grinding the sides of flat disk-shaped parts, such as saws, etc., and for a variety of other work. For example, to finish the side of a circular plate *w*, wheel *g* is placed in the position shown by the plan view, and the surface is ground as the table and work revolve in the directions indicated by the arrows. The grinding is done by the lower edge or face of the wheel, and the latter is slowly fed downward until the part has been ground to the required thickness.

The surface grinder is indispensable in the tool-room for truing parts that have been distorted by hardening and for producing fine accurate surfaces. Many of the machines built at the present time are also efficient for producing flat surfaces in connection with manufacturing operations. Ordinarily the surface grinder is used for finishing parts which have been milled or planed approximately to size, although many pieces are ground from the rough on the large machines used for manufacturing purposes.

Fig. 24 shows a plain surface grinder of medium size which operates on the principle illustrated by diagram *A*, Fig. 23. The part to be ground is attached to table *A*, and the grinding is done by wheel *G* which can be adjusted to the proper height by handwheel *B*. The stroke of the table is controlled by the position of dogs *D* and D_1 which operate the reverse lever *C*. As the table reciprocates, the wheel with the column which supports it, feeds laterally at each end of the stroke.

The movement of the table and the lateral feeding movement of the wheel are automatic when grinding, but they can be effected by hand for making adjustments. Crank *E* is for traversing the table, and wheel *F* operates the hand cross feed.

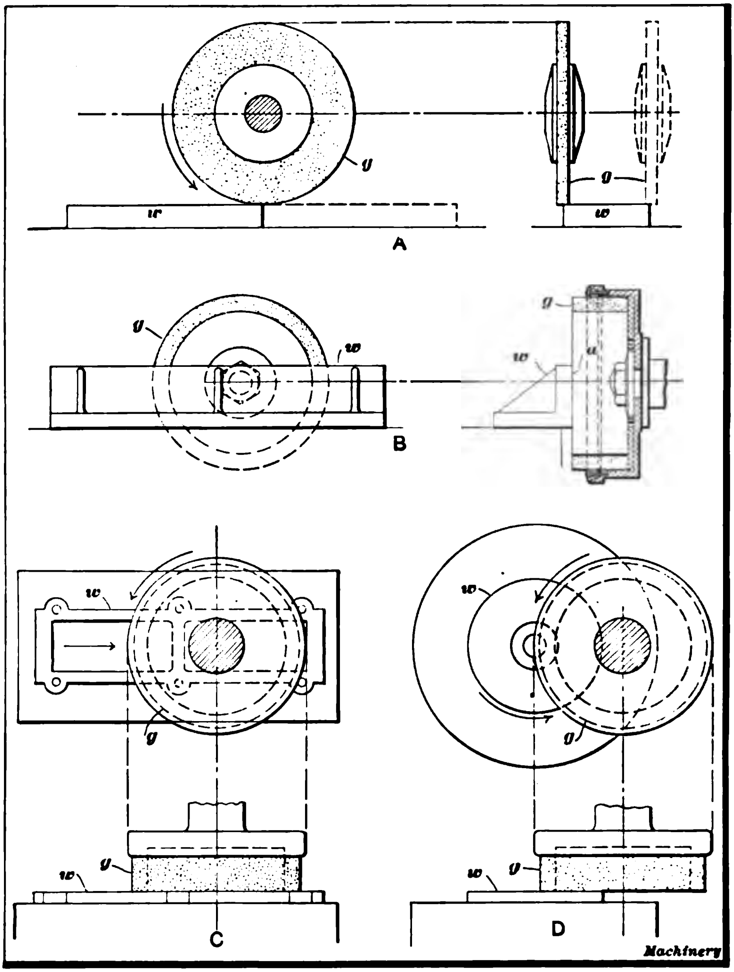

Fig. 23. Diagrams illustrating Four Methods of Surface Grinding

The belt which drives the grinding wheel connects with pulley *H* and the latter is driven by belt *I* from an overhead shaft. The reciprocating movement of the work table is derived from the belts *J* and *K*. One of these belts is open and the other crossed, so that the pulleys which they engage rotate in opposite directions. Interposed between these pulleys there is a clutch which is splined to a shaft that operates the table driving mechanism. This clutch is engaged with first one pulley and then the other, whenever the dogs *D* strike lever *C*, thus reversing the direction of the table's movement. The motion of lever *C* is transmitted to the clutch at the rear, by means of suitable links and levers. This movement of lever *C* (which is caused by engagement with dogs *D*), not only operates the table, but also operates the mechanism for feeding the grinding wheel laterally.

The traversing motion of the work table can be stopped automatically when the wheel has fed across the part being ground, by means of a

Fig. 24. Walker Surface Grinder of Reciprocating Type

trip mechanism. In connection with this mechanism there are two adjustable collars mounted on a horizontal rod located on the left side of the machine. There is also a trip-finger attached to the wheel housing, and whenever this finger engages one of the collars, the horizontal rod is shifted slightly, which makes it impossible for the reverse clutch at the rear to engage the driving pulleys; consequently, the reciprocating motion of the table is stopped. The point at which the trip mechanism operates, depends upon the position of the stop-collars which are adjusted so that the table will stop after the wheel has passed across the surface to be ground.

Some surface grinders which grind with the periphery of the wheel like the machine illustrated in Fig. 24, are designed along the lines of an ordinary planer; in fact the construction is almost identical except that a grinding wheel is mounted on the crossrail, instead of a tool-head. When this type of machine is in operation, the work table reciprocates and the wheel feeds laterally across the surface to be ground.

Horizontal Face Grinding Machine

A face grinding machine is illustrated in Fig. 25. This type operates by traversing the work past the face of ring-wheel *G*, as previously explained in connection with diagram *B*, Fig. 23. The part being ground is clamped to table *A* which has an automatic reciprocating movement.

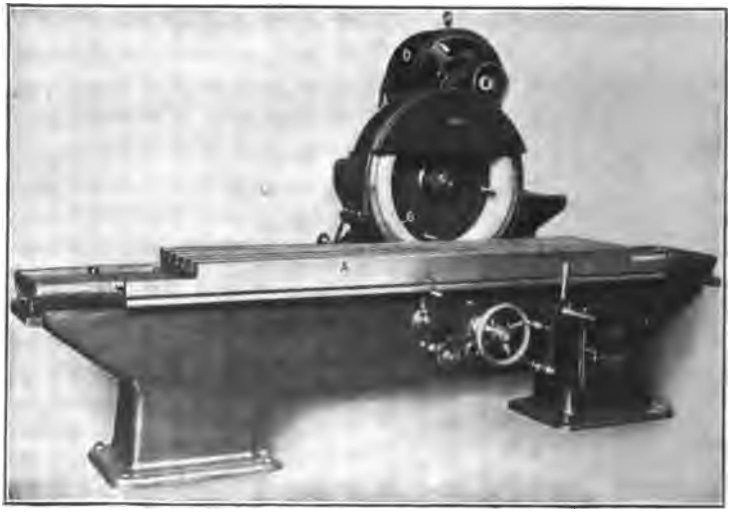

Fig. 25. Diamond Motor-driven Face Grinder

The length of the stroke is regulated by dogs (not in place) which engage reverse lever *C*. The wheel has an adjustable automatic power feed, and both the wheel and work table can be moved by hand. This particular machine is driven by a motor *D* which is connected to the wheel spindle by a belt.

The face grinder has some advantages over the type of machine using a wheel that grinds on the periphery. In fact, the advantages are similar to those which a face milling cutter has over an axial milling cutter. In the first place, the power consumption is less and plane surfaces are produced with fewer passes of the grinding wheel. The radius of a cup wheel also remains the same until it is worn out, instead of changing constantly, as with a disk wheel. The type of face grinder shown in Fig. 25, is generally used for grinding quite heavy parts and it is especially adapted to that class of work which can be held to better advantage when the surface to be finished is in a vertical plane. For example, the ends of rather long castings, such as machine legs, etc., can easily be ground on this style of grinder, because the work can be clamped to the table of the machine, in a horizontal position. Evidently it would be impracticable to grind work of this class on a machine having a vertical spindle, because the castings would have to be held in an upright position. The horizontal face grinder is often used in locomotive shops for truing or finishing the

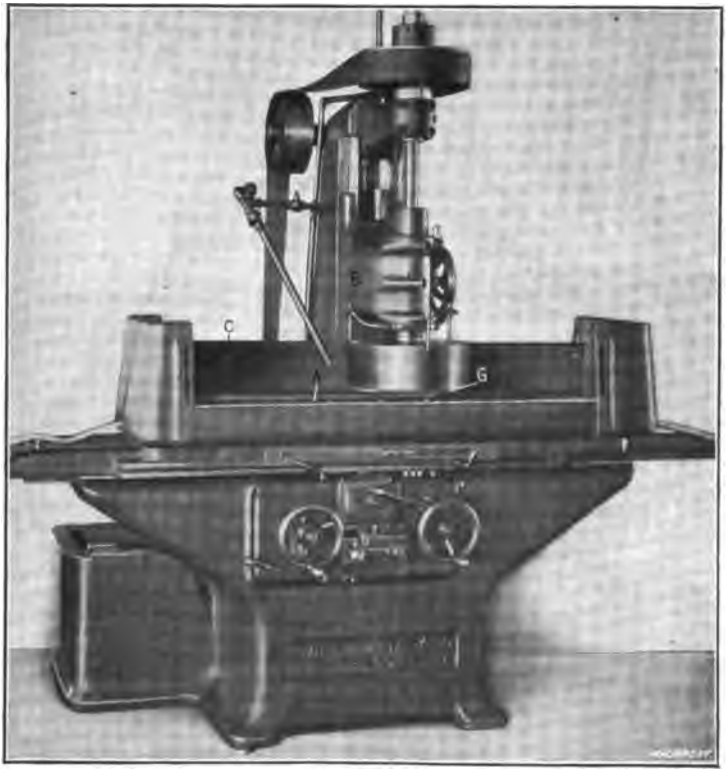

Fig. 26. Pratt & Whitney Vertical Surface Grinder

bearing surfaces of guide-bars, and it can be employed to advantage for many other grinding operations.

Vertical Surface Grinder

Fig. 26 shows a surface grinder of the vertical type. The grinding is done by ring or cup wheel *G* which covers the full width of the work. With this machine, the work can be given either a reciprocating or rotary motion, depending upon the shape of the part being ground. For grinding rectangular surfaces, or parts that should move in a straight line beneath the wheel, the table *A* is given a reciprocating movement, the length of which is controlled by dogs in the usual manner. On the other hand, the sides of saws, rings or flat disk-shaped parts are rotated while being ground, by placing them on a rotary chuck which is mounted on the grinder table. When the rotary chuck is in use, the table remains stationary.

It will be seen from the foregoing that this machine operates either as illustrated by diagram *C*, Fig. 23, or as shown by diagram *D*. The grinding wheel and its spindle is carried by a head *B* which can be fed vertically on the face of the column. The vertical feed can be operated automatically or by hand, and be disengaged automatically at any predetermined point. The reciprocating table has two rates of feed or travel and it can be moved by hand, if desired. This grinder is equipped with a pump for supplying cooling water to the wheel. The water is pumped into the hollow spindle, at the top, and passes down to the inside of the grinding wheel, after which it is driven outward by centrifugal force between the wheel and the work. An outside stream of cooling water is also provided and the table is surrounded by a water guard *C* which prevents the water from flying about.

The vertical type of grinder can be used advantageously for grinding long rectangular surfaces, disk-shaped parts (by using the circular attachment) and it is very efficient for grinding a number of small castings simultaneously. When several parts are to be ground at the same time, they are grouped on the table of the machine or on a magnetic chuck, so that the wheel will grind each casting as the table feeds along. It is comparatively easy to hold several small castings on a grinder of this type, because they are placed horizontally on the machine, and, as the wheel operates on the top surfaces, the pressure of grinding is mostly downward against the table and bed, which provide a solid unyielding support. This type of machine is used extensively for grinding from the rough; that is, castings or forgings are finished by grinding without any preliminary machining operation, such as planing or milling. This practice is followed when it is not necessary to remove very much metal.

Rotary Surface Grinder

Still another type of surface grinder is shown in Fig. 27. This machine is designed for rotary grinding exclusively, the principle of its operation being indicated by diagram *D*, Fig. 23. A cup wheel *G* is carried by an upper slide *B* and the work is held on a rotary magnetic chuck *C* mounted on lower slide *D*. The wheel spindle is driven from a horizontal shaft at the rear by a quarter-turn belt, as shown, whereas the work table is driven from drum pulley *E*. When the machine is in operation, the wheel is fed down against the work until the latter is finished to the required thickness, by operating hand-lever *F*. The wheel slide is fed against a positive stop, and the thickness of the work is varied by adjusting the lower slide which is equipped with a vertical feed screw. This screw is operated by handwheel *H* which is graduated to thousandths of an inch. When the lower slide has been set, its position is not changed for successive operations except to compensate for wheel wear.

The link-and-lever mechanism seen at the side of the column, connects the wheel slide with a jaw clutch inside the work-table driving drum, and disconnects this drum from the shaft on which it is mounted, when the wheel slide is in the upper position. By this means, the work spindle is automatically stopped whenever the wheel is raised from the work. As the wheel is moved vertically by lever *F*, it will be seen that the latter controls the starting and stopping of the work-table. This lever also controls the magnetizing current for the chuck, and the demagnetizing current for neutralizing the residual magnetism

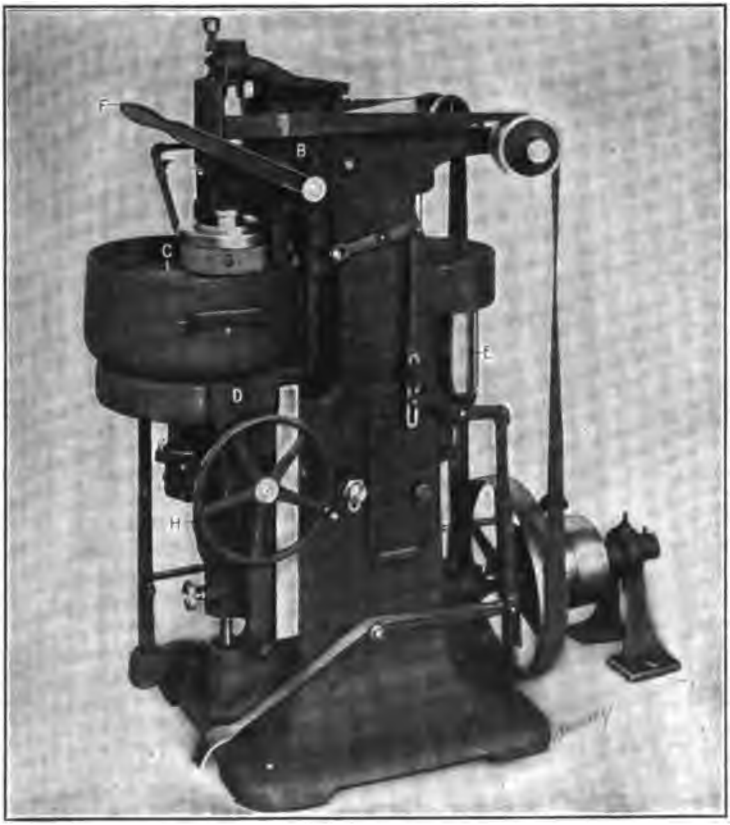

Fig. 27. Walker Rotary Surface Grinder

always found in a magnetic chuck after the electric current has been switched off. If desired, the drum-clutch operating mechanism can be disengaged, and the motion of the work-table be controlled independently by means of the foot lever seen at the base of the machine.

This machine can be used for concave grinding, in which case the knee supporting the work-table is tilted to the required angle. Work having a concave surface is not held directly against the magnetic chuck, but on an auxiliary plate. The magnetic power of the main chuck is transmitted through this auxiliary plate, the upper surface of which is shaped to suit the surface of the work. The use of an auxiliary plate in connection with the grinding of a milling saw is illustrated in Fig. 28. After the saw is ground concave on one side, it is held for grinding the opposite side on a plate *A* having a convex face. If the saw were held for grinding the last side against the flat face of the regular chuck, it would be sprung down in the middle, so that both sides would not be finished alike, or to the same concavity. Fig. 29 shows how a number of parts can be ground simultaneously on a rotary surface grinder. In this instance, three castings are arranged in a group on the magnetic chuck, in such a way that they support each other to some extent, while the top surfaces are being ground flat.

Fig. 28. Grinding Side of Saw Concave

Fig. 29. Grinding Three Castings Simultaneously

These views indicate, in a general way, the kind of work that is ground on a machine of this type.

Use of Magnetic Chucks

The method of holding work to the table of a surface grinder depends, of course, more or less on the shape of the part to be ground. Ordinary clamps and bolts are sometimes used, but where electric power is available, magnetic chucks are preferable for most work. The magnetic chuck is a special form of electro magnet which is connected by wires and a control switch, with the electric power circuit. The top surface against which the parts are held, has a series of positive and negative holes which are separated by an insulating material. When in use, the chuck is clamped onto the table of the surface grinder, and the work is held by magnetic force when the current is turned on.

A rectangular magnetic chuck is illustrated in Fig. 30. This is the form used on surface grinders of the reciprocating type, whereas for rotary grinders, round chucks are employed. The control switch is located at *D*, and the work is held against surface *A* which has a number of positive and negative poles, as the engraving shows. There is a thin steel aligning strip *B* attached to the rear side of the chuck and also a vertically adjustable back-rest *C* which is used to support parts

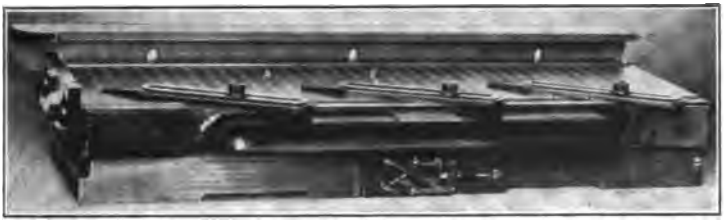

Fig. 30. Walker Magnetic Chuck

that are high in proportion to their width. In addition, there is an end-stop *E* having vertical adjustment. The work to be ground is simply laid on the chuck face, against end-stop *E* and the back-rest *C*. The slotted fingers *E* which are provided on this particular chuck, are also used, in some cases, to stay the work edgewise and prevent it from shifting. Magnetic chucks are sometimes used on planers, as well as surface grinders, in which case fingers *E* are of especial value.

This chuck is equipped with a duplex switch which enables the chuck

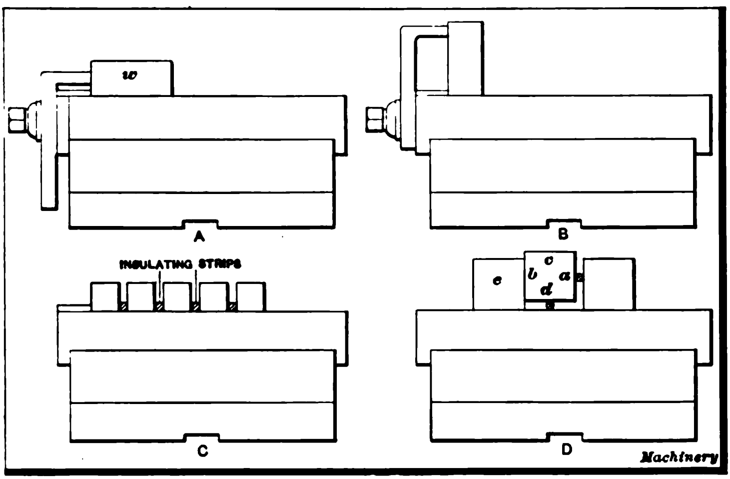

Fig. 31. End Views illustrating Different Methods of holding Work on Magnetic Chuck

face to be demagnetized so that work can easily be removed after the grinding operation. This demagnetizing is accomplished by simply reversing the current through the chuck coils, momentarily, until the residual magnetism is removed. In order to do this, the switch is opened and moved until the switch bars are nearly in contact with the posts at the opposite end of the switch. The handle is then gripped tightly with the tips of the fingers, and the bars are quickly moved in and out of contact with the posts. This movement, when timed correctly, will remove the magnetism lift by the previous charge. When demagnetizing, if the contact should be for too long a period, the chuck will simply become oppositely charged, and in such a case it can be discharged again by making quick contact with the posts on the opposite side. It should be mentioned that this switch does not demagnetize the work itself. This is necessary, however, for certain classes of work, because some materials become more or less permanently magnetized and this causes them to attract small particles, which is sometimes quite objectionable. When the work must be demagnetized, a special apparatus called a demagnetizer is used.

The way the back-rest *C* of the magnetic chuck shown in Fig. 30, is used is illustrated by the diagrams *A* and *B*, Fig. 31, which represent end views of the chuck. The operation is that of grinding a true rectangular block *w*. While the sides are being ground, the block is held as indicated at *A*. The edges are then ground square with the sides by holding the block against the aligning strip and back-rest, as shown at *B*. Sketch *C* shows how a number of strips are held on the chuck and ground simultaneously. When parts are arranged in this way, it is sometimes advisable to place magnetic insulating strips of brass or paste-board between them, so that the magnetism will get an independent grip on each piece and hold it firmly against the face of the chuck.

Sketch *D*, shows how a piece is sometimes held for grinding the sides square to each other. Two of the sides, as at *a* and *b*, are first ground by holding the work directly against the face of the magnetic chuck. One of these finished sides, as at *b*, is then held against the vertical surface of an accurately finished square block *e*, while the upper side is ground. The lower side, instead of resting directly on the chuck face. is placed upon a piece of drill rod to reduce the contact area. In this way, the work is held more securely against block *e*, than against the chuck face, because the holding power depends upon the area of the surface in contact with the magnetized part. If the side *d* were in direct contact with the chuck face, side *b* might not be held evenly against block *e*, in which case the work would not be ground square. In this instance, the work is further secured by a block on the right side which is separated by drill rod to reduce the contact area.

Magnetic chucks are made in many different styles and shapes. Some are so arranged that the clamping face can be set at any angle for taper grinding and others have faces that are vertical. There is also the rotary type which has previously been referred to, and other special designs. The rotary form is used when a continuous rotary movement is required, instead of a reciprocating motion.

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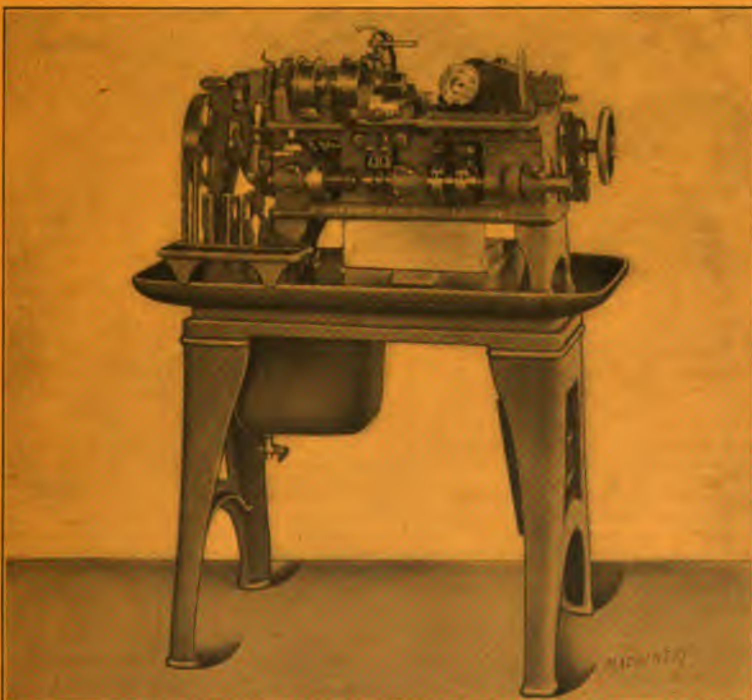
AUTOMATIC SCREW MACHINE PRACTICE

OPERATION OF THE BROWN & SHARPE AUTOMATIC SCREW MACHINES

BY DOUGLAS T. HAMILTON



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NUMBER 99

AUTOMATIC SCREW MACHINE PRACTICE

PART I

OPERATION OF THE BROWN & SHARPE AUTOMATIC SCREW MACHINES

By DOUGLAS T. HAMILTON

CONTENTS

49-55 Lafayette Street, New York City

Automatic Screw Machine Practice for the Brown & Sharpe automatic screw machines is covered in eight Reference Books. Nos. 99 to 106, inclusive. Reference Book No. 99, "Operation of the Brown & Sharpe Automatic Screw Machines," deals with the construction of these machines and the setting-up of the tools. No. 100, "Designing and Cutting Cams for Automatic Screw Machines," gives detailed instruction on cam design, and describes a simplified method for milling cams. No. 101, "Circular Form and Cut-off Tools for the Automatic Screw Machine," deals with the general arrangement and the calculations of these tools, and describes the different methods employed in their making. No. 102, "External Cutting Tools for the Automatic Screw Machine," deals with the design and construction of box-tools, taper turning tools, hollow mills, and shaving tools. No. 103, "Internal Cutting Tools for the Automatic Screw Machine," deals with centering tools, cross-slide drilling attachments, counterbores, reamers, and recessing tools. No. 104, "Threading Operations on the Automatic Screw Machine," treats on cam design for threading operations, threading dies, taps and tap drills, die and tap holders, and thread rolling. No. 105, "Knurling Operations on the Automatic Screw Machine," describes the construction of knurling holders, and gives directions for the making of knurls and the design of tools and cams used in connection with knurling operations. No. 106, "Milling, Cross-drilling and Burring Operations on the Automatic Screw Machine," describes screw-slotting attachments, index drilling attachments, and burring attachments, giving directions for their use and for the design of cams for them.

CHAPTER I

CONSTRUCTION OF THE BROWN & SHARPE AUTOMATIC SCREW MACHINES

The object of this treatise is to give the operator a clear idea of the construction of the Brown & Sharpe automatic screw machines, so as to enable him to operate these machines to the best advantage. The various mechanisms, together with their functions and operation, will be dealt with in detail, and the procedure to follow in setting the tools held in the turret and on the cross-slide will be illustrated and described. The No. 00 Brown & Sharpe automatic screw machine, front, rear and plan views of which are shown in Figs. 1, 2 and 3, is made the main subject of this treatise, but wherever the Nos. 0 and 2 machines differ in construction, these differences will be explained. A brief description of the principal features of automatic turret forming and cutting-off machines will also be included, together with tabular and other data of value to the operator.

Principles of Operation

Before proceeding with the description of the construction of the Brown & Sharpe automatic screw machines, the general principles of operation will be briefly outlined. The work spindle is driven from the overhead works by friction pulleys *A* and *B*, see Figs. 1 and 2, by open and cross belts, thus providing for the rotation of the work in either direction. The other operating mechanisms receive their motion from the driving shaft O_3 at the rear (see Fig. 7), which is driven by pulley *C* from the over-head works. The driving shaft carries all the clutches and tripping mechanisms for starting the machine, indexing the turret, reversing the spindle, feeding the stock, and opening and closing the collet, and also drives the front camshaft *D*, and the lead camshaft through a worm and worm-wheel and spur and bevel gearing.

The camshafts, which carry plate cams for operating the front and rear cross-slides *E* and *F* and turret slide *G*, are driven at the required speed for the different jobs by means of change gears *H*. A set of plate cams is made up for each job; the cams are held on the shafts in their correct relation to each other by means of locating pins. The turret *I*, which carries the end-working tools, is provided with six holes, and is indexed by means of tripping levers operated by adjustable dogs held on drum *J*. Drum *K* carries dogs for operating the collet opening and closing and feeding mechanisms. The spindle is reversed when cutting a thread by adjustable dogs held on drum *L*, which can be detached from camshaft *D* by separating coupling *M*. The length of feed is controlled by rotating crank *N*; turning it to the right increases the length of feed, and turning it to the left shortens it. The machine is started and stopped by throwing the clutch *O* in or out by means of handle *P*. When the bar is exhausted a bell *R* is rung to notify the operator.

Construction of the Spindle

The spindle A_1, see Fig. 4, runs in phosphor-bronze bearings B_1 and C_1. The front bearing B_1 is split and tapered, and is adjusted by means of nuts D_1 and E_1, in case of wear. A brass liner is placed in the slot in the bearing, and when the latter is worn, this liner should be removed, reduced to the required thickness, and replaced. When the liner is replaced, nut D_1 should be tightened. This bearing is also pro-

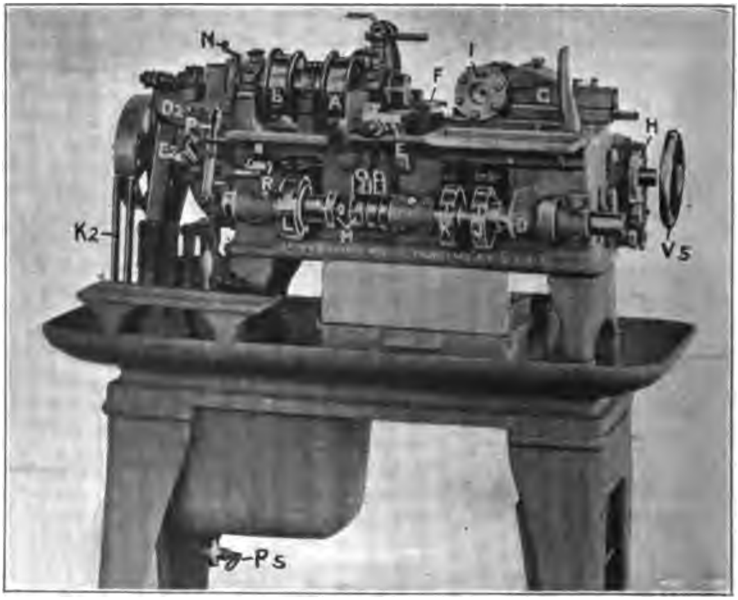


Fig. 1. Front View of No. OO Brown & Sharpe Automatic Screw Machine

vided with saw slots around its circumference, in which strips of wood are inserted, so that the bearing will have more flexibility and yield more easily to the adjusting nuts.

The rear bearing C_1 is made straight, and is held in the box by nuts F_1 and G_1. The thrust is taken at the rear of the spindle, the thrust bearing consisting of a hardened steel washer H_1 and a bronze washer I_1. Washer H_1 is held against a shoulder on the end of the spindle by nut G_1 and loose washer I_1, the latter running against the hardened and ground inside face of nut G_1. To take up the end play of the spindle, loosen nut F_1 and tighten nut G_1, locking them in place again after adjusting.

The pulleys *A* and *B* which drive spindle A_1 through friction clutch *S*, are driven by open and cross belts from the countershafting. The pulleys rotate freely on the spindle, being provided with steel bushings

J_1 and rollers K_1 which are held in bronze cages L_1. The rollers run on the hardened and ground part of the spindle. The pulleys are oiled from oil reservoirs, the latter being filled by removing screws M_1. Any good machine oil is suitable for oiling these pulleys.

Friction Clutches

The friction clutch body S is tapered to an angle of 12 degrees at each end, and comes in contact with the driving pulleys A or B, when shifted in either the one or the other direction. It is made from phosphor-bronze, turned cone-shaped on each end, and slotted to hold clutch levers N_1, which are made from double-shear steel. These clutch levers are held in the clutch body by screws, and are fulcrumed in notches cut in the spindle. The clutch sleeve O_1 which operates on these levers

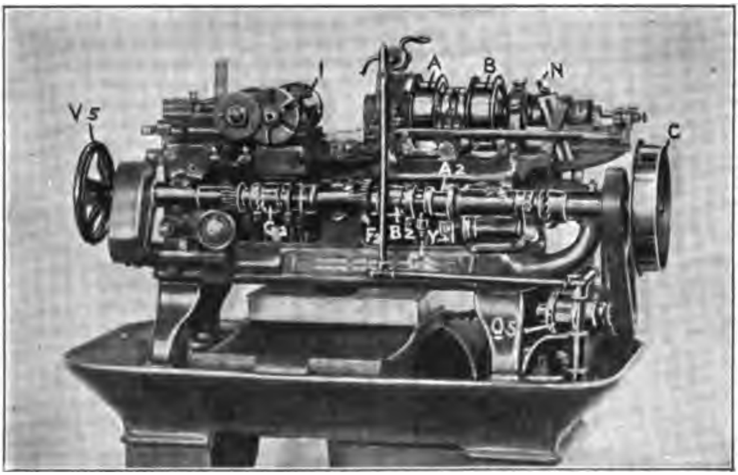


Fig. 2. Rear View of No. 00 Brown & Sharpe Automatic Screw Machine

is slotted to hold hardened steel shoes P_1 which bear on the hardened ends of the clutch levers.

The coned ends of the clutch body are forced into the pulleys by sliding sleeve O_1 over levers N_1. When sleeve O_1 is forced to the right it depresses the right-hand end of levers N_1, and as the lower portion of these levers are fulcrumed in the spindle, which cannot move longitudinally, it is evident that this action must move the clutch body, because the levers are held to it by screws. When the sleeve O_1 is forced in the opposite direction, the same action takes place, the cone-end of the clutch body engaging with the pulley to the left. To adjust the clutches to provide for wear, pulleys A and B are moved in towards the cones of the clutch body by loosening set-screws Q_1 and adjusting the nuts R_1.

The clutch sleeve O_1 is set central by means of screws T, Fig. 3. In making this adjustment a slight play should be allowed in the clutch fork U to avoid friction, except at the point of reversal. Care should also be taken not to run in the screws V too far into the clutch ring W, so as to split it. This clutch is made in halves and held together by pins.

On the No. 00 machine, the spindle is reversed to run backwards by means of the spring plunger Y, Fig. 2, and on the Nos. 0 and 2 machines by the cam A_2. The spring plunger on the No. 00 machine, when released, instantly engages the cone of the clutch with the pulley nearest the collet, and rotates the spindle backwards. To run forward, the clutch is operated by the cam A_2 to engage pulley B. Cam A_2, in turn, is operated by clutch B_2, and is released by lever C_2, one revolution of the driving shaft being required for the No. 00, and ½ revolution for the Nos. 0 and 2 machines. Lever C_2, again, is operated by a dog held on drum L on the front camshaft, see Figs. 1 and 6.

Operation of the Spring Collet

The spring collet S_1, Fig. 4, which holds the work, is held in sleeve T_1 in the front end of the spindle. This sleeve is driven by a pin in

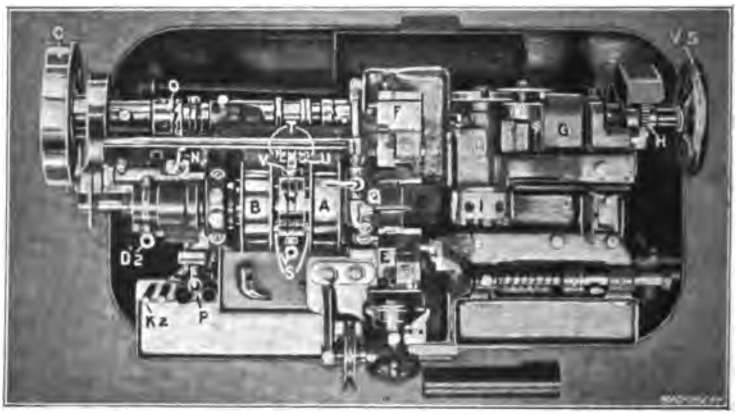


Fig. 3. Plan View of No. 00 Brown & Sharpe Automatic Screw Machine

the spindle, which fits in a slot cut in the sleeve. The front end of the sleeve is ground tapered and fits over the collet S_1. The collet has no end play, being held tightly against the inside ground face of the cap U_1, thus insuring accurate feeding of the stock regardless of any slight variation in size. Spring collet S_1 is closed by means of sleeve T_1, which slides over it and is operated by tube V_1. This tube, on the Nos. 00 and 0 machines, extends through the spindle to the levers W_1, which, in turn, are acted upon by sleeve Y through lever D_2 and cam E_2, Figs. 1 and 6.

The collet closing and stock feeding mechanism are operated by the same cam E_2 (on the Nos. 00 and 0 machines), which is driven through spur gears F_2 and positive clutch G_2, Figs. 2 and 7. Clutch G_2 is engaged by depressing lever H_2 by a dog held on drum K (see Figs. 1 and 6). The driving shaft makes one revolution, whereupon the clutch is disengaged by the pin lever H_2, Fig. 7, acting upon the cam surface of the clutch, returning it to its original position—out of mesh.

To adjust spring collet S_1, Fig. 4, loosen nut I_2 and turn nut J_2 until the holding capacity of the clutch is properly regulated; then re-tighten nut I_2 and lock both nuts by means of the spanner wrenches provided for this purpose. Great care should be exercised in adjusting these nuts. If they are so adjusted that the collet S_1 bears too tightly on the work, either the collet or closing levers W_1 will be broken. A good

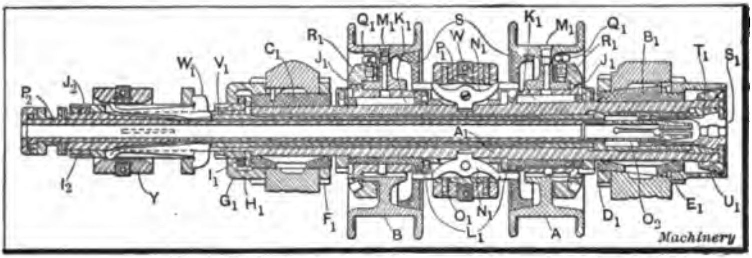


Fig. 4. Section through Spindle, Boxes, Pulleys, etc., of the No. 00 Brown & Sharpe Automatic Screw Machine

method to follow in regulating the proper grip of the collet upon the work is to adjust nuts I_2 and J_2, and then test the grip of the collet by operating fork D_2 by means of the handle K_2 (see Figs. 1 and 3). In this way the proper grip can be secured without difficulty.

On the No. 2 machine the sleeve T_1 (see Fig. 5) is forced over the collet S_1 directly by the levers W_1, the latter being operated by sleeve Y_1 and a cam on the intermediate shaft directly under the spindle.

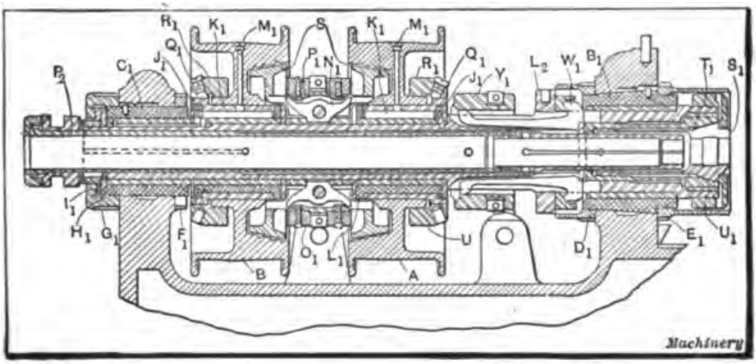


Fig. 5. Section through Spindle, Boxes, Pulleys, etc., of the No. 2 Brown & Sharpe Automatic Screw Machine

To adjust the grip of the collet on the stock, loosen the clamp screw in nut L_2, and turn the knurled nut toward the front of the machine to tighten the collet, reversing the direction of the nut to loosen it.

Operation of the Feeding Mechanism

The feeding mechanism derives its motion from pulley C through spur gear F_2 (Fig. 2) to gear M_2 on central shaft N_2 (Fig. 10). Pulley C is engaged by a positive clutch O (Fig. 7), which is brought into action by means of the starting lever P; in this way the feed is always

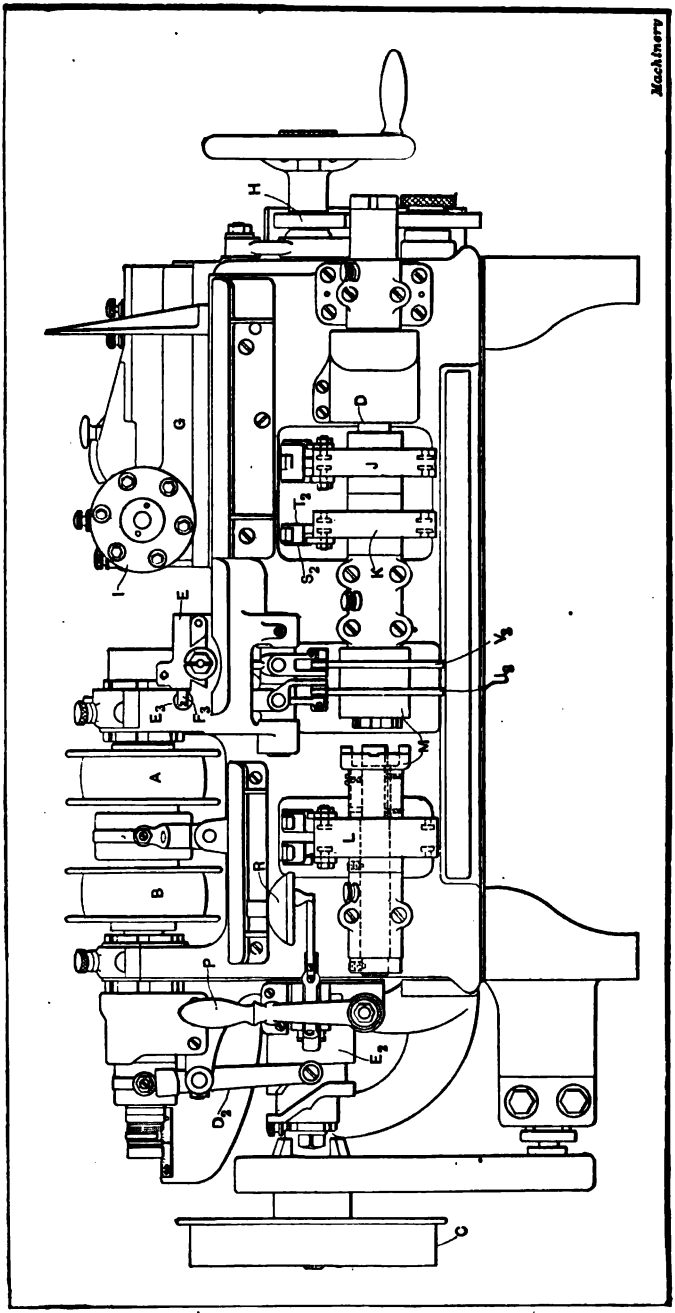


Fig. 6. Front Elevation of the No. 00 Brown & Sharpe Automatic Screw Machine

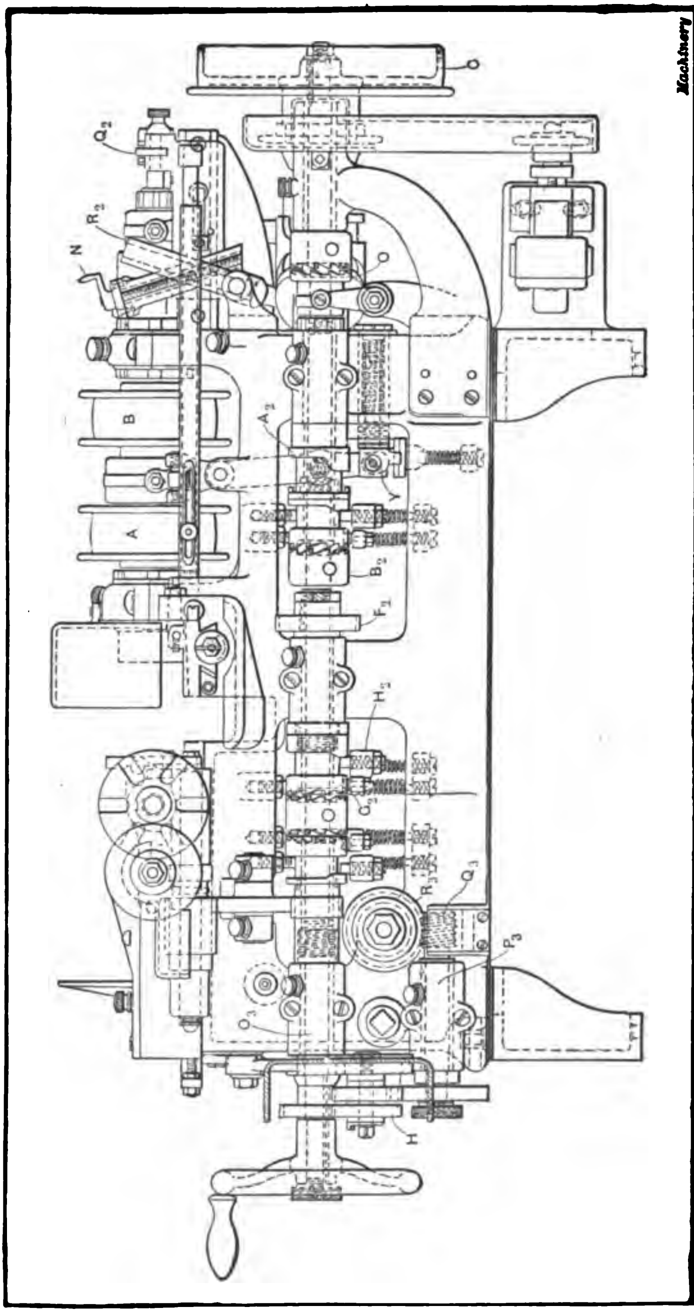


Fig. 7. Rear Elevation of the No. 00 Brown & Sharpe Automatic Screw Machine

under complete control. The stock is fed out by means of a feed finger O_2 (Fig. 4), which is provided with a left-hand thread, and is screwed into the feed tube P_2, the latter passing completely through the spindle. The outer end of the feed tube is connected to the feeding mechanism or slide by means of a latch Q_2, Figs. 7 and 8. The feed slide carrying the latch has a slot cut in it, in which is a sliding block connected to arm R_2, the latter being operated by cam E_2. The sliding block is adjusted in the feed lever by means of a screw and crank *N*, and as the arm R_2 always moves a fixed distance, the length

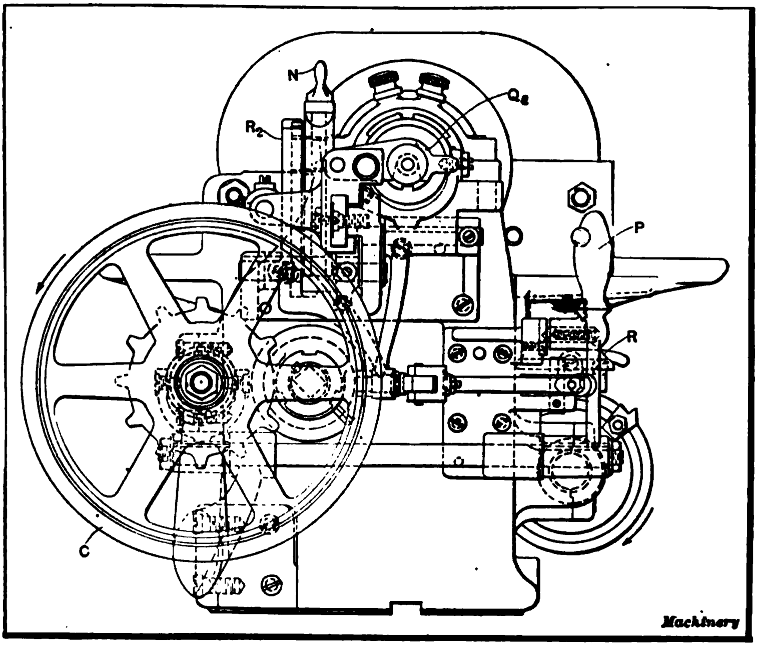


Fig. 8. End Elevation of the No. 00 Machine showing Collet Operating Mechanism

of the feed is obtained by varying the position of the block. A graduated scale which indicates the length to which the stock is fed, is mounted on the feed slide.

When it is desired to change the feeding finger, the feed tube can be withdrawn by lifting the latch. The feeding of the stock can be discontinued by turning up dog S_2, Fig. 6, attached to lever T_2, thus allowing the trip dogs on the drum *K* to pass by without raising the lever. When it is desired to feed stock more than the usual capacity of the machine, two or more dogs can be placed on the left side of the drum, and the feeding mechanism operated several times.

Operation of the Cross-slides

The front and rear cross-slides *E* and *F* are operated by plate cams U_2 and V_2 held on the front camshaft *D*, Figs. 6 and 9. The front cross-slide is operated by a direct lever or segment gear W_2 that has teeth cut in its upper end meshing in a rack Y_2; which, in turn, fits in a slot in the base of the cross-slide. This rack is threaded on one end and is provided with a split adjusting nut A_3 which is used for changing the position of the cross-slide relative to the center of the spindle. The screw binding these nuts should always be tightened after the cross-slide has been set to travel the required distance. The rear cross-slide is fitted up in the same manner, but is operated through an intermediate lever or segment gear B_3 to reverse the motion, thus bringing the cams for operating both slides in a convenient position.

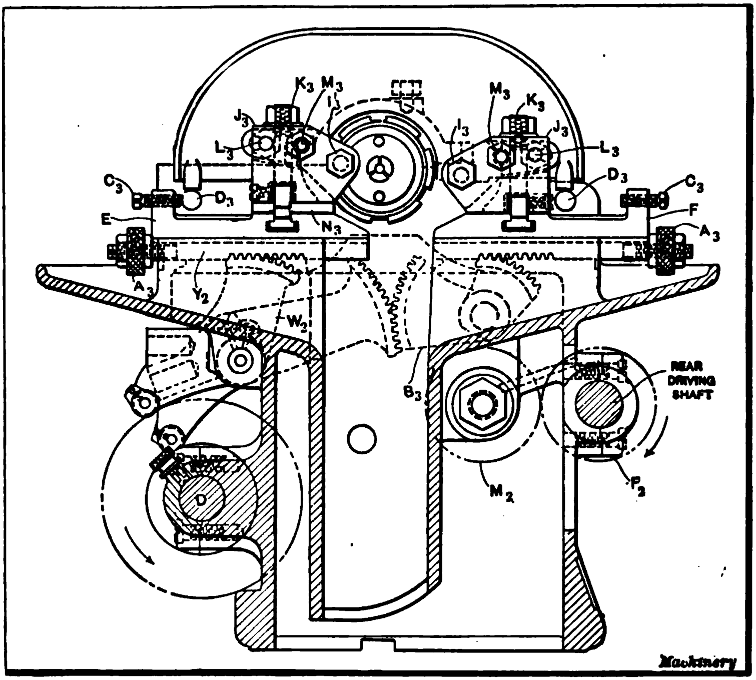


Fig. 9. Partial Section of No. 00 Machine showing Operation of Cross-slides

The cross-slides are made to travel to exactly the same point by set-screw C_3 which comes in contact with stop D_3. The cross-slides E and F are returned to their "back" position by means of coil springs and plungers E_3, the latter coming in contact with plugs F_3 screwed into the cross-slides. When setting the circular form and cut-off tools, the slides can be operated by hand by means of a rod inserted into holes provided for that purpose in the ends of the slide-operating segment gears.

The cross-slide tools are circular in form, and are held by screws I_3 to the toolposts J_3, the latter being retained on the cross-slides by T-bolts and nuts K_3. Eccentric nuts are provided on the screws L_3 at the rear of the toolpost, which make it possible to easily and quickly

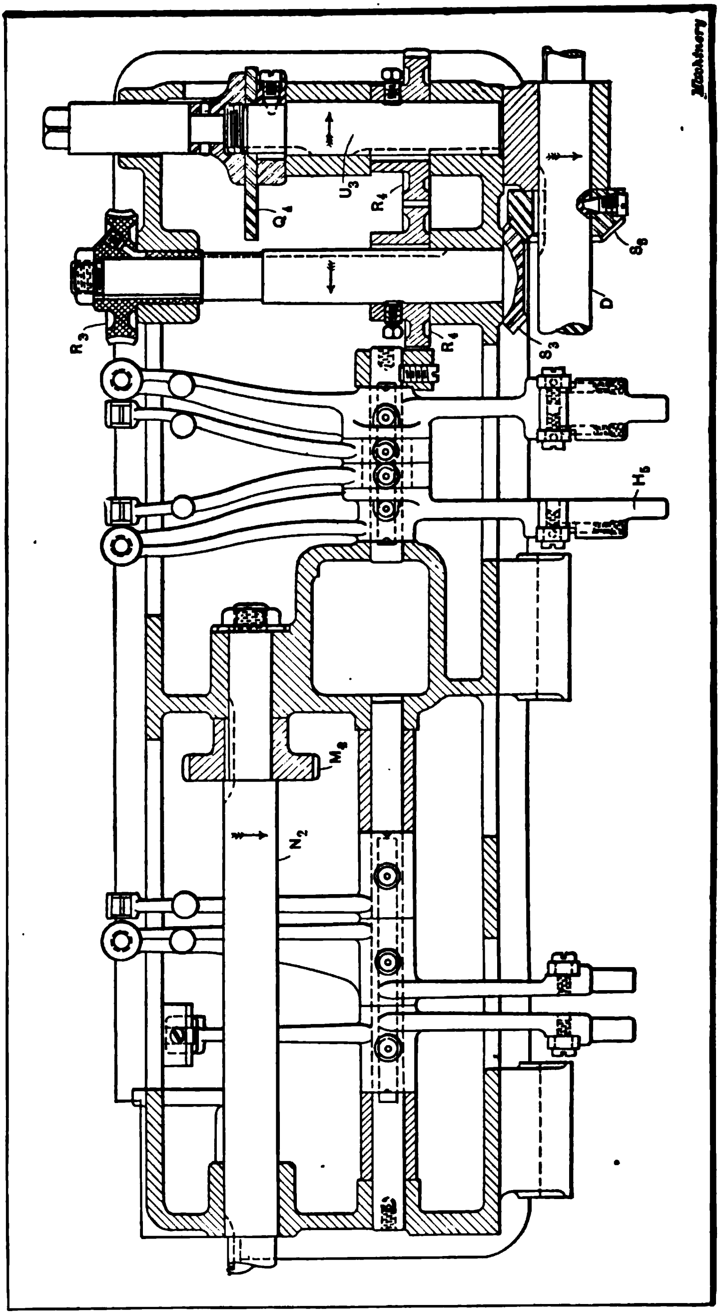


Fig. 10. Partial Section of No. 00 Machine showing Operation of the Front and Lead Cam-shafts, Tripping Levers, etc.

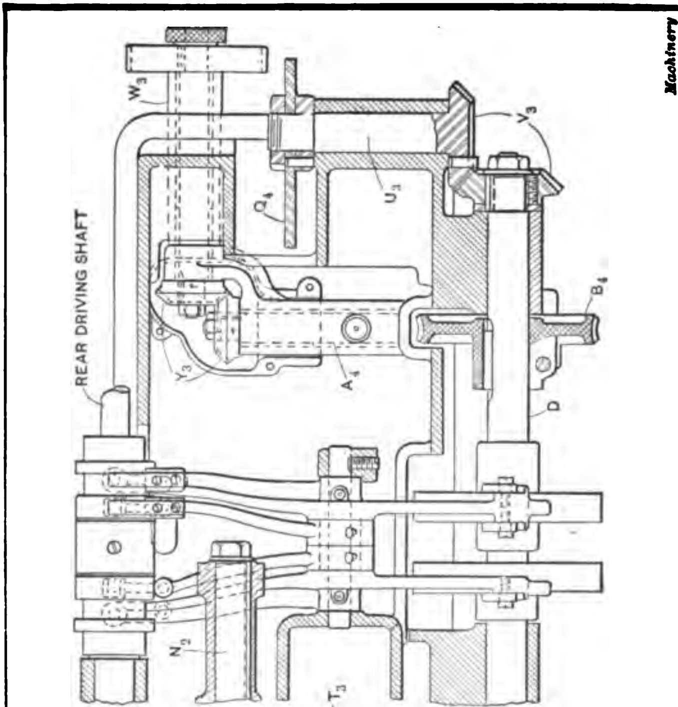


Fig. 12. Partial Section showing how the Front and Lead Camshafts are operated on the No. 2 Machine

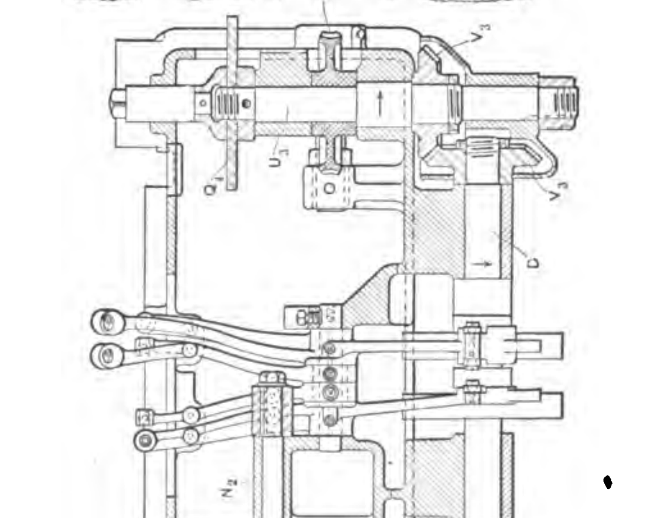


Fig. 11. Partial Section showing how the Front and Lead Camshafts are operated on the No. 0 Machine

adjust the circular tools to the proper height. Additional clamping means for the circular tools are provided for by hook-bolts and nuts M_3. The circular tools are ground on the face for sharpening without changing their outline. The block N_3 is provided for raising or lowering the toolposts, so that the circular tools can be ground below center to give sufficient rake.

The manner in which the front camshaft is driven is illustrated in Figs. 7 and 10. Power is transmitted from the rear driving shaft O_3

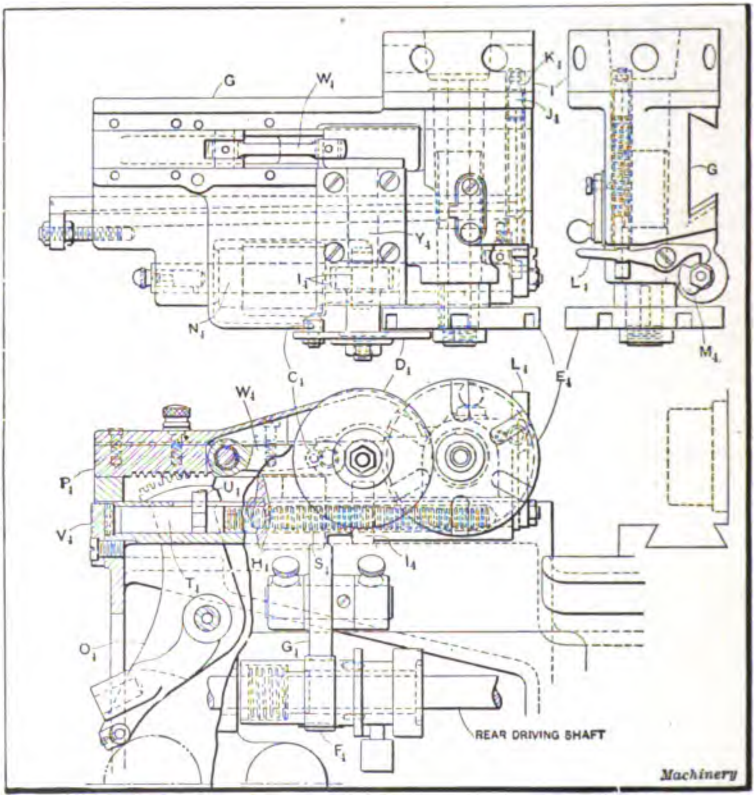


Fig. 13. Plan and Rear Elevation of No. 00 Machine showing Operation of Turret Slide, etc.

through the change gearing H to the worm-shaft P_3. Double-pitch worm Q_3 drives worm-wheel R_3, which through bevel gears S_3 rotates front camshaft D. On the Nos. 0 and 2 machines, the power is transmitted differently as can be seen in Figs. 11 and 12. On the No. 0 machine the power is transmitted from the rear driving shaft through the change gearing to a single-pitch worm, the latter driving the worm-wheel T_3 on the lead camshaft U_3, which furnishes power to the camshaft D through bevel gears V_3. The arrangement is slightly different on the No. 2 machine. The power in this case comes from the rear driving shaft through the change gearing to the so-called "worm-shaft" W_3, which through bevel gears Y_3 drives the single-pitch worm on shaft A_4 and the worm-wheel B_4 on front cam-shaft D.

Operation of the Turret Slide

The turret I, Fig. 13, which holds the working tools, is mounted vertically on the side of the turret slide G. The turret has a long tapered shank which forms the bearing in the turret slide. It is rotated by means of a hardened roll C_4 on a disk D_4, which engages in radial grooves in the disk E_4. Disk D_4 is driven from the rear driving shaft through spur gears F_4, G_4, and H_4, and helical gears I_4. There are six

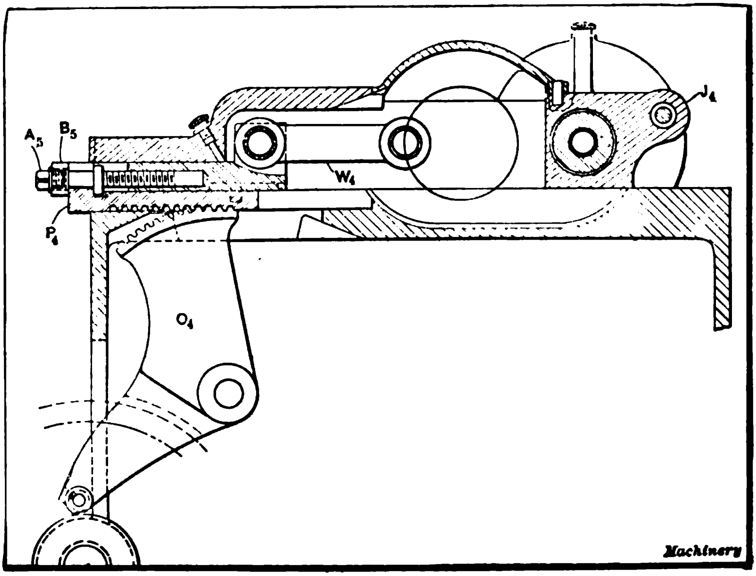


Fig. 14. Partial Section of No. 2 Machine showing Operation of Turret Slide

holes in the turret, disk D_4 making six revolutions for every complete revolution of the turret. The turret is locked in position by the hardened tapered plug J_4 which fits in a hardened bushing K_4 in the turret. This plug is operated by a trip latch L_4, which is withdrawn by a cam M_4 on one end of the shaft N_4. The locking pin or plug is withdrawn from the turret by hand by pushing back latch L_4.

Slide G upon which the turret I is mounted receives its forward movement from the lead cam Q_4 (Fig. 10) through the bell crank lever O_4 and rack block P_4. The lead camshaft (Fig. 10) is driven from the rear driving shaft through worm-wheel R_3 and spur gears R_4. The turret slide is returned by a coil spring S_4, plunger T_4 and pin U_4, shown in Fig. 13, the plunger is located in its "back" position by a stop-block V_4.

The quick return and advance of the turret slide and the revolving of the turret are controlled independently of the lead cam by the crank

W_4, which is connected eccentrically to the turret revolving shaft Y_4. This crank indexes the turret while the roll on the bell crank lever O_4 is passing from the highest point of the lead cam to the starting point of the lobe for the next cut. Crank W_4 is driven from the rear driving shaft, as previously described, by a positive clutch, the latter being operated by tripping levers and dogs on drum *J*, Fig. 6.

As the crank revolves it allows spring S_4, Fig. 13, to return the turret slide. The turret is then revolved, as described, and when the crank comes to rest after making one complete revolution, the machine is

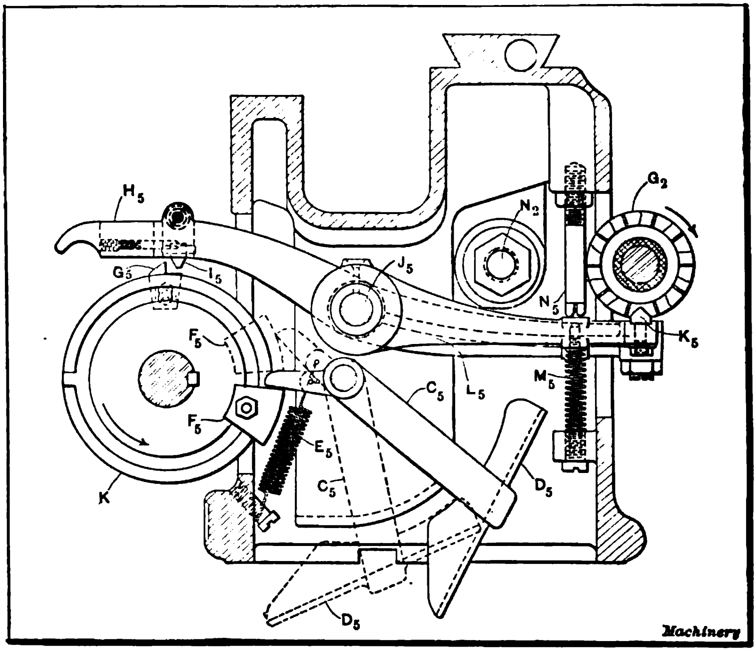


Fig. 15. Partial Section of No. 00 Machine showing Operation of Deflector, Tripping Levers, etc.

ready for the next operation. The bell crank lever O_4 bears against the bed at the extreme forward movement and insures the positive return of the turret slide should the spring fail, owing to the binding of the turret tools on the work. The turret slide is not adjustable lengthwise on the Nos. 00 and 0, but on the No. 2 machine an adjustment of 1 inch is provided for by a screw A_5 and lock nut B_5, Fig. 14.

On the No. 0 machine the indexing disk D_4, Fig. 13, is driven as before described from the rear driving shaft through spur gears, but the turret revolving shaft Y_4 receives its motion from shaft N_4 through bevel gears. The lead camshaft U_3 is driven from front camshaft *D* through bevel gears V_3.

The indexing disk D_4 on the No. 2 machine (see Fig. 13) is driven in a manner similar to that of the No. 0 machine, but in this case D_4

is a spur gear. The latch L_4 on the No. 0 and 2 machines is operated by a cam on indexing disk D_4. The lead camshaft U_3 is driven from the front camshaft D through bevel gears V_3, as shown in Fig. 12.

Operation of the Deflector

To separate the chips and oil from the work which is cut off, a deflector is provided, as shown in Fig. 15. This deflector consists of a bell-crank C_5 to which a pan or chute D_5 is integrally cast. The crank is operated by spring E_5 and cam block F_5 on drum K, which lifts up the forward end of the crank, moving the deflector into the position shown by the dotted lines. This brings it directly under the fixed

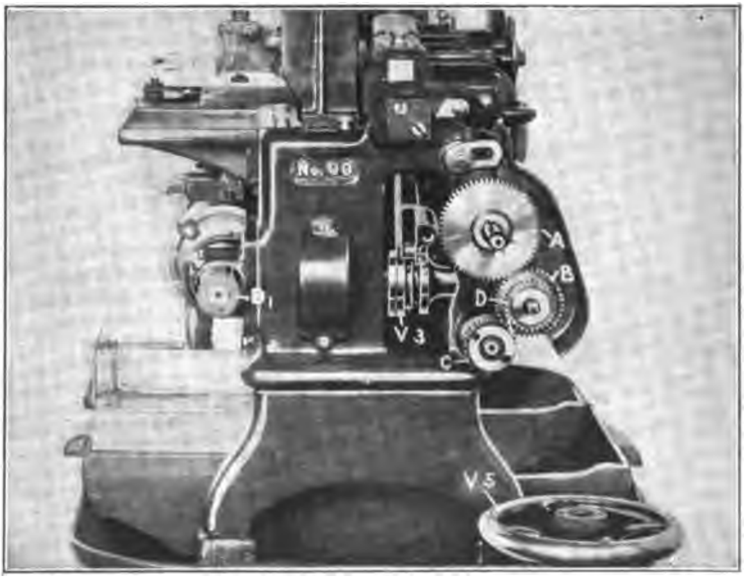


Fig. 16. End View of No. 00 Machine showing Arrangement of Change Gears

chute of the machine, so that the work is deflected from the pan for the chips into the pan provided for holding the work. The cam block is adjustably mounted on the drum so that it can be moved into the desired position for operating the deflector. On work requiring a small amount of machining, the deflector must remain under the chute for a longer period than is required on longer operations; therefore, cam blocks having different lengths of arcs are provided, to allow the deflector to remain under the chute for a greater or less time.

Fig. 15 illustrates clearly the construction and action of the tripping lever for operating clutch G_2, Fig. 2. The operation is as follows: A dog G_5 on drum K lifts tripping lever H_5 by means of the block I_5, and as H_5 is fulcrumed on shaft J_5, this action lowers the rear end of the lever. A pin held in the rear end of the lever by adjusting nuts, fits in a recess in the cam which forms one jaw of the clutch G_2, and as the

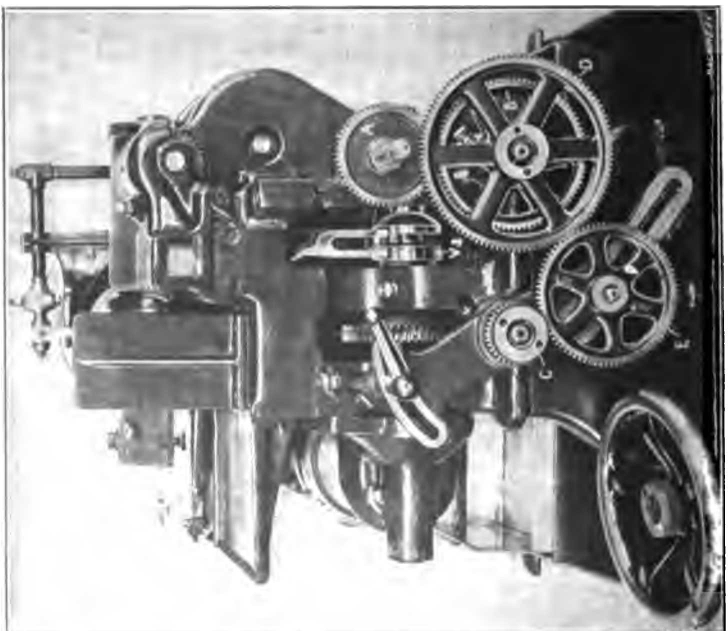


Fig. 17. End View of No. 0 Machine showing Arrangement of Change Gears

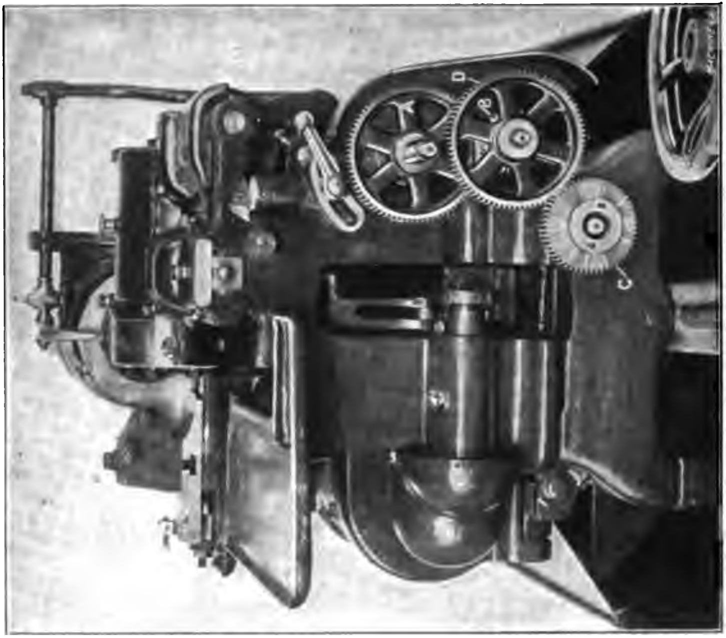


Fig. 18. End View of No. 2 Machine showing Arrangement of Change Gears

pin is withdrawn, the cam is forced out into engagement with the driving part of the clutch by a spring. The cam G_2 is located in the correct relation (each time it is disengaged from the driving clutch) to the collet closing mechanism by a V-groove in the cam body in which a stop K_5 in the lever L_5 fits. The stop is kept in contact with the cam body by a spring M_5 and is stopped in its "up position" by a stud N_5. All the tripping levers and clutches for the feeding, spindle reversing and turret indexing mechanisms are operated in a similar manner.

Operation of Oil Pump—Arrangement of Change Gears

The oil pump O_5, Fig. 2, is driven from the driving shaft by means of a chain and sprockets, which are shown guarded, and is provided

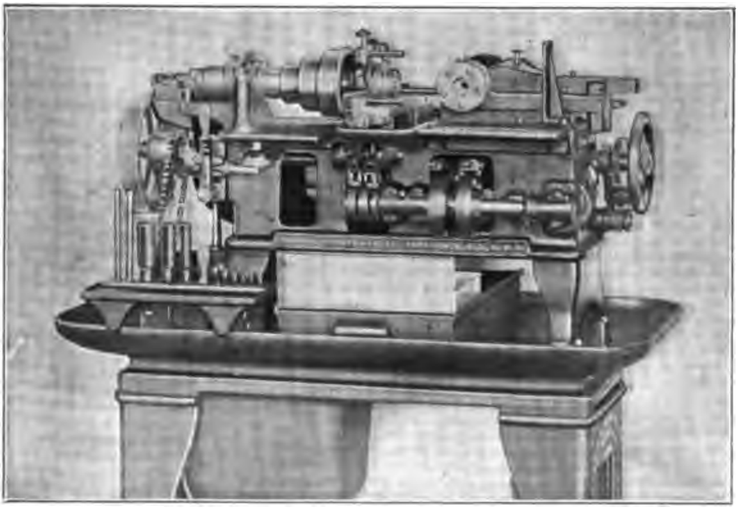


Fig. 19. No. 00 Brown & Sharpe Automatic Turret Forming Machine, Front View

with suitable piping. The pump is not stopped when the feed is disengaged, but continues in operation, thus insuring a steady stream of oil as soon as the tools commence to cut. Care should be taken to see that the pipe is not blocked up and that the oil pan is filled with oil. The oil is removed from the pan by opening the cock P_5, Fig. 1.

The speed of the front and lead camshafts is changed for the different jobs by means of change gears, as shown in Figs. 16, 17 and 18. Fig. 16 shows the arrangement of gearing for the No. 00 machine, where A is the gear on the driving shaft; B, the idler gear; and C the gear on the worm shaft. When it is desired to compound the gearing on this machine, another gear D is placed on the idler stud and a gear not shown is placed on the driving shaft. When the gearing is compounded, B becomes "first gear on stud," and D, "second gear on stud." The arrangement of the gearing for the No. 0 machine is shown in Fig. 17. Here A is the gear on the driving shaft; B, "first gear on stud"; D, "second gear on stud"; E, an intermediate gear; and C the gear on the worm-shaft. On the No. 2 machine the gearing is arranged as shown in Fig. 18, where *A* is the gear on the driving shaft; *B*, "first gear on stud"; *D*, "second gear on stud"; and *C* the gear on the worm-shaft.

Automatic Turret Forming and Cutting-off Machines

The automatic turret forming machine, the No. 00 size of which is shown in Fig. 19, is intended for work not requiring the reversal of the spindle. It is practically of the same design and capacity as the regular automatic screw machine, except that it is driven by a four-step cone pulley. The preceding description applies to these machines in general, and the collets, cams, tools, etc., are all interchangeable with the regular "automatics" of the same size.

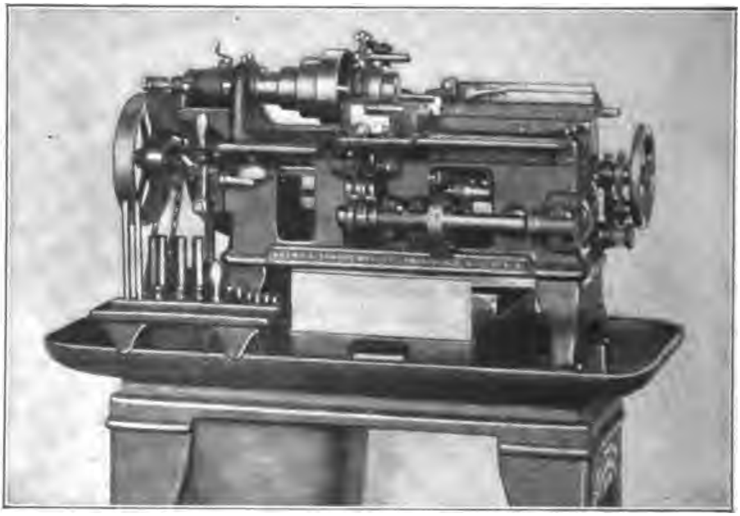


Fig. 20. No. 00 Brown & Sharpe Automatic Cutting-off Machine, Front View

The automatic cutting-off machine, size No. 00 of which is shown in Fig. 20, is driven by cone pulleys in the same manner as the turret forming machines and at the same speed. It has no turret, but is provided with a tool-slide for carrying a stop hollow-mill, box-tool or drill. It is of the same chuck capacity as the regular automatics, but the tool-holder is adjustable so that much longer work can be accommodated. The tool-slide on the No. 00 machine has a movement of 1¼ inch. The shortest distance (approximately) between the face of the tool-holder and the face of the collet when the lead lever roll is on the largest diameter of the cam, is 1¾ inch on the No. 00, 2 inches on the No. 0, and 2½ inches on the No. 2 machine. The greatest distance obtainable, approximately, with the lead lever roll on the smallest diameter of the cam, is 10 inches on the No. 00, 14 inches on the No. 0, and 17 inches on the No. 2 machine. The tools, cams, collet, etc., are interchangeable with the regular automatic screw machines of the same size.

CHAPTER II

SETTING THE TOOLS AND OPERATING AUTOMATIC SCREW MACHINES

In "setting-up" the Brown & Sharpe automatic screw machines, the most simple tools should, generally, be set first. As a rule these are the circular form and cut-off tools which are held on the cross-slides. Before any of the tools are set, however, the collet and feed finger should be changed for the size of work required, the proper change gears put on, and the driving belt placed on the required step.

Setting the Circular Form and Cut-off Tools

After the feed finger and spring collet have been put in place, the stock is inserted and pushed out far enough so that it can be faced off with the circular cut-off tool. The cut-off tool is then clamped to the toolpost and set with its cutting edge as close as possible to the height of the center of the work. The spindle is rotated and the end of the stock faced off, using lever K_2, Fig. 21, to operate the cross-slide. This procedure is followed until the cut-off tool is set correctly. The circular form tool is then clamped to the toolpost and the same procedure followed.

Fig. 21 shows an operator setting the cutting edge of a circular form tool to the height of the center of the work by means of the adjusting nut L_3. Care should be taken in setting the circular form and cut-off tools so that they will form the work parallel, and cut it off with a square face. This is accomplished by means of the adjusting screws a in the rear of the toolpost, which can be adjusted when nut K_3 is slackened slightly. When a circular form tool is placed on the front cross-slide, it is necessary to put the rising block N_3 under the toolpost. All dirt and oil should be removed from the surfaces of the rising block, toolpost and cross-slide, so that the cutting edge of the circular form tool, which should be ground at right angles to the side face, can be set parallel with the center line of the work. If this is not done, it will be found that the work will be slightly tapered.

The rolls in the cam levers require careful attention. If the pin in these rolls are not a good running fit, the roll will stick and wear out of round. This will result in the production of pieces which vary in diameter, due to the changes of position of the roll for the different pieces.

In setting the tool on the front cross-slide, the cutting edge should never be below the center of the work, but should be set preferably above or at the height of the center. The cutting edge of the tool on the rear cross-slide should be set just the reverse in reference to the center of the work, when the latter is running forward. When the work is running backward, the position of the cutting edges of the tools on the front and rear cross-slide should be reversed from that for the forward rotation of the work. If the cutting edges of the circular tools are not set in the positions described, the work, when rotating, has a tendency to pull them around, thus increasing the diameter of the work, and causing chattering.

When the circular form tool is used for finishing the work to an exact diameter, the set-screw C_3, Fig. 21, should always be set so that it will come in contact with the stop D_3 when the work is turned to the desired diameter. In setting this stop it should be so adjusted that it will put a slight strain on the cross-slide operating lever. The

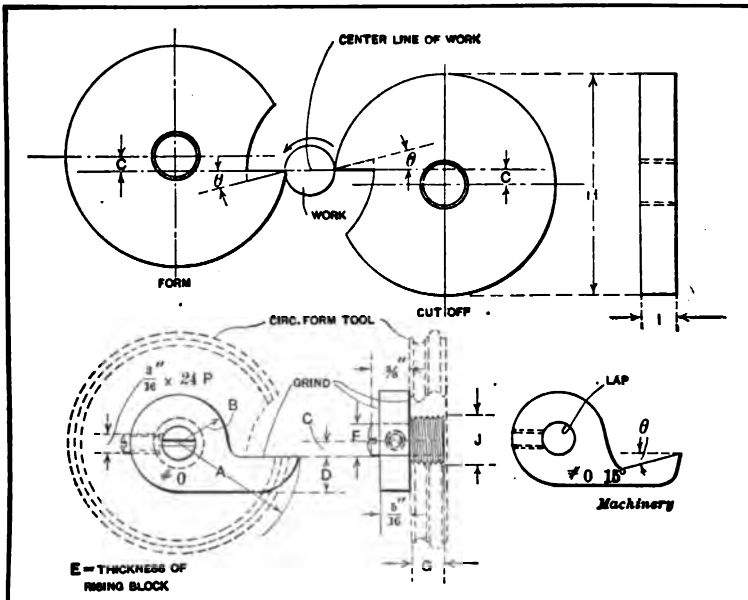
Fig. 21. Operator setting a Circular Form Tool

resulting action keeps the roll in close contact with the cam, and thus assures the parts formed being of the same diameter. When the circular form tool wears slightly, the set-screw C_3 can be adjusted back a slight amount, and the strain which has been set up in the lever will allow the tool to turn the work to the desired diameter. The cross-slide is adjusted back and forth to bring the cross-slide tools in contact with the work by means of split nut A_3, which is locked by means of a screw. Gib Q_5 should be adjusted so that there will be no unnecessary side play of the cross-slide in the bed.

Sharpening Circular Form and Cut-off Tools

The circular form and cut-off tools should be carefully sharpened when they become dull. If the cutting edge is not ground at right angles to the side face of the circular tool, the work produced will be slightly tapered. For this reason the circular tool when being sharpened should be held on a table, the top surface of which is at right angles to the side face of the emery wheel. The cutting edge is then brought up against the side face of the emery wheel, and the tool ground. To insure that the tool is ground correctly, a templet similar to that shown in the illustration accompanying Table I is made for

TABLE I. PROPORTIONS FOR TEMPLETS AND CIRCULAR TOOLS



Number of Machine	Dimensions in Inches									
	A	B	C	D	E	F	G	H	I	J
00	1	7/16	1/8	5/16	1/4	1/4	7/32	1 3/4	1/4	3/8–16 P. R. H.
0	1 1/4	1/2	5/32	11/32	5/16	5/16	9/32	2 1/4	5/16	1/2–14 P. R. H.
2	1 5/8	5/8	1/4	3/8	3/8	3/8	11/32	3	3/8	5/8–12 P. R. H.

the circular tools used on each size of machine. The dimensions of this templet for the various sizes of machines are given in this table. The distance *G* is made less than the thinnest tool, so that the screw will not prevent the tool from lying flat on the table when grinding.

These templets should preferably be made of tool steel, hardened and ground as indicated. The hole should be lapped and the plug made a good fit for it. To the right of the illustration a templet is shown with its top face ground at an angle *θ*, and the size of the machine and angle stamped on it. Circular tools are ground with top rake for cutting machine steel, tool steel, etc. The cutting angles for the various materials are as follows:

ANGLE OF TOP RAKE ON CIRCULAR TOOLS

Material	Angle θ, in Degrees
Brass rod	0
Drill rod and tool steel	8 to 10
Gun-screw iron	12
Machine steel	15
Norway iron	18

The sizes and pitches of the tapped holes in the circular tools are listed in column *J* of Table I, where the thread is given as right-hand. Sometimes the tools are tapped left-hand, especially in the case of wide

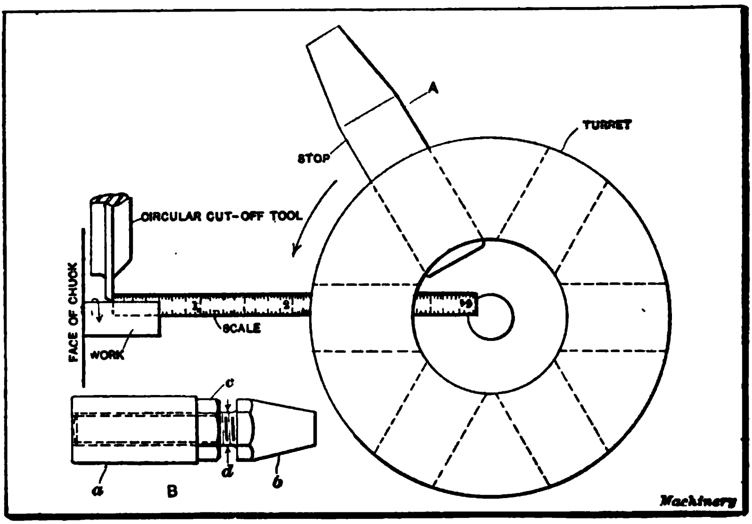


Fig. 22. Simple Method for setting a Stop

forming tools; they are then set on the front cross-slide, with the work running forward. As a rule, the tools are tapped right-hand and the hook bolt M_3 and bolt I_3, Fig. 9, tightly clamped, thus holding the circular tool securely.

Setting the Stop

When the circular cut-off tool has been set correctly, the chuck is opened by lifting the tripping lever, and the stock is fed out the desired length by hand; this length can be easily measured off by the method shown in Fig. 22. A flexible scale, the length of which depends on the size of the machine, is placed in an empty hole in the turret and brought up against the inside face of the circular cut-off tool. The cut-off tool is now brought up against the work by means of the handle operating the cross-slide. It is then an easy matter to set the stock to the desired length. When this has been done, the chuck is closed and the turret swung around so that the stop comes in line with the stock.

When the stop is in this position, the roll should be on the quick rise of the lead-cam so that by rotating the cam, the roll will rise up onto the lobe, thus forcing the stop back into the turret the required amount, where it can be locked with the lock-screw provided for that purpose.

When it is necessary to have the length of the piece to within a limit of 0.010 inch or less, the stop *A* in Fig. 22 gives considerable trouble, because the only way in which it can be set is by tapping it in or out, which is a rather difficult matter. A stop which gives better results is shown at *B*. The parts *a*, *b* and *c* are made from machine steel and casehardened. The body *a* is drilled and tapped for a screw the diameter of which is made in accordance with the size of the machine in which the stop is to be used: For the No. 00, $d = 5/16$ inch; for the No. 0, $d = 3/8$ inch; and for the No. 2, $d = 1/2$ inch.

For the No. 00 machine the number of threads per inch of the screw should be thirty-two, which would mean that one revolution would give

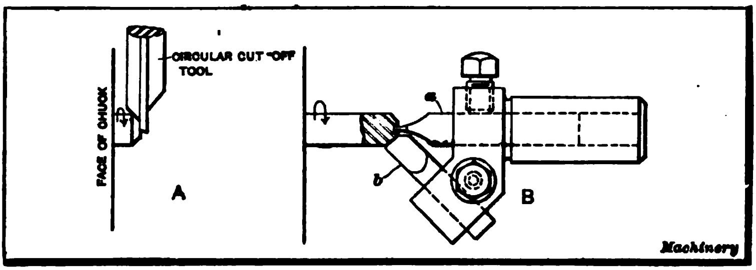


Fig. 23. Chamfering the End of the Work

an adjustment of 0.03125 inch. For the other machines, the screw should have twenty threads per inch. The stop proper, *b*, is made of hexagonal stock to fit the standard wrenches supplied with the machines. The nut *c* is made of the same shape and from the same size of stock as *b*. By having the stop hexagonal, as shown, it is an easy matter to set it within 0.005 inch, by means of the faces on stop *b*, as the relation of these to the nut can be noted, provided the latter is held with a wrench while part *b* is rotated.

Setting a Hollow-mill or Box-tool

Before reducing the diameter of the work by means of a hollow-mill or box-tool, it is necessary to chamfer the front end of the work to facilitate the starting of the cutter on a light cut until the tool is properly supported. One method of pointing the end of the work is shown at *A* in Fig. 23. Here the circular cut-off tool has an angular projection on its face next to the chuck, which points the bar before it is fed out for the next piece. This method is generally used when the work is not very long and runs practically true. It is sometimes impossible, however, to point the bar with a cut-off tool, and in that case the bar is usually pointed by a combination centering and pointing tool, as shown at *B*. This tool can be used when the bar does not project more than 3½ times its diameter from the face of the chuck, and when it is unfinished or of irregular shape. Tool *a* is used for centering the work, thus preparing it for drilling a hole, while tool *b* is used for pointing the end of the bar.

In setting a box-tool, the bar should project out of the spring collet only far enough to allow it to be turned down for a short distance; otherwise the work will not be held rigidly, and will spring away from the cutting tool. The cutting tool is first set to turn the work to within about 0.0005 or 0.001 inch of the finished diameter; then the supports are forced up tightly into contact with the work and clamped. It will be found that when the stock is fed out to the desired length, the supports bearing against the work tightly, the tool turns it slightly

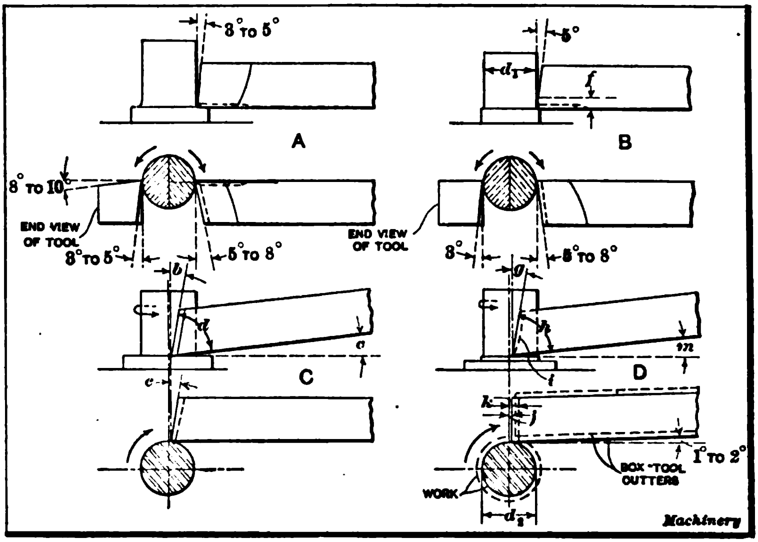


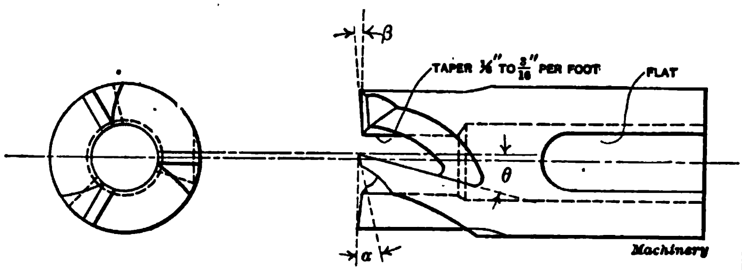
Fig. 24. Cutting-angles for Box Tool Cutters

smaller in diameter. The box-tool cutter is brought in contact with the work by means of the handle K_2, Fig. 21, on the No. 00 machine, which is inserted in the lead lever O_4, Fig. 13, and by the lever R_8 on the Nos. 0 and 2 machines, as shown in Fig. 33. These levers should always be removed before engaging the driving clutch. For additional information regarding the application of external tools to the work, see MACHINERY'S Reference Book No. 102, "Automatic Screw Machine Practice—External Cutting Tools."

Cutting-angles for Box-tool Cutters

The cutting angle on a box-tool cutter depends largely on the method used in holding it, and on how it is applied to the work. In Fig. 24 a few methods of the application of box-tool cutters to the work are shown, and the angles at which they should be ground for various materials. A box-tool cutter, to give good results, should have sufficient clearance and rake so that it will remove the metal with the least possible resistance. Generally, in automatic screw machine work, the box-tool cutter is set radially to the work, for cutting brass, as shown at *A*. When held in this manner the cutting angles are approximately as given in the illustration. This type of tool is used particularly for roughing work. For finishing work on brass, the tool is set as indicated at *B*, and the cutting face is ground parallel for a short distance *f*, which for usual conditions equals one-fifth of the smallest diameter of the work being turned. For steel, the box-tool cutter should be set tangentially to the work, as shown at *C* and *D*.

TABLE II. CUTTING ANGLES FOR HOLLOW-MILLS



Angle	Material to be Cut		
	Brass Rod	Machine Steel	Tool Steel
	Cutting Angle in Degrees		
α	8	15	10
β	8	5	3
θ	0	15	10

The angles on the box-tool cutter shown at *C* for cutting various materials is as follows:

Cutting-angles for Tool Steel

$b =$ 8 deg.
$c =$ 8 to 10 deg.
$d =$ 72 to 74 deg.
$e =$ 8 deg.

Cutting-angles for Machine Steel

$c =$ 8 to 10 deg.
$e =$ 10 deg.
$d =$ 70 to 72 deg.
$b =$ 10 deg.

The method of grinding the tools shown at *C* is commonly used for roughing purposes on steel, but will not produce an absolutely square shoulder on the work. For finishing cuts, the box-tool cutter is ground as shown at *D*.

The cutting angles for this type of tool are as follows:

Cutting-angles for Tool Steel

$m =$ 8 to 10 deg.
$g =$ 8 to 10 deg.
$h =$ 72 to 74 deg.

Cutting-angles for Machine Steel

$m =$ 10 to 12 deg.
$g =$ 15 to 18 deg.
$h =$ 60 to 65 deg.

While the cutting face on the tool shown at *D* is straight, it is usually advisable, especially when cutting machine steel and Norway iron to give it more "lip," and is indicated by the dotted line *i*. This produces a curling chip, and is conducive to better and more efficient cutting. It is not advisable in most cases to make the box-tool cutters for finishing from high-speed steel for cutting steel and Norway iron, if an exceptionally good finish is desired.

At *D* in Fig. 24 is shown the method used in adjusting the tangent cutter. The face of the cutter should be set at a distance *j* back from the center of the work. This gives the tool more clearance on the periphery of the work. The distance *j* should equal (for Norway iron and machine steel) one-tenth of the smallest diameter of the work being turned. When the tangent cutter is adjusted in a vertical direction, it should also be moved back an amount equal to *k*, as shown by the dotted lines in the illustration, so that *k* bears the same relation to the larger diameter as *j* does to the smaller.

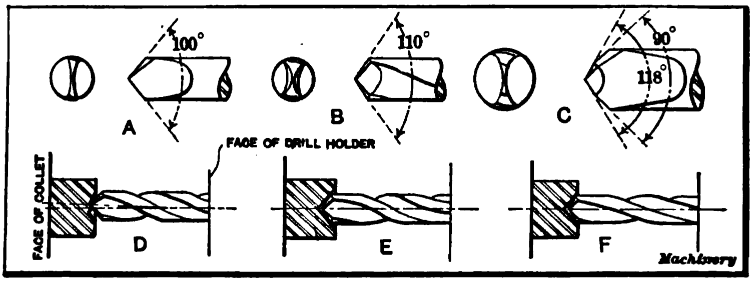


Fig. 25. Centering Tools—Incorrect and Correct Methods of Centering

Sometimes, when cutting machine steel, it is advisable to set the tool at an angle of from 1 to 2 degrees from the horizontal plane. This increases the clearance between the periphery of the work and the cutting face of the tool, and is accomplished by means of adjusting screws in the box-tool.

Cutting-angles for Hollow-mills

The illustration accompanying Table II shows a type of hollow-mill which is used on the automatic screw machine in cases where it is necessary to remove a large amount of material. The cutting angles for the lips of the hollow-mill are given in this table for various materials. Unless the operator has equipment sufficiently accurate to grind hollow-mills, he should not attempt to do so, as unsatisfactory results will be obtained if all the prongs or teeth do not do their share of the cutting. Preferably hollow-mills should be sharpened in the tool-room on an ordinary cutter grinder.

Setting Centering Tools and Drills

When the drill used is less than 1/8 inch in diameter, and is to pass entirely through the work, a centering or spotting drill should always be used. The centering tool should be ground and set so that it will not leave a teat in the work. It also should have an included angle less than that used on the drill. In Fig. 25, three types of centering tools are shown at *A*, *B* and *C*. The tool shown at *A* is used principally for brass work, while that shown at *B* is used for steel work, and is made similar to an ordinary twist drill. The tool shown at *C* is used when a large center is to be "spotted" in steel.

At *D* is shown the effect of using a centering tool with an included angle greater than that used on the drill, and also by having it set so that it leaves a teat in the hole. It is evident that when the drill is projecting out of the holder for a considerable distance (because it is to pass entirely through the work) it will not enter concentrically, but

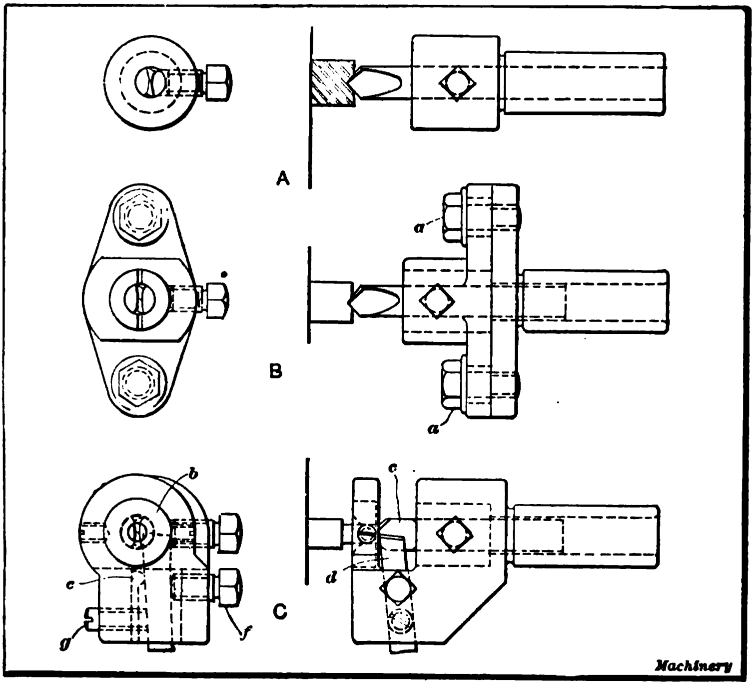


Fig. 26. Various Types of Centering Tool Holders

will be deflected by the teat. If the centering tool is made with an included angle less than that used on the drill, the result will be as shown at *F*, even if a teat has been left in the hole. Here the drill is well supported before its point would touch the teat; hence it would not be deflected. At *E* is shown the position that a drill should take in a correctly centered hole.

Holders for centering tools are illustrated at *A*, *B* and *C* in Fig. 26. The type of holder shown at *A* is frequently used, but is not recommended, owing to the difficulty of setting the centering tool concentric with the work. Preferably the floating holder shown at *B* should be used, as the centering tool can then be set concentric. after which the screws *a* are tightened. The holder shown at *C* is used when the work projects to a considerable distance out of the collet, and the center is to be concentric with the part already turned. This holder carries a bushing *b*, held by a screw in the front part of the holder, a centering tool *c*, and facing tool *d*. The centering tool *c* is retained in a bushing by a set-screw, while the facing tool *d* is held down on block *e* by another set-screw. The headless screw *g* is used for adjusting.

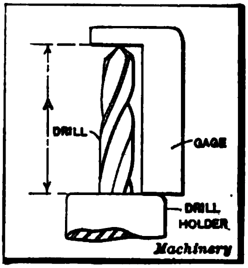


Fig. 27. Gage for setting a Drill

To set the centering tool *B*, the holder carrying it is placed in the turret, the latter swung down, the spindle stopped, and the centering tool brought in contact with the work. The screws *a* are then loosened, the tool set concentrically, and the screws tightened. The lead cam is then rotated by handwheel V_5, Fig. 29, until the roll rises up onto the starting point of the lobe for feeding the centering tool into the work. The holder is tapped back into the turret so that the point of the tool just clears the end of the work; then the holder is clamped in the turret. If upon trial it is found that the centering tool does not project in to the required distance, it is a simple matter to bring it out.

Before setting the drill, see that it is ground correctly for the material upon which it is to work, that is, to the desired angle and lip clearance. For brass work, the lip should be almost ground off, especially when a broken chip and not a curling one is desired. For steel the drill should be given a fairly good lip. The procedure given for

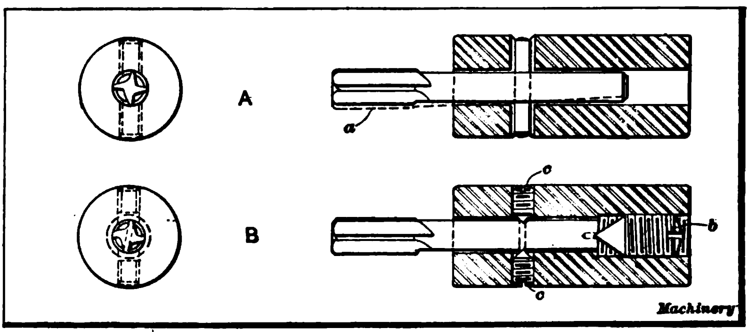


Fig. 28. Floating Reamer Holders

setting the centering tool also applies to setting a drill. For information regarding drill grinding see Chapter IV of Machinery's Reference Book No. 94, "Operation of Machine Tools—Drilling Machines."

Prepare in time for the failure of a drill, as considerable time is lost in regrinding and resetting. A good idea is to have a number of drills lying on the tray already ground, and to use a gage for setting the drills as shown in Fig. 27. This gage is made from sheet steel about 1/16 inch thick. The dimension *A* is made equal to the distance that the drill is required to extend out of the holder. If there is more than one drill in the turret, which would be necessary when a deep hole is to be produced, a gage of this description should be made for setting each drill. These gages should be marked according to the position that the drill for which they are used takes in relation to the other drills; that is, "1st," "2nd," etc., and kept in the same box as the other tools used on the job. If this precaution is taken, no time will be lost in setting a drill, because the machine need not be stopped. The clamping screw holding the drill can be released, the drill pulled out and a fresh one inserted while the machine is running.

Setting Counterbores and Reamers

A counterbore provided with a leader should always be held in a floating holder. Before setting the counterbore, of course, the hole should be drilled; then the procedure for setting centering tools

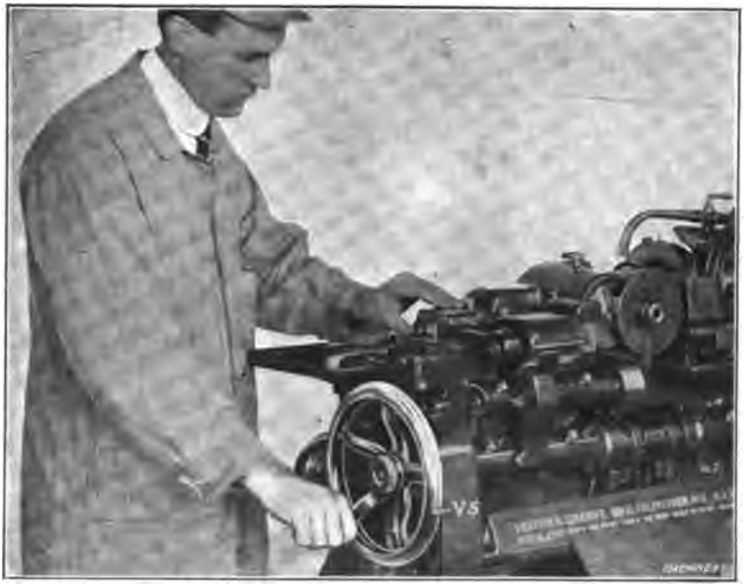


Fig. 29. Operator setting the Spindle Reversing Dogs for Threading

should be followed, except that the leader is inserted, bringing the face of the counterbore in contact with the end of the work. When the counterbore is not provided with a leader, a floating holder similar to that shown at *B* in Fig. 26 should be used.

Reamers which are to produce deep holes should be held in floating holders. Two types of floating holders are shown at *A* and *B* in Fig. 28. The one shown at *A*, however, is not recommended for automatic screw machine work, because the reamer drops down as shown at *a* if too much clearance is allowed between the hole in the holder and the reamer shank, thus preventing the reamer from centering easily into the work, and sometimes breaking it. The holder at *B* should be used in preference, because the reamer is guided by means of the screws *b* and *c*, and can be given the desired amount of "float" by screws *e*. When a reamer is only to project a short distance into the work, the holder shown at *B* in Fig. 26, can be used.

Setting Dies and Taps

Before a die or tap and its holder are placed in the turret, the dogs should be set in position to reverse the spindle in the correct relation to the threading lobe on the lead cam. The two parts of clutch *M* (see Figs. 1 and 6) should first be engaged, so that the shaft carrying the disk on which the dogs are located will be rotated in step with the other driving mechanism of the machine. Then the shifter is pulled over and the main spindle started. The lead-cam is now rotated by means

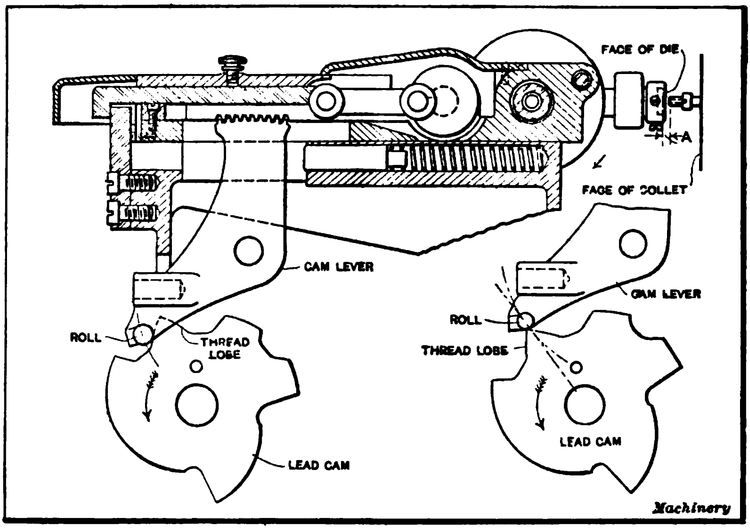


Fig. 30 Fig. 31

Showing the Position of the Roll on the Cam Lobe Relative to the Reversal of the Spindle

of hand-wheel V_5, Fig. 29, the operator also pressing his thumb against the turret slide and bearing on the turret base. While rotating the hand-wheel V_5, he watches to see when the spindle reverses; and by keeping his thumb in contact with the turret slide he can tell when the roll drops over the highest point of the lobe on the cam. When the spindle reverses at the same instant that the roll drops over the highest point of the lobe on the cam, the dog is set in the desired position. This is illustrated graphically, for setting a die, in Figs. 30 and 31. In Fig. 30 a button die is shown, held in a holder, in position ready to start on the work. The face of the die should be set the distance *A* from the end of the work. This distance varies from 1/16 to 3/16 inch, depending on the pitch of the thread and the length of the threaded portion. In Fig. 31 the cam roll is set just back of the highest point of the lobe; when the roll is at this point, the spindle should reverse.

After the first setting, if it is found that the die does not travel onto the work far enough, the holder is brought further out of the turret. The same procedure is followed in setting a tap, except that it should be set more carefully, only going into the work a slight distance when starting, and the holder moved out of the turret until the desired depth is reached. It is sometimes found necessary, after setting the tripping dogs, to adjust them slightly, especially when using the draw-out type of die or tap-holder. The turret should not be indexed until the die or tap is clear of the work.

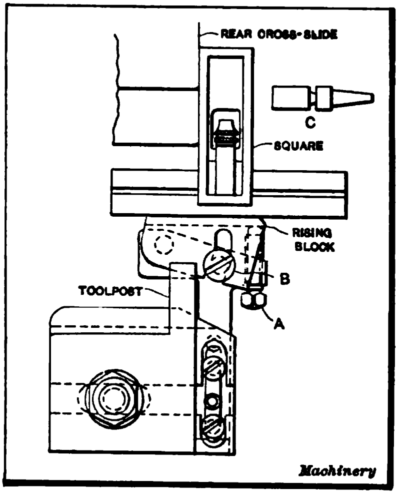


Fig. 32. Setting a Rising Block with a Square

Setting Swing Tools and Taper-turning Tools

Swing tools are used for both internal and external cutting, and are operated under three different conditions: first, the cutting tool is fed into the work from the cross-slide alone; second, the cutting tool is fed longitudinally by the turret; third, the cutting tool is fed inward by the cross-slide and longitudinally by the turret. For the first condition, the rising block need not be set in any particular relation to the axis of the spindle. When straight turning is to be produced under the second condition, the face of the rising block should be set parallel with the axis of the spindle. For the third condition, when the work is to be turned taper, the face of the rising block should be set at an angle with the axis of the spindle.

In Fig. 32 is shown a simple method of setting the face of the rising block parallel with the axis of the spindle. An ordinary adjustable square is held against the face of the rear cross-slide, and screw *A* is adjusted until the block is set correctly, after which screw *B* is tightened. This method can be used when it is not necessary to have the rising block set exactly parallel with the axis of the spindle.

A better and more accurate method is shown in Fig. 33. Here a Brown & Sharpe dial test indicator *B* is used. A split bushing is inserted in one of the holes in the turret, and a bent rod with the indicator is held in it. The finger of the indicator is brought to bear against the face of the rising block *C*, and the turret is traversed by handle R_3 on the No. 0 and 2 machines, and by using handle K_2, Fig. 21, on the No. 00 machine, inserting it in the turret traversing lever. While the turret is being traversed back and forth, the movement of the needle on the dial is noted, and the screw *A* adjusted until no movement is transmitted to the needle.

The setting of the rising block for operating a taper turning tool or a swing tool for taper turning is generally accomplished by the cut and try method, the first time the tools are set up. Most operators, when setting up a job for the second time, use what is called a "set piece" to set the tools by. This is a piece of work which has been made correctly to size, but which is not entirely cut off, as shown at *C* in Fig. 32. It is gripped in the collet, and the turning tool as well as the circular form and cut-off tools are set to it.

Setting Shaving Tools

There are two distinct types of shaving tools employed on the automatic screw machines, each type requiring the use of a different holder. Fig. 34 shows a shaving tool holder and shaving tool which

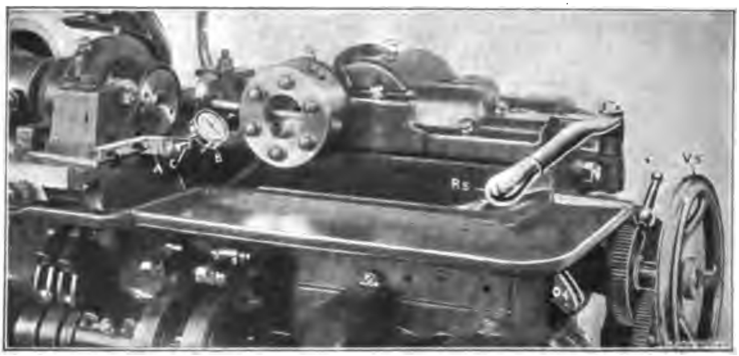


Fig. 33. Setting the Rising Block with the Aid of a Brown & Sharpe Dial Test Indicator

is used without a support for the work. This type of tool is used when the work is large enough in diameter to withstand the cutting pressure. The angles on the shaving tools shown to the right of the illustration for the different materials are as follows:

Material	Cutting-angle in Degrees
Brass rod	$A = 20$, $B = 30$, $C = 10$.
Machine steel	$A = 30$, $B = 40$, $C = 15$.
Tool steel	$A = 40$, $B = 50$, $C = 15$.

These angles need only be approximated, but the table gives a fair idea of preferable angles to which a shaving tool should be ground for shaving long work. Another type of shaving tool-holder and shaving tool is shown in Fig. 35. This type is used principally on steel work which is long in proportion to the diameter. It consists of a shaving tool *A* and support *B*. The support *B* is made an exact duplicate of the shaving tool *A*, except that it is not backed off for cutting, and is slightly rounded on the front end. It should always be set a slight amount back of the cutting edge of the shaving tool. At *C* and *D* is shown the way in which these shaving tools should be made. At *C* the tool is shown machined and ready for hardening, and at *D* the front part, shown partially separated at *C*, is removed and the tool ground ready for work. The cutting angles for this tool are as follows:

Material	Cutting-angle in Degrees
Brass rod	$a=10$, $b=10$.
Machine steel	$a=15$, $b=15$.
Tool steel	$a=20$, $b=15$.

Setting the Belt-shifting Attachment

The belt shifting attachment on the Nos. 0 and 2 machines, which is used for changing the spindle from a fast to a slow speed or *vice*

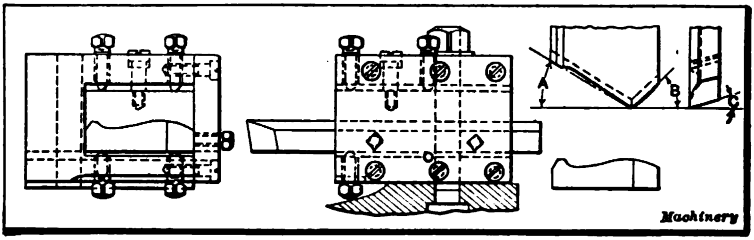


Fig. 34. Shaving Tool and Holder for Long Work

versa, is shown set up on a No. 0 machine in Fig. 36. This attachment is driven from the rear driving shaft through gears *A* and *B*, which rotate disk *C*, carrying rod *D*, the latter being connected eccentrically to the disk and operating the shifter on the countershafting, as illustrated in Figs. 42 and 43 and Figs. 44 and 45. Gear *A* has half as many teeth as gear *B*, so that for every revolution of the driving shaft the belt is shifted once. This attachment is operated by clutch *E*, which is brought into and out of engagement by a tripping lever

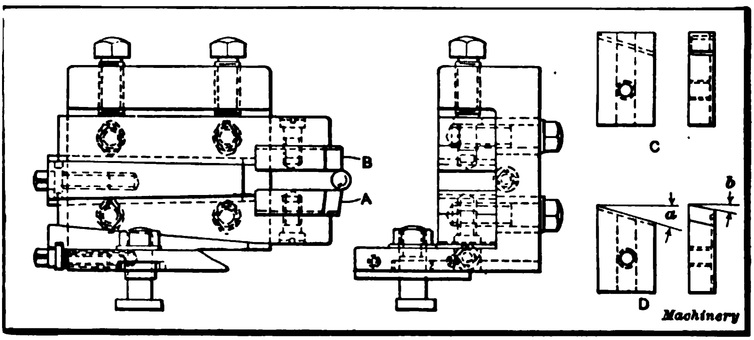


Fig. 35. Shaving Tool and Holder provided with a Support for the Work

and dog carried on the drum on the front camshaft. It is not advisable to shift the belt when a tap is in or a die on the work, but the spindle should rather be rotated at the lowest speed when the tap or die engages or disengages the work.

The No. 00 machine is not equipped with this belt shifting device, but for steel work a threading attachment as shown at *A* in Fig. 37 is used. This attachment is also supplied for the Nos. 0 and 2 machines, but its driving capacity is limited to the following sizes of taps or dies. For the No. 00, the maximum diameter of tap or die that can be driven by this device is 1/8, 40 threads; on the No. 0 machine 3/16, 32 threads; and on the No. 2 machine 1/4, 22 threads. When a larger diameter tap or die and a coarser thread than this is to be cut in the No. 00 machine, the two speeds of the spindle are employed, which, of course, necessitates the using of left-hand turning

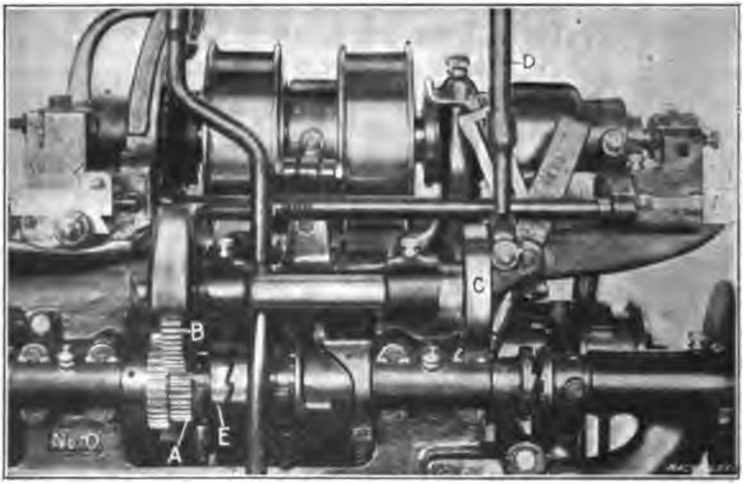


Fig. 36. The Belt-shifting Attachment used for Threading

Fig. 37. Ratio Threading Attachment

tools in the turret. On the Nos. 0 and 2 machines, the belt shifting arrangement, previously described, should be used.

The ratio threading attachment shown at *A* in Fig. 37 is held in the turret and driven by a belt *B* from the countershaft, through pulley *C* and bevel gears *D*. The spring *E* acts in the same manner as the spring in the ordinary draw-out die or tap holder.

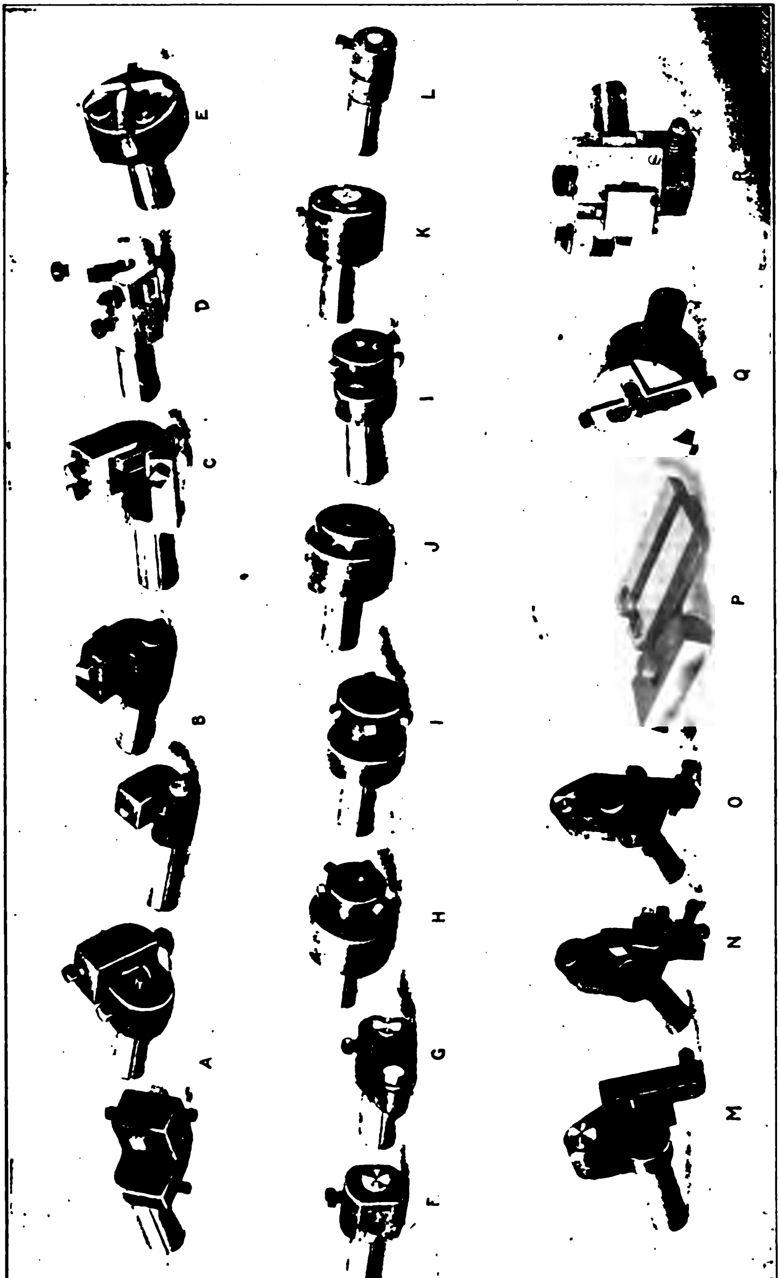


Fig. 38. Representative Group of Standard Tools for Brown & Sharpe Automatic Screw Machines

There are a number of special cross-slide and turret attachments which can be obtained for the Brown & Sharpe automatic screw machines for various operations. The method of setting these attachments, of course, is entirely governed by the work and the construction of the attachment itself. Figs. 38 and 39 show groups of standard tools which are used on the Brown & Sharpe automatic screw machines. The names of the tools shown in Fig. 38 are:

Knee tool, and centering and facing tools.	*A*,
Box-pointing tools.	*B*,
Box-tool (two cutters).	*C*,
Box-tool (one cutter).	*D*,
Adjustable hollow mill (finishing).	*E*,
Drill holder.	*F*,
Floating holder.	*G*,
Button die holder (releasing).	*H*,
Button die holder(draw-out).	*I*,
Tap holder (releasing).	*J*,
Tap holder (draw-out).	*K*,
Small tap holder (draw-out).	*L*,
Swing knurl or thread roll-holder.	*M*,
Swing turning tool.	*N*,
Recessing tool holder.	*O*,
Rising block with adjustable guide.	*P*,
Taper turning tool.	*Q*,
Angular cutting-off tool.	*R*,

The names of the standard tools shown in Fig. 39 are:

Turret knurl holder.	A_1,
Cross-slide knurl holder(side).	B_1,
Cross-slide knurl holder (top).	C_1,
Spring collet.	D_1,
Feed finger.	E_1,
Centering tool and turret back rests.	F_1,
Auxiliary work support.	G_1,
Double-throw cross-slide attachment.	H_1,
Slabbing attachment.	I_1,
Cross-slide cutting-off tool post (high).	J_1,
Cross-slide cutting-off tool post (low).	K_1,
Tool post for straight forming tools.	L_1,
Cross-slide drilling attachment.	M_1,
Brake for spindle.	N_1,

With the exception of the auxiliary work support shown at G_1 in Fig. 39, all of the standard tools and attachments illustrated are dealt within detail in MACHINERY'S Reference Books, Nos. 99 to 106, inclusive, on "Automatic Screw Machine Practice." The attachment G_1 is used for steadying the work and making it run "dead" true when it is desired to turn down a portion of the work perfectly concentric with the remainder of the piece, which is not to be operated on. This device is fastened over the hood enveloping the spring collet and ex-

Fig. 39. Representative Group of Standard Tools and Attachments for the Brown & Sharpe Automatic Screw Machines

tends in front of the latter. The bushing *a*, shown solid, is then drilled and reamed out from the turret, after which it is hardened, inserted again and lapped.

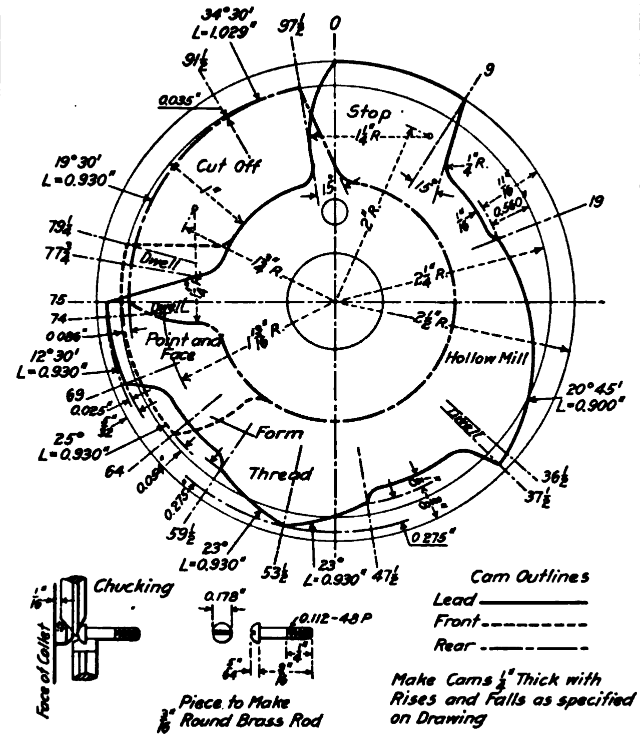
Instructions for Setting-up a Job on the Automatic Screw Machine

To illustrate the method followed in setting-up a job on the Brown & Sharp automatic screw machines, we will assume that a set of cams as illustrated in Fig. 40 have been designed and made for producing a button-head screw on the No. 00 machine. These came, together with the special and standard tools which are numbered, are turned over to the operator. He also receives a drawing similar to that shown in Fig. 40. We will assume that the machine has been set up for another piece of work, so that it is necessary to dismantle it. The first thing the operator does is to remove all the tools from the turret and the cams from the front and rear end shafts. He also removes the spring collet by removing the cap, and the feed tube by lifting the latch; then he unscrews the feed finger, which is threaded left-hand. The change gears are now removed, leaving the machine dismantled ready for the new job.

To proceed, the operator first inserts the spring collet, puts on the cap, and then screws the new feeding finger into the feed tube, and inserts the latter into the spindle. He then puts the stock into the feed tube, and places a suitable pipe in the stand in which the stock is to revolve. This pipe should be central with the feed tubes, thus reducing the wear in the hole of the latter. The belts are now placed on their proper cones, as illustrated in Fig. 41, to give the desired spindle speeds for the job. All belts should be without rivets, and preferably should be laced with wire, as this gives a smoother running belt. Now oil all the bearings with good machinery oil, and also the friction clutch. The latter should be oiled at least twice a day. Then see that the reservoir in the tank is filled with good lard oil, the latter being absolutely necessary if the machine is to be run economically and to its full capacity.

After the belts have been placed on the proper cones, the collet, feed finger, etc., having been inserted, the change gears should be put on as illustrated in Fig. 16. These gears are held by thumb nuts which should be tightened with the pin wrench supplied for that purpose. The handwheel V_8 is next put on for operating the machine by hand.

Before putting on the cams, set the collet so that it has the proper grip on the stock. The method for doing this has been described in Chapter I. Now open the collet again and push the stock out far enough to be faced off by the cut-off tool. Close the collet by means of the handle and start the spindle. Now set the cross-slide circular form and cut-off tools directly at the height of the center of the work, and in their proper relation to each other. Next put on the front and rear cross-slide cams; and if the job, as this one does, requires a threading operation, the shaft with the drum carrying the tripping dogs for reversing the spindle, should be connected with the front camshaft.



Name of Piece: Button Head Screw

Gears		Time to Make 1 Piece 6½ Seconds	Spindle Speeds	
No. 52	On Drive Shaft	Gross Production 10 hours = 5538	Forward	Backward
No. 34	On Worm Shaft	Made on No. 00 B. & S. Auto. Scr. Mach.	2400 R.P.M.	2400 R.P.M.
No.	On 1st Stud	Material Used: 3/16" Round Brass Rod	R.P.M.	R.P.M.
No.	On 2nd Stud	Remarks: Use 6 hole Turret	Surface Speeds	
		Machine, and Tool Numbers	For Stock	117.81 F.P.M.
		as specified	For Thread	70.37 F.P.M.
			For Drilling	F.P.M.

Revs.	Hunds.	Start	Finish	Rise	Feed	Operations
23.4	9	0	9			Feed stock to stop and chuck
26.0	10	9	19			Revolve Turret
48.1	18½	19	37½	0.560"	0.0123"	Turn (Hollow Mill) Dwell 0.10
26.0	10	37½	47½			Revolve Turret
15.6	6	47½	53½	0.275"	0.122"-48	Die on } Reverse Spindle
15.6	6	53½	59½	0.275"	0.122"-48	Die off }
11.7	4½	59½	64			Clearance and Revolve Turret
38.65	15½	64	79½	0.054"	0.00155"	Form (Circular Tool) Dwell 0.15
15.6	6	69	75	0.025"	0.00192"	Point and Face Dwell 0.10
42.9	16½	75	91½	0.051"	0.00119"	Start Cut-off } Circular Tool
15.6	6	91½	97½	0.035"	0.00224"	Finish Cut-off }
6.5	2½	97½	100			Clearance }

Special Tools	Tool No.	Dwg. No.	Standard Tools	Tool No.	Dwg. No.
Circular Form Tool	1678	L.7218	Stop	1368	T.S. 50
Circular Cut-off Tool	1679	L.7218	Floating Holder	1472	L.7685
Cams, Lead, Front, Rear	1680	L.7219	Hollow Mill	1763	T.S.100
Slotting Bushing	1681	L.6301	Button Die Holder	1875	L.7860
			0.112-48 P Button Die	1673	T.S.150
			Pointing and Facing Tool	1520	L.7679

Remarks:

Fig. 40. Setting-up Chart for making a Button Head Screw on the No. 00 Brown & Sharpe Automatic Screw Machine

Next, set in the cross-slides by adjusting nuts A_8, Fig. 21, so that the circular form and cut-off tools travel in to the required distance. Place the hollow-mill in the turret, set it correctly, and also set the tripping dog so as to revolve the turret. Put the box-tool in the turret, set it, and also set the dog for indexing the turret. The die is then set as previouslyy described, and all the tripping dogs are set to index the turret completely around. After all the tools have been set in their proper relation, make a piece, except threading, by turning the handwheel; at the threading operations drop down the die so that it does not pass onto the work. Gage the piece thus made; if it is correctly to size, and the tripping dogs for reversing the spindle and the die have been properly set, throw the feed clutch by means of handle *P*, Fig. 1, and start the machine.

When the bar is all used up, the chuck should be opened by tripping the lever, and the turret revolved by withdrawing the locking pin, so that it will not interfere with the short piece left in the chuck, which should be driven out for the insertion of a new bar. To insert the new bar, turn the handwheel sufficiently to bring the shoulder of the feed tube against the end of the spindle, and push out the bar just far enough so that its front end can be faced off with the cut-off tool. Now turn the turret back into position and start the machine by throwing in the clutch. The ends of the rods of stock should be ground to remove the burrs, thus insuring their entering and feeding freely and evenly through the feed tube.

The work should always be tested after the insertion of a new bar of stock. If the parts made are short or thin, the tools will become dull much more quickly; consequently the work should be tested more frequently in that case, so that any errors may be corrected as soon as possible.

CHAPTER III

COUNTERSHAFT ARRANGEMENT AND SPINDLE SPEEDS

The arrangement of the spindle speeds for the No. 00 automatic screw machine, as well as the spindle speeds of the No. 00 automatic turret forming and the No. 00 automatic cutting-off machines, are shown in Fig. 41. The spindle speeds obtainable on the No. 0 automatic screw machine, as well as the arrangement of the countershaft with respect to the main shaft, is shown in Figs. 42 and 43. The spindle speeds obtainable on the No. 0 automatic turret forming machine and on the No. 0 automatic cutting-off machine are also given. The arrangement of the spindle speeds for the No. 2 automatic screw machines are shown in Figs. 44 and 45, where the spindls speeds for the No. 2 automatic turret forming and automatic cutting-off machines are also given.

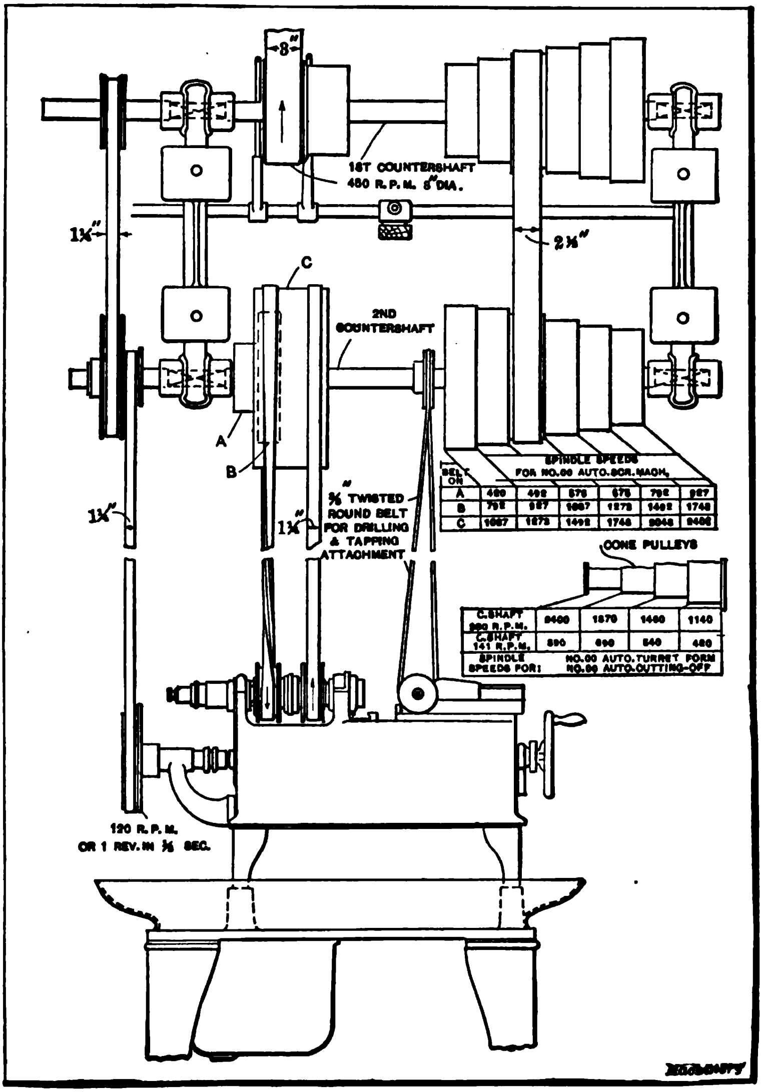
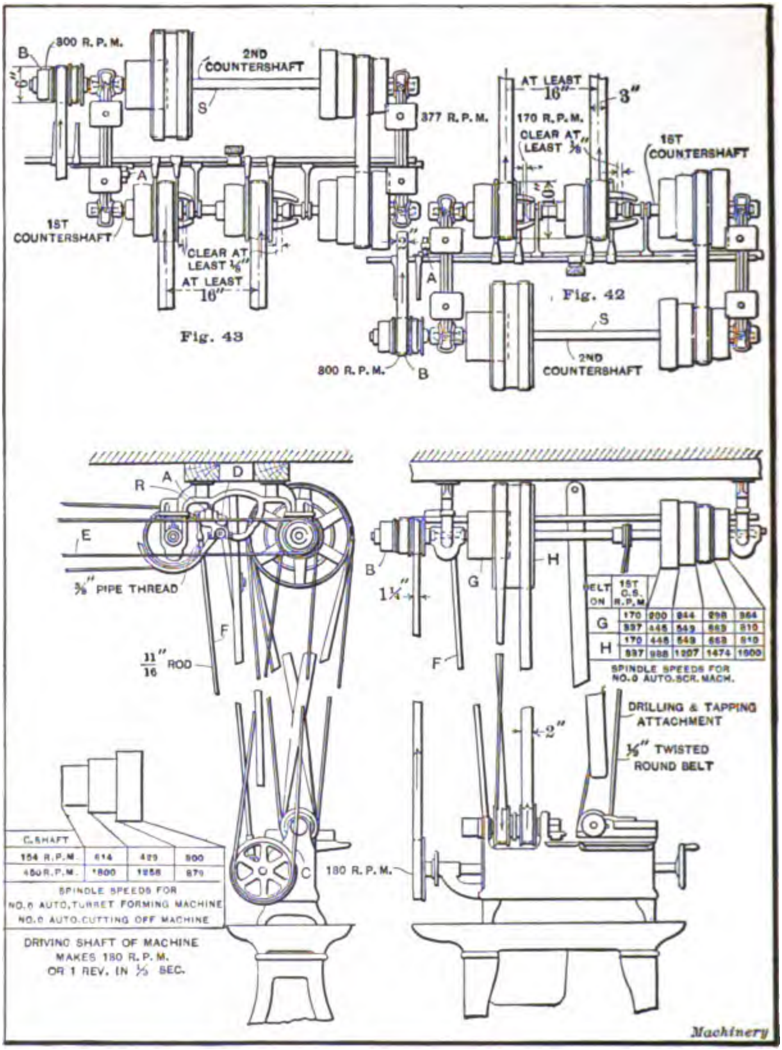


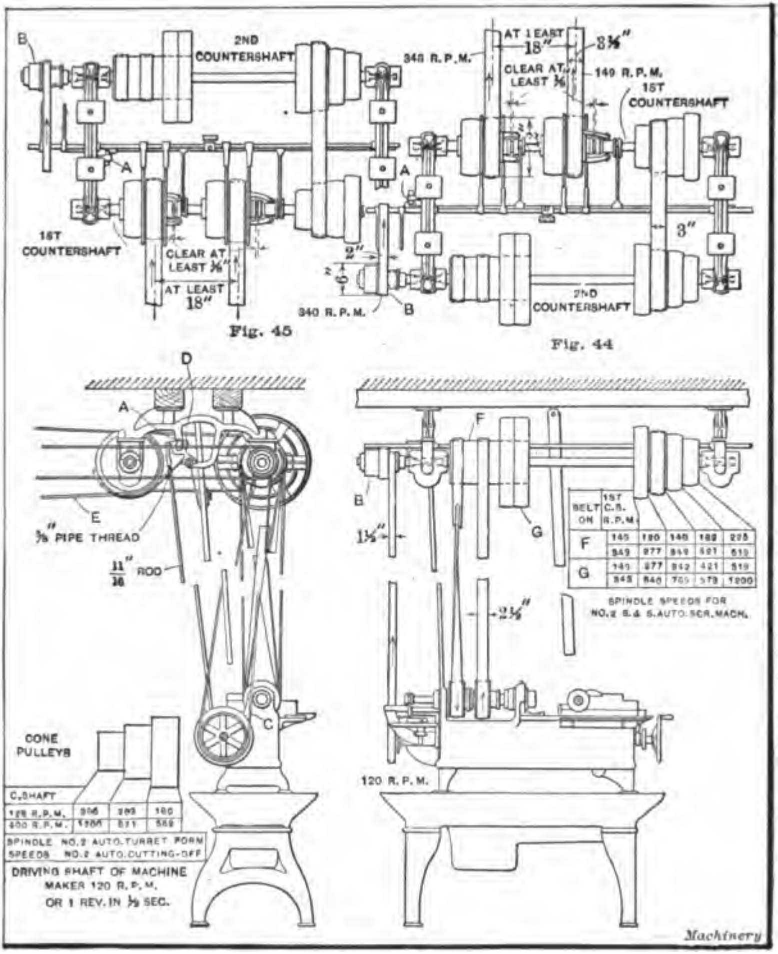
Fig. 41. Arrangement of Spindle Speeds for No. 00 Brown & Sharpe Automatic Screw Machines

The counter-shaft arrangement shown in Figs. 41 to 45 drives both the main spindle and the rear driving shaft. The rear driving shaft is driven independently of the cone pulleys by a double loose pulley mounted on the end of the second countershaft. This pulley acts as an intermediate between the main line and the feed mechanism, driving the latter at a constant speed. The belts are all controlled by means of one shifter handle.



Figs. 42 and 43. Arrangement of Spindle Speeds for No. 0 Brown & Sharpe Automatic Screw Machines

For the No. 0 machine, the countershafting may be set up as in Fig. 42 or as in Fig. 43, to suit the location of the main line-shaft. In Fig. 42, *A* is on the outside of the hanger, and in Fig. 43, on the inside. The first countershaft is always nearest the main line-shaft, and the sides *R* of the hangers are always its support. The long shaft *S* with pulley *B* may be placed in either pair of boxes, so that belt *C* will clear the feed-slide of the machine. If belt *E* interferes with the shifter-rod at *D*, belts *E* and *C* may be crossed. The belts will gen-



Figs. 44 and 45. Arrangement of Spindle Speeds for No. 2 Brown & Sharpe Automatic Screw Machines

erally clear, as the main line-shaft is usually lower than the countershaft. Rod *F* can be nearly vertical when the drilling attachment is not used.

For the No. 2 machine, the countershaft can be set up as in Fig. 44, or as in Fig. 45, to suit the location of the main line-shaft. In Fig. 44, *A* is on the outside of the hanger, and in Fig. 45, on the inside. The long shaft with pulley *B* can be placed in either pair of boxes, so that belt *C* will clear the feed-slide of the machine. If belt *E* should interfere with the shifter-rod at *D*, belts *E* and *C* may be crossed. Belt *E* will generally clear as the main line-shaft is, as a rule, lower than the countershaft.

TABLE II. SURFACE SPEED OF STOCK

Diameter of Stock	Decimal Equivalent	Revolutions Per Minute															
		2400	2048	1800	1748	1492	1474	1273	1200	1087	988	973	927	810	792	675	640
		Surface Speed in Feet per Minute															
1/16	0.062	39.3	33.5	29.4	28.6	24.4	24.1	20.8	19.6	17.9	16.2	15.9	15.2	13.2	12.9	11.0	10.5
5/64	0.078	49.1	41.9	36.8	35.7	30.5	30.1	26.0	24.5	22.2	20.2	19.9	18.9	16.9	16.2	13.8	13.1
3/32	0.094	61.4	52.4	46.1	44.7	38.1	37.7	32.6	30.7	27.8	24.2	24.9	22.7	20.7	20.3	16.6	16.4
7/64	0.109	68.5	58.4	51.3	49.9	42.6	42.0	36.3	34.2	31.0	28.3	27.8	26.5	23.1	22.6	19.3	18.3
1/8	0.125	78.5	67.0	58.9	57.2	48.8	48.2	41.6	39.3	35.6	32.3	31.8	30.3	26.5	25.9	22.1	20.9
9/64	0.141	88.6	75.6	66.4	64.5	55.1	54.4	47.0	44.3	40.1	36.4	35.9	34.1	29.9	29.2	24.9	23.6
5/32	0.156	98.0	83.6	73.5	71.4	60.9	60.2	52.0	49.0	44.4	40.4	39.7	37.9	33.1	32.4	27.6	26.1
11/64	0.172	107.9	92.1	81.0	78.6	67.1	66.3	57.3	54.0	48.9	44.4	43.8	41.7	36.4	35.6	30.4	28.8
3/16	0.187	117.8	100.5	88.3	85.8	73.2	72.3	62.5	58.9	53.3	48.5	47.8	45.5	39.8	38.9	33.1	31.4
13/64	0.203	127.6	108.9	95.7	93.0	79.3	78.4	67.7	63.8	57.8	52.5	51.7	49.3	43.1	42.1	35.9	34.0
7/32	0.219	137.6	117.3	103.1	100.1	85.4	84.4	72.9	68.7	62.2	56.6	55.7	53.1	46.4	45.3	38.6	36.6
15/64	0.234	147.3	125.7	110.4	107.2	91.5	90.4	78.1	73.6	66.7	60.6	59.7	56.9	49.7	48.6	41.4	39.3
1/4	0.250	157.1	134.0	117.8	114.4	97.6	96.5	83.3	78.5	71.1	64.7	63.7	60.7	53.0	51.8	44.2	41.9
9/32	0.281	176.7	150.8	132.5	128.7	109.8	108.5	93.7	88.3	80.0	72.7	71.6	68.2	59.7	58.2	49.7	47.1
5/16	0.312	196.3	167.5	147.3	143.0	122.0	120.6	104.1	98.2	88.9	80.8	79.6	75.8	66.3	64.7	55.2	52.4
11/32	0.344	215.9	184.3	161.9	157.3	134.2	132.6	114.6	107.9	97.8	88.9	87.6	83.4	73.0	71.2	60.7	57.6
3/8	0.375	235.6	201.0	176.7	171.6	146.4	144.7	125.0	117.8	106.7	97.0	95.5	91.0	79.6	77.6	66.3	62.9
13/32	0.406	255.2	217.8	191.4	185.9	158.5	156.8	135.4	127.6	115.6	105.1	103.5	98.6	86.3	84.1	71.8	68.1
7/16	0.437	274.9	234.5	206.2	200.2	170.7	168.8	145.8	137.4	124.5	113.2	111.4	106.2	92.9	90.6	77.3	73.3
15/32	0.469	294.5	251.3	220.9	214.5	183.0	180.9	156.2	147.3	133.4	121.2	119.4	113.8	99.6	97.0	82.8	78.5
1/2	0.500	314.2	268.1	235.6	228.8	195.1	192.9	166.6	157.1	142.3	129.3	127.4	121.3	106.2	103.5	88.3	83.8
17/32	0.531	333.8	284.8	250.3	243.1	207.3	205.0	177.0	166.9	151.2	137.4	135.3	128.9	112.9	109.9	93.9	89.0
9/16	0.562	353.4	301.6	265.1	257.4	219.5	217.1	187.5	176.7	160.1	145.5	143.3	136.5	119.5	116.4	99.4	94.2
19/32	0.594	373.1	318.3	279.8	271.7	231.7	229.1	197.9	186.5	168.9	153.6	151.2	144.1	126.2	122.9	104.9	99.5

TABLE III. SURFACE SPEED OF STOCK

Diameter of Stock	Decimal Equivalent	Revolutions per Minute 576	543	519	492	445	420	364	342	298	277	244	225	200	182	148	120
		Surface Feet in Inches per Minute															
9/32	0.281	42.6	40.0	38.2	36.2	32.7	31.7	26.8	25.2	21.9	20.4	18.0	16.9	14.7	13.4	10.8	8.8
5/16	0.312	47.1	44.4	42.4	40.2	36.4	34.4	29.8	28.0	24.9	22.7	20.1	18.4	16.4	14.5	12.1	9.8
11/32	0.344	51.8	48.9	46.7	44.3	40.0	37.8	32.7	30.8	26.8	24.9	21.9	20.2	18.0	16.4	13.3	10.8
3/8	0.375	56.5	53.3	50.9	48.3	43.8	41.2	35.7	33.6	29.3	27.2	23.9	22.1	19.6	17.9	14.5	11.8
13/32	0.406	61.2	57.7	55.2	52.3	47.3	44.7	38.7	36.4	31.7	29.5	25.9	23.9	21.3	19.4	15.7	12.8
7/16	0.437	66.0	62.2	59.4	56.4	51.0	48.1	42.6	39.2	34.1	31.7	27.9	25.8	23.0	20.8	16.9	13.7
15/32	0.469	70.7	66.6	63.7	60.4	54.6	51.5	44.6	42.0	36.6	34.0	29.9	27.6	24.5	22.3	18.6	14.7
1/2	0.500	75.4	71.1	67.9	64.4	58.2	55.0	47.6	44.8	39.0	36.3	31.9	29.5	26.2	23.8	19.4	15.7
17/32	0.531	80.1	75.5	72.2	68.4	61.9	58.4	50.6	47.6	41.4	38.5	33.9	31.3	27.8	25.3	20.6	16.7
9/16	0.562	84.8	80.0	76.4	72.5	65.5	61.8	53.6	50.4	43.9	40.8	35.9	33.1	29.5	26.8	21.8	17.7
19/32	0.594	89.5	84.4	80.7	76.5	69.2	65.3	56.6	53.2	46.3	43.1	37.9	35.0	31.1	28.3	23.0	18.6
5/8	0.625	94.2	88.8	84.9	80.5	72.8	68.7	59.5	55.9	48.7	45.3	39.9	36.8	32.7	29.8	24.2	19.6
21/32	0.656	98.9	93.3	89.2	84.5	76.4	72.1	62.5	58.7	51.2	47.6	41.9	38.7	34.4	31.3	25.4	20.6
11/16	0.687	103.7	97.7	93.4	88.5	80.1	75.6	65.5	61.5	53.6	49.9	43.9	40.5	36.0	32.8	26.6	21.6
23/32	0.719	108.4	102.1	97.6	92.6	83.7	79.0	68.5	64.3	56.1	52.1	45.9	42.3	37.6	34.2	27.8	22.6
3/4	0.750	113.1	106.6	101.9	96.6	87.3	82.4	71.4	67.1	58.5	54.4	48.0	44.2	39.3	35.7	29.0	23.6
25/32	0.781	117.8	111.0	106.1	100.6	91.0	85.9	74.4	69.9	60.9	56.7	50.0	46.0	40.9	37.2	30.3	24.5
13/16	0.812	122.5	115.5	110.4	104.6	94.6	89.3	77.4	72.7	63.4	58.9	52.0	47.9	42.5	38.7	31.5	25.5
27/32	0.844	127.2	119.9	114.6	108.6	98.3	92.7	80.4	75.5	65.8	61.2	54.0	49.7	44.2	40.2	32.7	26.5
7/8	0.875	131.9	124.3	118.8	112.7	101.9	96.2	83.3	78.3	68.2	63.5	56.0	51.6	45.8	41.7	33.9	27.5
29/32	0.906	136.6	128.8	123.1	116.7	105.5	99.6	86.3	81.1	70.7	65.8	58.0	53.4	47.5	43.2	35.1	28.5
15/16	0.937	141.3	133.2	127.3	120.7	109.2	103.0	89.3	83.9	73.1	68.0	60.0	55.2	49.1	44.7	36.3	29.4
31/32	0.969	146.0	137.6	131.6	124.7	112.8	106.5	92.3	86.7	75.5	70.3	62.0	57.1	50.8	46.2	37.5	30.4
1	1.000	150.7	142.1	135.8	128.7	116.4	109.9	95.2	89.5	78.0	72.6	64.0	58.9	52.4	47.7	38.7	31.4

Surface Speed of Stock

Tables II and III give surface speeds of stock varying in diameter from 1/64 to 1 inch. All the spindle speeds obtainable on the various sizes of automatic screw machines are included, except a few spindle speeds which are so near to those listed that the variation in the surface speed of the stock would be very slight. For diameters and spindle speeds not listed in the table, it will be an easy matter to find the equivalent surface speed in feet per minute by simple proportion.

TABLE IV. PRINCIPAL DIMENSIONS OF AUTOMATIC SCREW MACHINES

No. of Machine	00	0	2
No. of changes of spindle speeds	12	12	12
Dia. of hole through largest feed finger	5/16"	1/2"	7/8"
Dia. of hole through feed tube	21/64"	17/32"	1 1/32"
Extreme length of feed	2"	3"	4"
Extreme length that can be turned	1 1/4"	1 3/4"	2 1/8"
No. of holes in turret	6	6	6
Dia. of holes in turret	5/8"	3/4"	1"
Dia. of turret	3 5/8"	4"	5"
Greatest length of tool that turret will swing	2 1/4"	3 1/4"	3 7/8"
Least distance bet. turret and collet face	1 5/8"	2 1/2"	2 1/2"
Greatest distance bet. turret and collet face	3"	4 1/4"	6 1/4"
Greatest dia. that turret will swing and clear turret slide	1 5/8"	2 5/8"	2 7/8"
Adjustment of turret	..	..	1"
Movement of cross-slides	1"	1 1/4"	1 3/4"
Distance from center of spindle to floor	46"	46"	46"
Floor space	22" x 40"	23" x 51"	26" x 60"

In Table IV are given the principal dimensions of the Brown & Sharpe automatic screw machines. The dimensions here given will be found useful both by the operator of the machine and the designer of cams and tools for automatic screw machine work.

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No. 51. Principles and Practice of Assembling Machine Tools, Part II.

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No. 53. Use of Logarithms and Logarithmic Tables.

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No. 98. Operation of Machine Tools.—Grinding Machines.

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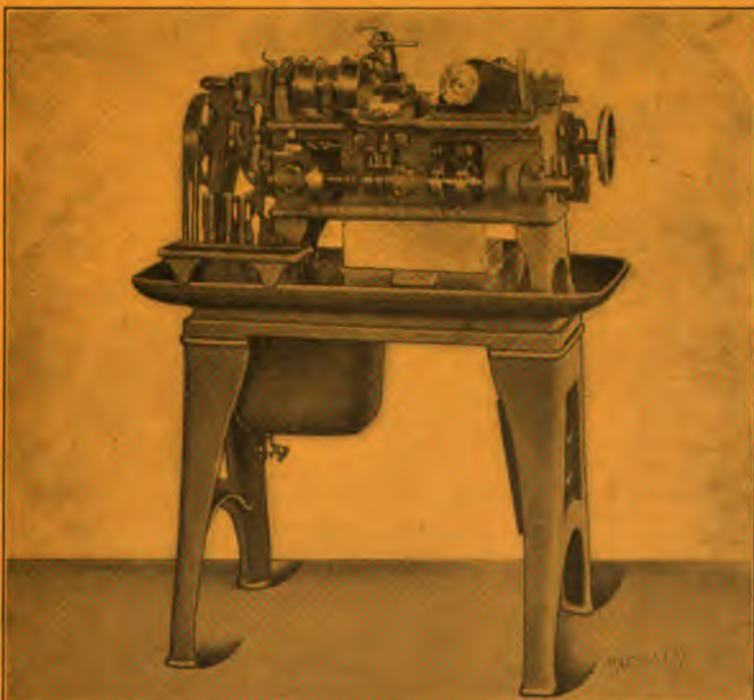

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NUMBER 100

AUTOMATIC SCREW MACHINE PRACTICE

PART II

DESIGNING AND CUTTING CAMS FOR BROWN & SHARPE AUTOMATIC SCREW MACHINES

By DOUGLAS T. HAMILTON

CONTENTS

49-55 Lafayette Street, New York City

Automatic Screw Machine Practice for the Brown & Sharpe automatic screw machines is covered in eight Reference Books, Nos. 99 to 106, inclusive. Reference Book No. 99, "Operation of the Brown & Sharpe Automatic Screw Machines," deals with the construction of these machines and the setting-up of the tools. No. 100, "Designing and Cutting Cams for Automatic Screw Machines," gives detailed instruction on cam design, and describes a simplified method for milling cams. No. 101, "Circular Form and Cut-off Tools for the Automatic Screw Machine," deals with the general arrangement and the calculations of these tools, and describes the different methods employed in their making. No. 102, "External Cutting Tools for the Automatic Screw Machine," deals with the design and construction of box-tools, taper turning tools, hollow mills, and shaving tools. No. 103, "Internal Cutting Tools for the Automatic Screw Machine," deals with centering tools, cross-slide drilling attachments, counterbores, reamers, and recessing tools. No. 104, "Threading Operations on the Automatic Screw Machine," treats on cam design for threading operations, threading dies, taps and tap drills, die and tap holders, and thread rolling. No. 105, "Knurling Operations on the Automatic Screw Machine," describes the construction of knurling holders, and gives directions for the making of knurls and the design of tools and cams used in connection with knurling operations. No. 106, "Milling, Cross-drilling and Burring Operations on the Automatic Screw Machine," describes screw-slotting attachments, index drilling attachments, and burring attachments, giving directions for their use and for the design of cams for them.

CHAPTER I

DESIGNING SCREW MACHINE CAMS

The object of the present chapter is to give the average mechanic and draftsman a clear idea of the methods employed when designing special tools and cams for the Brown & Sharpe automatic screw machine. The first thing to be explained is the change-gear mechanism, as on this are based the fundamental principles used in the construction of the tables for laying out cams. Following this, the construction of the rise and drop on the cams, which is governed by the amount of clearance necessary for one tool to pass another will be treated. Then

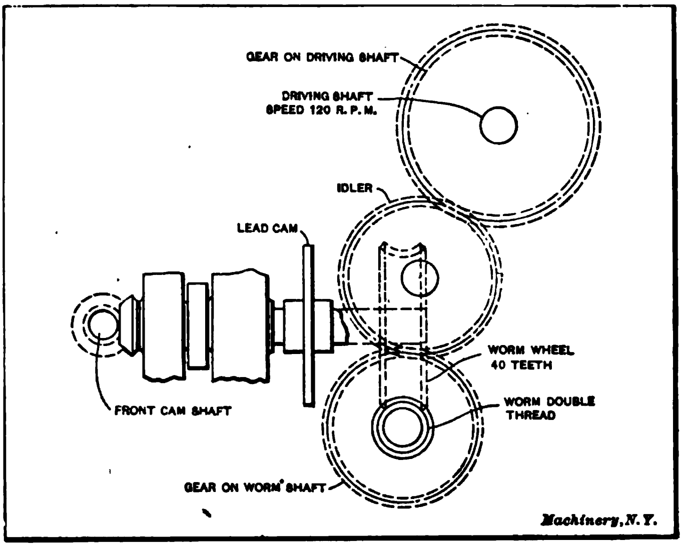


Fig. 1. Diagram of Gearing on the No. 00 Brown & Sharpe Automatic Screw Machine

a number of general points which should be of value especially to those who are not experienced in this class of work, are given.

Change-gear Mechanism

A system of simple gearing is used on the No. 00 Brown & Sharpe automatic screw machine, as clearly shown in Fig. 1. The worm has a double thread; hence for every revolution of the worm, the worm-wheel travels through a distance of two teeth. To find the change gears, assume that it is required to make one piece in 12 seconds. This necessitates that the worm-wheel make one revolution in 12 seconds. As there are 40 teeth in the worm-wheel and the worm has a double thread, the worm shaft will make $40 \div 2$ or 20 revolutions in 12 seconds. The driving shaft runs constantly at 120 R. P. M. or 2 revolutions per second. Then the driving shaft will make 12 × 2 or 24 revolutions in 12 seconds. As, in this case, the driving shaft is required to run the faster, we will put the gear with the smaller number of teeth on that shaft. Now if we have gears having 20 and 24 teeth, respectively, they will "do the trick," but after referring to the gears supplied with the machine we find that a gear with 24 teeth is not available, so multiplying the number of teeth in each by two (which does not change the ratio) the gears will be: 40-tooth gear on driving shaft; 48-tooth gear on worm shaft.

On the No. 0 Brown & Sharpe automatic screw machine there is also one driving and one driven gear, but on this machine the gear

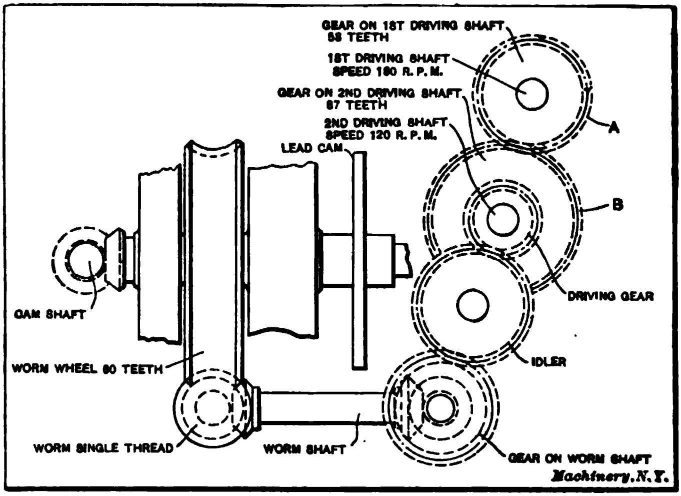


Fig. 2. Diagram of Gearing on the No. 0 Brown & Sharpe Automatic Screw Machine

which is called the driver is placed on the second driving shaft as shown in Fig. 2. Then, before finding the change gears it is necessary to find the speed of the gear on this second driving shaft. The first driving shaft runs constantly at a speed of 180 R. P. M. Then the speed of the second driving shaft $= \dfrac{180 \times 58}{87} = 120$ R. P. M. To find the change gears, assume that it is required to make one piece in 36 seconds. (To obviate confusion, we will call the second driving shaft, which runs at 120 R. P. M., the main driving shaft). Since the cam shaft is to make one revolution in 36 seconds and as there are 60 teeth in the worm-wheel and the worm has a single thead. the worm shaft will make 60 revolutions in 36 seconds. The driving shaft which runs at 120 R. P. M., or two revolutions per second, will make 72 revolutions in 36 seconds. From this we see that the driving shaft is required to run the faster of the two, and, hence, the smaller gear will be put on this shaft. The gears to use could have 60 and 72 teeth, respectively; or, by dividing the number of teeth in each by two, we have 30 and 36 teeth, respectively.

The gears can also be found directly by the formula:

$$\frac{120 \times D}{W} = \frac{3600}{S} \qquad (1)$$

where D = number of teeth in gear on driving shaft,
W = number of teeth in gear on worm shaft,
S = time in seconds to make one piece.

Then, $\frac{120 \times D}{W} = \frac{3600}{36}$ or $120\ D = 100\ W$; $W = 1.2\ D$.

Let $D = 30$. Then $W = 30 \times 1.2 = 36$.

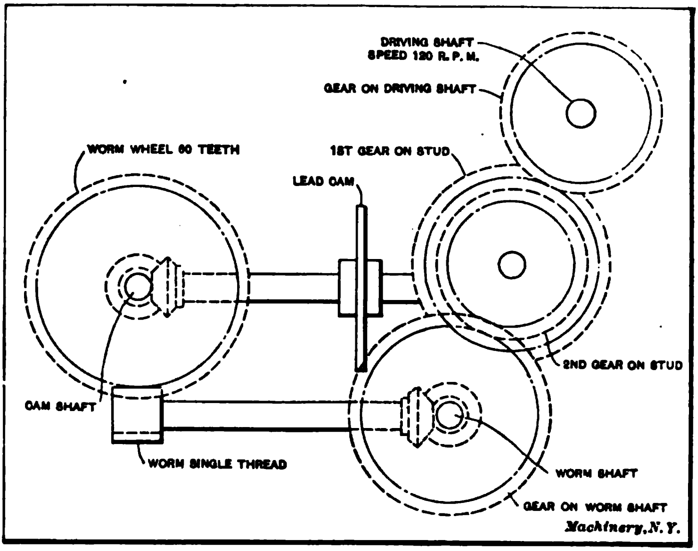


Fig. 3. Diagram of Gearing on the No. 2 Brown & Sharpe Automatic Screw Machine

A system of compound gearing is used on the No. 2 Brown & Sharpe automatic screw machine making it necessary to find the various gears by factoring. To explain the method of finding the gears we will take a practical example. Let it be required to find the gears to make one piece in 28 seconds. Referring to Fig. 3 we find that the speed of the driving shaft is 120 R. P. M. There are 60 teeth in the worm-wheel and the driving worm has a single thread. Thus the cam shaft must make one revolution in 28 seconds. The worm shaft will make 60 revolutions in 28 seconds as the worm has a single thread. The driving shaft makes 2 revolutions per second or 56 revolutions in 28 seconds. It will thus be seen that the worm shaft (or driven shaft) is required to run the faster of the two. Therefore, the product of the number of teeth in the driven gears should be smaller than the product of the number of teeth in the driving gears. The ratio of the gearing equals $\frac{60}{56}$. By dividing the numerator and denominator into factors and multiplying each pair of factors by the same number we find the gears:

$$\frac{60}{56} = \frac{10 \times 6}{4 \times 14} = \frac{(10 \times 8) \times (6 \times 6)}{(4 \times 8) \times (14 \times 6)} = \frac{80 \times 36}{32 \times 84}.$$

Then the gears are as follows:

80, gear on driving shaft; 36, second gear on stud; 32, first gear on stud; 84, gear on worm shaft.

How Tables for Laying out Cams are Constructed

Before a table can be constructed it is necessary to know the range of spindle speeds obtainable and also the speed of the driving shaft. Then the number of seconds to make one piece is placed in the first column of the table, and the number of revolutions to complete one piece is placed under the various spindle speeds as shown in Table I. The total number of revolutions to make one piece is found by the following formula: $r = \frac{R \times S}{60}$, where R = revolutions of spindle per minute (R. P. M.), S = time in seconds to make one piece, and r = total number of revolutions to make one piece. The total number of revolutions to complete one piece can also be found by adding together the number of revolutions required for each operation plus the revolutions required for clearance, feeding the stock, and revolving the turret. The number of seconds to make one piece is found by the following formula:

$$S = \frac{r \times 60}{R}. \qquad (2)$$

The time required to feed stock and revolve the turret on the various Brown & Sharpe automatic screw machines is as follows: No. 2 machine, 1 second; No. 0 machine, 2/3 seconds; No. 00 machine, 1/2 second. The revolutions of the spindle required to feed stock and revolve the turret on the various machines are found by the following formulas:

No. 2 machine, $r_1 = R \div 60$ (3)

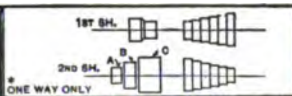
No. 0 machine, $r_1 = R \div 90$ (4)

No. 00 machine, $r_1 = R \div 120$ (5)

where r_1 = revolutions of spindle to feed stock and revolve turret,
R = speed of spindle in revolutions per minute.

Now, to convert the revolutions required to feed stock into hundredths of the cam surface, it is necessary to know the time in seconds required to make one piece and the speed of the spindle. For example, let it be required to construct a table for laying out cams

TABLE I. CHANGE GEARS AND DATA FOR LAYING OUT CAMS.
No. 00 BROWN & SHARPE AUTOMATIC SCREW MACHINE



BELT ON	*A	B	C
Spindle speeds	420	792	1087
	492	927	1273
	576	1087	1492
	675	1273	1748
	792	1492	2048
	927	1748	2400

Number of revolutions to make one piece. Spindle speeds are given in each column head as Min. / Sec. / ½ Sec.

Time in seconds to make one piece.	Gross product in ten hours	Net product in ten hours gross minus 10%	Gears on driving shaft.	1st gear on stud.	2nd gear on stud.	Gear on worm shaft.	Hundredths of cam surface to feed stock	420 / 7 / 3.5	492 / 8.2 / 4.1	576 / 9.6 / 4.8	675 / 11.2 / 5.6	792 / 13.2 / 6.6	927 / 15.4 / 7.7	1087 / 18.1 / 9.1	1273 / 21.2 / 10.6	1492 / 24.8 / 12.4	1748 / 29.1 / 14.6	2048 / 34.1 / 17.1	2400 / 40. / 20.
3	12000	10800	70			21	17	21	25	29	34	40	46	54	64	75	87	102	120
4	9000	8100	50			20	13	28	33	38	45	53	62	72	85	99	117	137	160
5	7200	6400	60			30	10	35	41	48	56	66	77	91	106	124	146	171	200
6	6000	5400	50			30	9	42	49	58	67	79	93	109	127	149	175	205	240
7	5142	4600	60			42	8	49	57	67	79	92	108	127	149	174	204	239	280
8	4500	4000	60			48	7	56	66	77	90	106	124	145	170	199	233	273	320
9	4000	3600	60			54	6	63	74	86	101	119	139	163	191	224	262	307	360
10	3600	3200	40			40	5	70	82	96	112	132	154	181	212	249	291	341	400
11	3272	2900	40			44	5	77	90	106	124	145	170	199	233	274	320	375	440
12	3000	2700	40			48	5	84	98	115	135	158	185	217	255	298	350	410	480
13	2769	2400	40			52	4	91	107	125	146	172	201	236	276	323	379	444	520
14	2571	2300	30			42	4	98	115	134	157	185	216	254	297	348	408	478	560
15	2400	2100	40			60	4	105	123	144	169	198	232	272	318	373	437	512	600
16	2250	2000	30			48	4	112	131	154	180	211	247	290	339	398	466	546	640
17	2117	1900	20			34	3	119	139	163	191	224	263	308	361	423	495	580	680
18	2000	1800	30			54	3	126	148	173	202	238	278	326	382	448	524	614	720
19	1894	1700	20			38	3	133	156	182	214	251	294	344	403	472	554	649	760
20	1800	1600	20			40	3	140	164	192	225	264	309	362	424	497	583	683	800
21	1714	1500	20			42	3	147	172	202	236	277	324	380	446	522	612	717	840
22	1636	1450	20			44	3	154	180	211	247	290	340	399	467	547	641	751	880
23	1565	1400	20			46	3	161	189	221	259	304	355	417	488	572	670	785	920
24	1500	1350	20			48	3	168	197	230	270	317	371	435	509	597	699	819	960
25	1440	1300	20			50	3	175	205	240	281	330	386	453	530	622	728	853	1000
26	1384	1250	20			52	3	182	213	250	292	343	402	471	552	647	757	887	1040
27	1333	1200	20			54	3	189	221	259	304	356	417	489	573	671	787	922	1080
28	1285	1150	20			56	3	196	230	269	315	370	433	507	594	696	816	956	1120
29	1241	1100	20			58	3	203	238	278	326	383	448	525	615	721	845	990	1160
30	1200	1050	20			60	3	210	246	288	337	396	463	543	636	746	874	1024	1200
32	1125	1000	30	30	48	60	3	224	262	307	360	422	494	580	679	796	932	1092	1280
34	1050	950	20	44	50	60	3	238	279	326	383	449	525	616	721	846	990	1161	1360
36	1000	900	30	30	54	60	3	252	295	346	405	475	556	652	764	895	1049	1229	1440
38	947	850	20	30	38	60	3	266	312	365	428	502	587	688	806	945	1107	1297	1520
40	900	800	20	30	40	60	3	280	328	384	450	528	618	724	849	995	1165	1365	1600
42	857	775	20	30	42	60	3	294	344	403	473	554	649	761	891	1045	1224	1434	1680
44	818	725	20	30	44	60	3	308	361	422	495	581	680	797	934	1094	1282	1502	1760
46	782	700	20	30	46	60	3	322	377	442	518	607	711	833	976	1144	1340	1570	1840
48	750	675	20	30	48	60	3	336	394	461	540	634	742	870	1018	1194	1398	1638	1920
50	720	650	20	30	50	60	3	350	410	480	563	660	773	906	1061	1243	1457	1707	2000
52	692	620	20	30	52	60	3	364	426	499	585	686	803	942	1103	1293	1515	1775	2080
54	666	600	20	30	54	60	3	378	443	518	608	713	834	978	1146	1343	1573	1843	2160
56	642	575	20	30	56	60	3	392	459	538	630	739	865	1015	1188	1393	1631	1911	2240
58	620	550	20	30	58	60	3	406	476	557	653	766	896	1051	1231	1442	1690	1980	2320
60	600	525	30	21	54	70	3	420	492	576	675	792	927	1087	1273	1492	1748	2048	2400
63	571	500	30	20	54	70	3	441	517	605	709	832	973	1141	1337	1567	1835	2150	2520
70	514	450	20	20	40	70	3	490	574	672	788	924	1082	1268	1485	1741	2039	2389	2800
77	467	420	20	20	44	70	3	539	631	739	866	1016	1190	1395	1634	1915	2243	2628	3080
84	428	385	20	20	48	70	3	588	689	806	945	1109	1298	1522	1782	2089	2447	2867	3360
91	395	355	20	20	52	70	3	637	746	871	1024	1201	1406	1649	1931	2263	2651	3106	3640

The number of hundredths given is always sufficient for feeding stock, but it is usually best to add 1-100 for revolving the Turret.

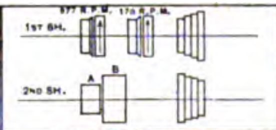
for the No. 2 Brown & Sharpe automatic screw machine. For a spindle speed of 182 R. P. M., as shown in Table III (assuming that it takes 10 seconds to make one piece), we find:

$$r = \frac{R \times S}{60} = \frac{182 \times 10}{60} = 30.3$$

or approximately 30 revolutions. We now put 30 revolutions in the

TABLE II. CHANGE GEARS AND DATA FOR LAYING OUT CAMS. No. 0 BROWN & SHARPE AUTOMATIC SCREW MACHINE

FEED GEARS



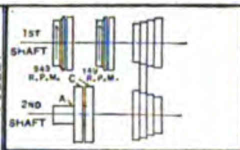
Time in Seconds to Make One Piece	Gross Product in Ten Hours	Net Product in Ten Hours Gross Minus 10%	Gear on A	1st Gear on B	2nd Gear on B	Gear on C	Hundredths of Cam Surface to Feed Stock	Number of Revolutions to Make One Piece											
							Spindle Speeds Min.	200	244	298	364	445	543	663	810	988	1207	1474	1800
							Sec.	3.3	4.1	4.9	6.1	7.4	9.1	11.1	13.5	16.4	20.1	24.5	30
							1 Sec.	2.2	2.7	3.3	4.	4.9	6.	7.3	9.	10.9	13.4	16.3	20.
							Spindle Speeds, Belt to Mach. on Pulley A / B: Fast					445	543	663	810	988	1207	1474	1800
							Slow					200	244	298	364	445	543	663	810
5	7200	6400	58	86	120	20	14	17	20	25	30	37	45	55	67	82	101	123	150
6	6000	5400	58	86	120	24	12	20	24	30	36	44	54	66	81	99	121	147	180
7	5142	4600	58	86	120	28	10	23	28	35	42	52	63	77	94	115	141	172	210
8	4500	4000	58	86	120	32	9	27	33	40	49	59	72	88	108	132	161	197	240
9	4000	3600	58	86	80	24	8	30	37	45	55	67	81	99	121	148	181	221	270
10	3600	3200	58	86	120	40	7	33	41	50	61	74	90	110	135	165	201	246	300
11	3272	2900	58	86	60	22	7	37	45	55	67	82	100	122	148	181	221	270	330
12	3000	2700	58	86	60	24	6	40	49	60	73	89	109	133	162	198	241	295	360
13	2769	2400	34	110	120	24	6	43	53	65	79	96	118	144	175	214	262	319	390
14	2571	2300	58	86	60	28	5	47	57	70	85	104	127	155	189	231	282	344	420
15	2400	2100	58	86	60	30	5	50	61	74	91	111	136	166	202	247	302	368	450
16	2250	2000	58	86	60	32	5	53	65	79	97	119	145	177	216	263	322	393	480
17	2117	1900	58	86	60	34	4	57	69	84	103	126	154	188	229	280	342	418	510
18	2000	1800	58	86	40	24	4	60	73	89	109	133	163	199	243	296	362	442	540
19	1894	1700	58	86	60	38	4	63	77	94	115	141	172	210	256	313	382	467	570
20	1800	1600	58	86	60	40	4	67	81	99	121	148	181	221	270	329	402	491	600
22	1636	1450	58	86	30	22	4	73	89	109	133	163	199	243	297	362	443	540	660
24	1500	1350	58	86	40	32	3	80	98	119	146	178	217	265	324	395	483	590	720
26	1384	1250	34	110	60	24	3	87	106	129	158	193	235	287	351	428	523	639	780
28	1285	1150	58	86	30	28	3	93	114	139	170	208	253	309	378	461	563	688	840
30	1200	1050	58	86	60	60	3	100	122	149	182	222	271	331	405	494	603	737	900
32	1125	1000	58	86	30	32	3	107	130	159	194	237	290	354	432	527	644	786	960
34	1059	950	58	86	30	34	3	113	138	169	206	252	308	376	459	560	684	835	1020
36	1000	900	58	86	20	24	3	120	146	179	218	267	326	398	486	593	724	884	1080
38	947	850	58	86	30	38	3	127	155	189	231	282	344	420	513	626	764	934	1140
40	900	800	58	86	30	40	3	133	163	199	243	297	362	442	540	659	805	983	1200
44	818	725	34	110	32	22	3	147	179	218	267	326	398	486	594	725	885	1081	1320
48	750	675	58	86	20	32	3	160	195	238	291	356	434	530	648	790	966	1179	1440
52	692	626	34	110	30	24	3	173	211	258	315	385	471	575	702	856	1046	1277	1560
56	642	575	58	86	32	60	3	187	228	278	340	415	507	619	756	922	1127	1376	1680
60	600	525	58	86	30	60	3	200	244	298	364	445	543	663	810	988	1207	1474	1800
65	553	490	34	110	60	60	3	217	264	323	394	482	588	718	877	1070	1308	1597	1950
70	514	450	34	110	80	86	3	233	285	348	424	519	633	773	945	1153	1408	1720	2100
75	480	430	58	86	24	60	3	250	305	372	455	556	679	829	1012	1235	1509	1842	2250
80	450	400	58	86	30	80	3	267	325	397	485	593	724	884	1080	1317	1609	1965	2400
90	400	360	58	86	20	60	3	300	366	447	546	667	814	994	1215	1482	1810	2211	2700
100	360	320	58	86	24	80	3	333	407	497	607	742	905	1105	1350	1647	2012	2457	3000
110	327	290	58	86	30	110	3	367	447	546	667	816	995	1215	1485	1811	2213	2702	3300
120	300	270	58	86	20	80	3	400	488	596	728	890	1086	1326	1620	1976	2414	2948	3600
135	266	235	58	86	20	90	3	450	549	670	819	1001	1722	1492	1823	2223	2716	3316	4050
150	240	215	58	86	24	120	3	500	610	745	910	1112	1358	1658	2025	2470	3017	3685	4500
165	218	195	58	86	20	110	3	550	671	819	1001	1224	1493	1823	2228	2717	3319	4053	4950
180	200	180	58	86	20	120	3	600	732	894	1092	1335	1629	1989	2430	2964	3621	4422	5400
195	184	165	34	110	30	90	3	650	793	968	1183	1446	1765	2155	2633	3211	3923	4790	5850
210	171	150	34	110	28	90	3	700	854	1043	1274	1557	1901	2321	2835	3458	4224	5159	6300
225	160	140	34	110	26	90	3	750	915	1117	1365	1669	2036	2486	3038	3705	4526	5527	6750
240	150	135	34	110	24	90	3	800	976	1192	1456	1780	2172	2652	3240	3952	4828	5896	7200
270	133	120	34	110	22	90	3	900	1098	1341	1638	2002	2444	2984	3645	4446	5431	6633	8100
300	120	105	34	110	26	120	3	1000	1220	1490	1820	2225	2715	3315	4050	4940	6035	7370	9000
330	109	100	34	110	24	120	3	1100	1342	1639	2002	2447	2987	3647	4455	5434	6638	8107	9900
360	100	90	34	110	22	120	3	1200	1464	1788	2184	2670	3258	3978	4860	5928	7242	8844	10800
390	92	80	34	110	20	120	3	1300	1586	1937	2366	2892	3530	4310	5265	6422	7845	9581	11700

column under 182 as shown, and proceed to find the revolutions to feed stock, which according to Formula (3) equals:

$$R \div 60 = 182 \div 60 = 3.03 \text{ revolutions.}$$

Now, to find the hundredths of the cam surface to feed stock, divide the revolutions to feed stock by the total revolutions of the spindle required to make one piece. In this case we find that it requires $\frac{3.03}{30.3} = 0.099$ or approximately 10 hundredths. It is always advisable

TABLE III. CHANGE GEARS AND DATA FOR LAYING OUT CAMS.
No. 2 BROWN & SHARPE AUTOMATIC SCREW MACHINE



SPINDLE SPEEDS: Belt to mach. on pulley	A				C			
FAST	277	342	421	519	640	789	973	1200
SLOW	120	148	182	225	277	342	421	519

Time in seconds to make one piece	Gross product in 10 hours	Net product in 10 hours gross minus 10%	Gear on driving shaft	1st gear on stud	2nd gear on stud	Gear on worm shaft	Hundredths of cam surface to feed stock	Number of revolutions to make one piece — Spindle speeds: Sec. 2, Min. 120	Sec. 2.467, Min. 148	Sec. 3.033, Min. 182	Sec. 3.75, Min. 225	Sec. 4.617, Min. 277	Sec. 5.7, Min. 342	Sec. 7.017, Min. 421	Sec. 8.65, Min. 519	Sec. 10.667, Min. 640	Sec. 13.15, Min. 789	Sec. 16.217, Min. 973	Sec. 20, Min. 1200
6	6000	5400	80	32	80	40	17	12	15	18	22	28	34	42	52	64	79	97	120
7	5142	4600	80	32	72	42	15	14	17	21	26	32	40	49	61	75	92	114	140
8	4500	4000	80	32	72	48	13	16	20	24	30	37	46	56	69	85	105	130	160
9	4000	3600	80	32	72	54	12	18	22	27	34	42	51	63	78	96	118	146	180
10	3600	3200	80	32	72	60	10	20	25	30	37	46	57	70	86	107	131	162	200
11	3272	2900	80	32	84	77	10	22	27	33	41	51	63	77	95	117	145	178	220
12	3000	2700	80	32	60	60	9	24	30	36	45	55	68	84	104	128	158	195	240
13	2769	2400	80	32	72	78	9	26	32	39	49	60	74	91	112	139	171	211	260
14	2571	2300	80	32	60	70	8	28	35	42	52	65	80	98	121	149	184	227	280
16	2250	2000	80	32	60	80	7	32	39	49	60	74	91	112	138	171	210	259	320
18	2000	1800	80	32	48	72	6	36	44	55	67	84	103	126	156	192	237	292	360
20	1800	1600	80	32	48	80	5	40	49	61	75	92	114	140	173	213	263	324	400
22	1636	1450	80	32	42	77	5	44	54	67	82	102	125	154	190	235	289	357	440
24	1500	1350	80	32	40	80	5	48	59	73	90	111	137	168	208	256	116	389	480
26	1384	1250	80	32	36	78	4	52	64	79	97	120	148	182	225	277	342	422	520
28	1285	1150	80	32	36	84	4	56	69	85	105	129	160	196	242	299	368	454	560
30	1200	1050	60	60	80	80	4	60	74	91	112	138	171	210	259	320	394	486	600
35	1028	925	60	60	72	84	3	70	87	106	131	162	199	246	303	373	460	568	700
40	900	800	60	60	54	72	3	80	99	121	150	185	228	281	346	427	526	649	800
45	800	700	60	60	48	72	3	90	111	136	169	208	256	316	389	480	592	730	900
50	720	625	60	60	48	80	3	100	124	152	187	231	285	351	432	533	657	811	1000
55	654	575	60	60	42	77	3	110	136	167	206	254	313	386	476	587	723	892	1100
60	600	525	40	80	60	60	3	120	148	182	225	277	342	421	519	640	789	973	1200
70	514	450	40	80	60	70	3	140	173	212	262	323	399	491	605	747	920	1135	1400
80	450	400	40	80	54	72	3	160	198	243	300	369	456	561	692	853	1052	1297	1600
90	400	350	40	80	48	72	3	180	222	273	337	415	513	631	778	960	1183	1459	1800
100	360	300	40	80	48	80	3	200	247	303	375	462	570	702	865	1067	1315	1622	2000
110	327	290	40	80	42	77	3	220	272	334	412	508	627	772	951	1173	1446	1784	2200
120	300	270	40	80	40	80	3	240	296	364	450	554	684	842	1038	1280	1578	1946	2400
135	266	240	36	72	40	90	3	270	333	409	506	623	769	947	1168	1440	1775	2189	2700
150	240	210	36	80	40	90	3	300	370	455	562	692	855	1052	1297	1600	1972	2432	3000
165	218	190	36	77	35	90	3	330	407	500	619	752	940	1158	1427	1760	2170	2675	3300
180	200	180	36	84	35	90	3	360	444	546	675	831	1026	1263	1557	1920	2367	2919	3600
195	184	160	32	78	36	96	3	390	481	591	731	900	1112	1368	1687	2080	2564	3162	3900
210	171	150	24	80	40	84	3	420	518	637	788	970	1197	1474	1817	2240	2762	3406	4200
225	160	140	32	90	36	96	3	450	555	682	844	1039	1283	1579	1946	2400	2959	3649	4500
240	150	135	24	80	40	96	3	480	592	728	900	1108	1368	1684	2076	2560	3156	3892	4800
270	133	120	32	72	24	96	3	540	666	819	1013	1247	1539	1895	2336	2880	3551	4379	5400
300	120	105	24	80	32	96	3	600	740	910	1125	1385	1710	2105	2595	3200	3945	4865	6000
330	109	95	24	88	32	96	3	660	814	1001	1238	1524	1881	2316	2855	3520	4340	5352	6600
360	100	90	22	88	32	96	3	720	888	1092	1350	1662	2052	2526	3114	3840	4734	5838	7200
390	92	80	24	78	24	96	3	780	962	1183	1463	1801	2223	2737	3374	4160	5129	6325	7800
420	85	75	24	84	24	96	3	840	1036	1274	1575	1939	2394	2947	3633	4480	5523	6811	8400
450	80	70	24	90	24	96	3	900	1110	1365	1688	2078	2565	3158	3893	4800	5918	7298	9000
450	75	65	24	88	22	96	3	960	1184	1456	1800	2216	2736	3368	4152	5120	6312	7784	9600

to add one hundredth for revolving the turret so that it will be securely locked in position before the tools advance on the work; then in this case it will require 11 hundredths to revolve the turret. Owing to the diameter of the cam roll there should never be less than three hundredths allowed for revolving the turret, irrespective of the speed at which the cam shaft is running.

Tables I to III give the change gears and data for laying out cams for the Nos. 00, 0 and 2 automatic screw machines. When the speed at

TABLE IV. CHANGE GEARS AND DATA FOR LAYING OUT CAMS. No. 00 TURRET FORMING AND CUTTING-OFF MACHINE

Time in Seconds to Make One Piece.	Gross Product in Ten Hours.	Net Product in Ten Hours. Gross minus 10%	Gear on Driving Shaft.	1st Gear on Stud.	2nd Gear on Stud.	Gear on Worm Shaft	Hundredths of Cam Surface to Feed Stock.	Spindle Speeds.							
							Min.	420	540	690	890	1140	1460	1870	2400
							Sec.	7	9	11½	15	19	24⅓	31	40
							½ Sec.	3½	4½	6	7½	9½	12	15½	20
								Number of Revolutions to Make One Piece							
3	12000	10800	70			21	17	21	27	34	44	57	73	93	120
4	9000	8100	50			20	13	28	36	46	59	76	97	125	160
5	7200	6400	60			30	10	35	45	58	74	95	122	156	200
6	6000	5400	50			30	9	42	54	69	89	114	146	187	240
7	5142	4600	60			42	8	49	63	81	104	133	170	218	280
8	4500	4000	60			48	7	56	72	92	119	152	195	249	320
9	4000	3600	60			54	6	63	81	104	134	171	219	280	360
10	3600	3200	40			40	5	70	90	115	148	190	243	312	400
11	3272	2900	40			44	5	77	99	127	163	209	268	343	440
12	3000	2700	40			48	5	84	108	138	178	228	292	374	480
13	2769	2400	40			52	4	91	117	150	193	247	316	405	520
14	2571	2300	30			42	4	98	126	161	208	266	341	436	560
15	2400	2100	40			60	4	105	135	173	222	285	365	467	600
16	2250	2000	30			48	4	112	144	184	237	304	389	499	640
17	2117	1900	20			34	3	119	153	196	252	323	414	530	680
18	2000	1800	30			54	3	126	162	207	267	342	438	561	720
19	1894	1700	20			38	3	133	171	219	282	361	462	592	760
20	1800	1600	20			40	3	140	180	230	297	380	487	623	800
21	1714	1500	20			42	3	147	189	242	311	399	511	654	840
22	1636	1450	20			44	3	154	198	253	326	418	535	686	880
23	1565	1400	20			46	3	161	207	265	341	437	560	717	920
24	1500	1350	20			48	3	168	216	276	356	456	584	748	960
25	1440	1300	20			50	3	175	225	288	371	475	608	779	1000
26	1384	1250	20			52	3	182	234	299	386	494	633	810	1040
27	1333	1200	20			54	3	189	243	311	400	513	657	841	1080
28	1285	1150	20			56	3	196	252	322	415	532	681	872	1120
29	1241	1100	20			58	3	203	261	334	430	551	706	904	1160
30	1200	1050	20			60	3	210	270	345	445	570	730	935	1200
32	1125	1000	30	30	48	60	3	224	288	368	475	608	779	997	1280
34	1050	950	20	44	50	60	3	238	306	391	504	646	827	1060	1360
36	1000	900	30	30	54	60	3	252	324	414	534	684	876	1122	1440
38	947	850	20	30	38	60	3	266	342	437	564	722	925	1184	1520
40	900	800	20	30	40	60	3	280	360	460	593	760	973	1247	1600
42	857	775	20	30	42	60	3	294	378	483	623	798	1022	1309	1680
44	818	725	20	30	44	60	3	308	396	506	653	836	1071	1371	1760
46	782	700	20	30	46	60	3	322	414	529	682	874	1119	1434	1840
48	750	675	20	30	48	60	3	336	432	552	712	912	1168	1496	1920
50	720	650	20	30	50	60	3	350	450	575	742	950	1217	1558	2000
52	692	620	20	30	52	60	3	364	468	598	771	998	1265	1621	2080
54	656	600	20	30	54	60	3	378	486	621	801	1026	1314	1683	2160
56	642	575	20	30	56	60	3	392	504	644	831	1064	1363	1745	2240
58	620	550	20	30	58	60	3	406	522	667	860	1102	1411	1808	2320
60	600	525	30	21	54	70	3	420	540	690	890	1140	1460	1870	2400
63	571	500	30	20	54	70	3	441	567	725	935	1197	1533	1953	2520
70	514	450	20	20	40	70	3	490	630	805	1038	1330	1703	2182	2800
77	467	420	20	20	44	70	3	539	693	886	1142	1463	1874	2400	3080
84	428	385	20	20	48	70	3	588	756	966	1246	1596	2044	2618	3360
91	395	355	20	20	52	70	3	637	819	1047	1350	1729	2214	2836	3640

which the spindle is to be run for any certain job, and the number of revolutions required to complete one piece, are known, the gears, product in ten hours and the time in seconds to make one piece as well as the number of hundredths of the cam surface required to feed the stock and revolve the turret, are found in the left-hand columns of the table, the total revolutions required to make one piece being given in the

TABLE V. CHANGE GEARS AND DATA FOR LAYING OUT CAMS. No. 0 TURRET FORMING AND CUTTING-OFF MACHINE

NUMBER OF REVOLUTIONS TO MAKE ONE PIECE (under Spindle Speeds)

Time in Seconds to Make One Piece	Gross Product in Ten Hours.	Net Product in Ten Hours, Gross Minus 10%	Gear on Driving Shaft.	1st Gear on Stud	2nd Gear on Stud	Gear on Worm Shaft	Hundredths of Cam Surface to Feed Stock.	Spindle Speeds. Min. 300 / Sec. 5. / 2/3 Sec. 3.3	Min. 429 / Sec. 7.2 / 2/3 Sec. 4.8	Min. 614 / Sec. 10.2 / 2/3 Sec. 6.8	Min. 879 / Sec. 14.7 / 2/3 Sec. 9.8	Min. 1258 / Sec. 21. / 2/3 Sec. 14.	Min. 1800 / Sec. 30. / 2/3 Sec. 20.
5	7200	6400	58	86	120	20	14	25	36	51	73	105	150
6	6000	5400	58	86	120	24	12	30	43	61	88	126	180
7	5142	4600	58	86	120	28	10	35	50	72	103	147	210
8	4500	4000	58	86	120	32	9	40	57	82	117	168	240
9	4000	3600	58	86	80	24	8	45	64	92	132	189	270
10	3600	3200	58	86	120	40	7	50	72	102	147	210	300
11	3272	2900	58	86	60	22	7	55	79	113	161	231	330
12	3000	2700	58	86	60	24	6	60	86	123	176	252	360
13	2769	2400	34	110	120	24	6	65	93	133	190	273	390
14	2571	2300	58	86	60	28	5	70	100	143	205	294	420
15	2400	2100	58	86	60	30	5	75	107	153	220	315	450
16	2250	2000	58	86	60	32	5	80	114	164	234	335	480
17	2117	1900	58	86	60	34	4	85	122	174	249	356	510
18	2000	1800	58	86	40	24	4	90	129	184	264	377	540
19	1894	1700	58	86	60	38	4	95	136	194	278	398	570
20	1800	1600	58	86	60	40	4	100	143	205	293	419	600
22	1636	1450	58	86	30	22	4	110	157	225	322	461	660
24	1500	1350	58	86	40	32	3	120	172	246	352	503	720
26	1384	1250	34	110	60	24	3	130	186	266	381	545	780
28	1285	1150	58	86	30	28	3	140	200	287	410	587	840
30	1200	1050	58	86	60	60	3	150	215	307	440	629	900
32	1125	1000	58	86	30	32	3	160	229	327	469	671	960
34	1059	950	58	86	30	34	3	170	243	348	498	713	1020
36	1000	900	58	86	20	24	3	180	257	368	527	755	1080
38	947	850	58	86	30	38	3	190	272	389	557	797	1140
40	900	800	58	86	30	40	3	200	286	409	586	839	1200
44	818	725	34	110	32	22	3	220	315	450	645	923	1320
48	750	675	58	86	20	32	3	240	343	491	703	1006	1440
52	692	620	34	110	30	24	3	260	372	532	762	1090	1560
56	642	575	58	86	32	60	3	280	400	573	820	1174	1680
60	600	525	58	86	30	60	3	300	429	614	879	1258	1800
65	553	490	34	110	60	60	3	325	465	665	952	1363	1950
70	514	450	34	110	80	86	3	350	501	716	1026	1468	2100
75	480	430	58	86	24	60	3	375	536	767	1099	1573	2250
80	450	400	58	86	30	80	3	400	572	819	1172	1677	2400
90	400	360	58	86	20	60	3	450	644	921	1319	1887	2700
100	360	320	58	86	24	80	3	500	715	1023	1465	2097	3000
110	327	290	58	86	30	110	3	550	787	1126	1612	2306	3300
120	300	270	58	86	20	80	3	600	858	1228	1758	2516	3600
135	266	235	58	86	20	90	3	675	965	1381	1978	2831	4050
150	240	215	58	86	24	120	3	750	1073	1535	2198	3145	4500
165	218	195	58	86	20	110	3	825	1180	1688	2417	3460	4950
180	200	180	58	86	20	120	3	900	1287	1842	2637	3774	5400
195	184	165	34	110	30	90	3	975	1394	1995	2857	4089	5850
210	171	150	34	110	28	90	3	1050	1502	2149	3077	4403	6300
225	160	140	34	110	26	90	3	1125	1609	2302	3296	4718	6750
240	150	135	34	110	24	90	3	1200	1716	2456	3516	5032	7200
270	133	120	34	110	22	90	3	1350	1931	2763	3956	5661	8100
300	120	105	34	110	26	120	3	1500	2145	3070	4395	6290	9000
330	109	100	34	110	24	120	3	1650	2360	3377	4835	6919	9900
360	100	90	34	110	22	120	3	1800	2574	3684	5274	7548	10800
390	92	80	34	110	20	120	3	1950	2789	3991	5714	8177	11700

right-hand columns. Tables IV to VI give the change gears and data for laying out cams for the Nos. 00, 0 and 2 turret forming and cutting-off machines. The same remarks apply to these as to the preceding tables.

The principal dimensions for the plate cams and the radii of the cross-slide and lead levers on the Nos. 00, 0 and 2 automatic screw machines, are given in Table VII. For notation see the illustration accompanying the table.

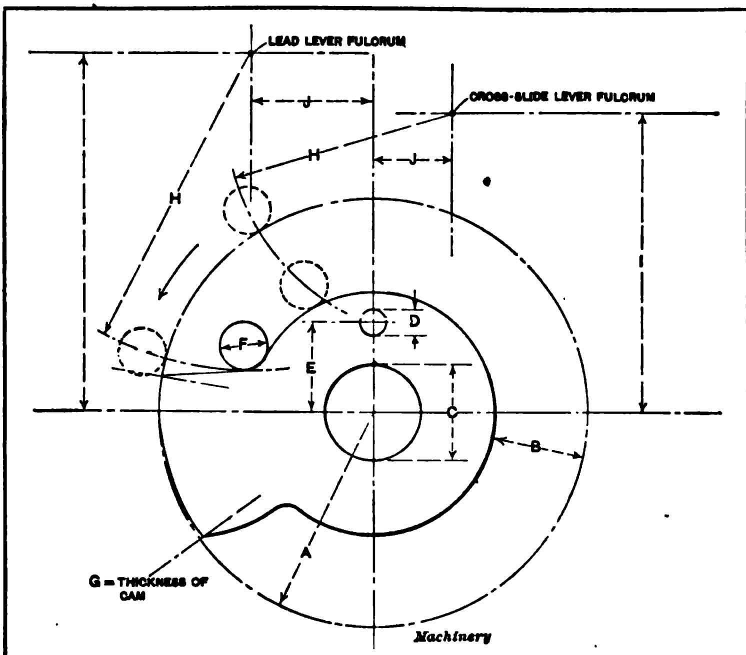
TABLE VI. CHANGE GEARS AND DATA FOR LAYING OUT CAMS.
No. 2 TURRET FORMING AND CUTTING-OFF MACHINE

Time in Seconds to Make One Piece.	Gross Product in 10 Hours.	Net Product in 10 Hours-Gross Minus 10%	Gear on Driving Shaft.	1st Gear on Stud.	2nd Gear on Stud.	Gear on Worm Shaft	Hundredths of Cam Surface to Feed Stock.	Spindle Speeds. Sec. / Min.			3 / 180	4.38 / 263	6.42 / 385	9.37 / 562	13.68 / 821	20 / 1200
6	6000	5400	80	32	80	40	17	NUMBER OF REVOLUTIONS TO MAKE ONE PIECE.			18	26	39	56	82	120
7	5142	4600	80	32	72	42	15				21	31	45	66	96	140
8	4500	4000	80	32	72	48	13				24	35	51	75	109	160
9	4000	3600	80	32	72	54	12				27	39	58	84	123	180
10	3600	3200	80	32	72	60	10				30	44	64	94	137	200
11	3272	2900	80	32	84	77	10				33	48	71	103	151	220
12	3000	2700	80	32	60	60	9				36	53	77	112	164	240
13	2769	2400	80	32	72	78	9				39	57	83	122	178	260
14	2571	2300	80	32	60	70	8				42	61	90	131	192	280
16	2250	2000	80	32	60	80	7				48	70	103	150	219	320
18	2000	1800	80	32	48	72	6				54	79	116	169	246	360
20	1800	1600	80	32	48	80	5				60	88	128	187	274	400
22	1636	1450	80	32	42	77	5				66	96	141	206	301	440
24	1500	1350	80	32	40	80	5				72	105	154	225	328	480
26	1384	1250	80	32	36	78	4				78	114	167	244	356	520
28	1285	1150	80	32	36	84	4				84	123	180	262	383	560
30	1200	1050	60	60	80	80	4				90	131	193	281	410	600
35	1028	925	60	60	72	84	3				105	153	225	328	479	700
40	900	800	60	60	54	72	3				120	175	257	375	547	800
45	800	700	60	60	48	72	3				135	197	289	422	616	900
50	720	625	60	60	48	80	3				150	219	321	468	684	1000
55	654	575	60	60	42	77	3				165	241	353	515	753	1100
60	600	525	40	80	60	60	3				180	263	385	562	821	1200
70	514	450	40	80	60	70	3				210	307	449	656	958	1400
80	450	400	40	89	54	72	3				240	351	513	749	1095	1600
90	400	350	40	80	48	72	3				270	394	577	843	1231	1800
100	360	300	40	80	48	80	3				300	438	642	937	1368	2000
110	327	290	40	80	42	77	3				330	482	706	1030	1505	2200
120	300	270	40	80	40	80	3				360	526	770	1124	1642	2400
135	266	240	36	72	40	90	3				405	592	866	1265	1847	2700
150	240	210	36	80	40	90	3				450	657	963	1405	2052	3000
165	218	190	36	77	35	90	3				495	723	1059	1546	2258	3300
180	200	180	36	84	35	90	3				540	789	1155	1686	2463	3600
195	184	160	32	78	36	96	3				585	855	1251	1827	2668	3900
210	171	150	24	80	40	84	3				630	920	1348	1967	2873	4200
225	160	140	32	90	36	96	3				675	986	1444	2108	3079	4500
240	150	135	24	80	40	96	3				720	1052	1540	2248	3284	4800
270	133	120	32	72	24	96	3				810	1183	1733	2529	3694	5400
300	120	105	24	80	32	96	3				900	1315	1925	2810	4105	6000
330	109	95	24	88	32	96	3				990	1446	2118	3091	4515	6600
360	100	90	22	88	32	96	3				1080	1578	2310	3372	4926	7200
390	92	80	24	78	24	96	3				1170	1709	2503	3653	5336	7800
420	85	75	24	84	24	96	3				1260	1841	2695	3934	5747	8400
450	80	70	24	90	24	96	3				1350	1972	2888	4215	6157	9000
480	75	65	24	88	22	96	3				1440	2104	3080	4496	6568	9600

Constructing the Rise on Cams

The rise on the cam should be such that the tools will gradually slow up as they approach the work. It is not necessary to lay out a uniform curve for the rise, as in most cases the cam rotates slowly, but when the cam is required to make one revolution in less than 5 seconds on the No. 0 or No. 2 screw machine, a curve for a more uniform speed should be constructed.

TABLE VII. DIMENSIONS OF CAMS AND CAM LEVERS



No. of Machine	00		0		2	
Principal Dimensions	Lead	Cross-slide	Lead	Cross-slide	Lead	Cross-slide
	Dimensions in Inches					
A	2 1/2	2 1/4	3 1/4	3	4	3 1/2
B	1 5/8	1	2	1 1/4	2 3/4	1 3/4
C	1	1	1 1/8	1 1/8	1 1/4	1 1/4
D	1/4	1/4	5/16	5/16	5/16	5/16
E	15/16	15/16	1	1	1 1/16	1 1/16
F	1/2	1/2	9/16	9/16	5/8	5/8
G	1/4	1/4	5/16	5/16	3/8	3/8
H	3 5/16	2 5/8	3 3/4	2 3/4	4.5	3.088
I	3 13/16	3 1/8	4 3/4	3 11/16	4.208	4 1/4
J	1 1/4	7/8	1/2	1 3/4	3 1/2	1 5/8

Generally the rise can be abrupt for about three-quarters of the way, and then gradually slow down as the tool approaches the work. A good method of laying out a curve of this form is shown in Fig. 4. The reason for making a curve of this form is that less time is necessary for one tool to clear another, which sometimes makes quite a considerable difference in the time required to produce one piece

To construct the rise, proceed as follows: Lay off on line *H* a distance *D* from the point *a*. Distance *D* varies with the clearance necessary between the turret and cross-slide tools. Then draw line *BC* at right angles to *H*. With *a* as a center, and a radius *R* describe an arc intersecting line *BC* at point *b*; again with *R* as a radius, and a center at *b*, describe the rise. Join the rise and the small diameter dwell of

TABLE VIII. DIMENSIONS FOR LAYING OUT CAM RISE FOR No. 00 BROWN & SHARPE AUTOMATIC SCREW MACHINE

Number of Seconds to make one Piece	Lead	Front and Back Cams
	D	R
From 3 to 5 seconds............	23/32	1 1/8
From 6 to 12 seconds........	3/4	1 1/4
From 13 to 30 seconds............	5/8	1 1/4

the cam with a circle having a diameter equal to the diameter of the roll. The distance *r* should then be measured off and recorded on the drawing to be used by the toolmaker when laying out the cams. The various values for the dimensions given in Fig. 4 for the rise, that have been found suitable, are specified in Tables VIII, IX and X.

Constructing Drop on Cams

The drop on the cams should be such that the cross-slides will drop back without shock. The turret slide drops back on a cushion spring,

TABLE IX. DIMENSIONS FOR LAYING OUT CAM RISE FOR No. 0 BROWN & SHARPE AUTOMATIC SCREW MACHINE

Number of Seconds to make one Piece	Lead		Front and Back Cams	
	D	R	D	R
From 5 to 12 seconds....	1 1/8	15/16	7/8	1 1/2
From 13 to 30 seconds....	1 1/8	2 3/8	7/8	2
From 32 to 60 seconds....	1	3 1/4	13/16	3

thus allowing the drop on the lead cam to be more abrupt, on the No. 0 and No. 2 screw machines, than it is on the front and rear cams. This is also true of the No. 00 machine, but as the drop is not great, very little time would be saved by using a smaller angle of drop for the lead than for the cross-slide cams. Referring to Fig. 4, it can be seen that the lever arm swings about a pivot, so that, to have a uniform drop, a special curve should be constructed. But, as this drop would be more difficult to make than a straight drop, a straight or angular drop is adopted. This gives the drop of the arm a variable motion, as can be seen by referring to Fig. 4; the roll will drop quickly to about the point e, then slow up and then increase in speed as it approaches the bottom. The cross-slides are forced back by a spring which serves to keep the roll in contact with the cam. The drop on

TABLE X. DIMENSIONS FOR LAYING OUT CAM RISE FOR No. 2 BROWN & SHARPE AUTOMATIC SCREW MACHINE

Number of Seconds to make one Piece	Lead		Front and Back Cams	
	D	R	D	R
From 6 to 14 seconds..	1 7/8	2 7/16	1 1/2	1 3/4
From 15 to 40 seconds..	1 3/4	2 3/8	1 1/4	1 13/16
From 45 to 90 seconds..	1 1/2	2 1/2	1 1/16	1 15/16
From 100 to 180 seconds.	1 3/8	3 1/4	15/16	2 1/16

the cam should not be laid off from a circle as shown by the dotted lines at c. This would mean that the roll would drop slower when dropping a short distance than when dropping a greater distance. The drop should be laid off from the hundredth line where the operation

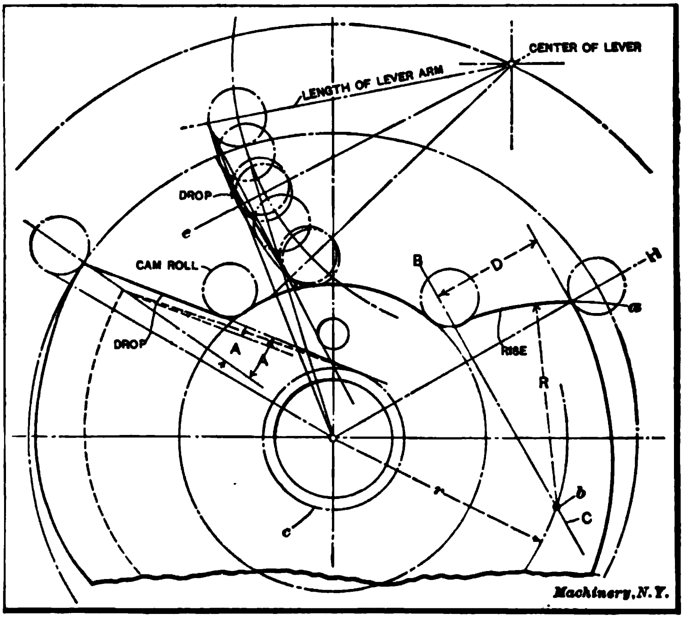


Fig. 4. Method of Laying out Rise and Fall on Cams

finishes as shown by the angle A. This assures the drop always being of the same speed, irrespective of the distance through which it has to drop. The following angles of drop have been found suitable for the given number of seconds required to make one piece.

DROP ON CAMS FOR No. 00 BROWN & SHARPE AUTOMATIC SCREW MACHINE

Number of Seconds to make One Piece	Lead, Front and Back
From 3 to 5 seconds	$A = 20$ degrees
From 6 to 12 seconds	$A = 15$ degrees
From 13 to 30 seconds	$A = 10$ degrees

DROP ON CAMS FOR No. 0 BROWN & SHARPE AUTOMATIC SCREW MACHINE

Number of Seconds to make One Piece	Lead	Front and Back
From 5 to 12 seconds	$A = 17$ degrees	16 degrees
From 13 to 30 seconds	$A = 14$ degrees	13 degrees
From 32 to 60 seconds	$A = 10$ degrees	9 degrees

DROP ON CAMS FOR No. 2 BROWN & SHARPE AUTOMATIC SCREW MACHINE

Number of Seconds to make One Piece	Lead	Front and Back
From 6 to 14 seconds	$A = 16$ degrees	22 degrees
From 15 to 40 seconds	$A = 14$ degrees	19 degrees
From 45 to 90 seconds	$A = 12$ degrees	16 degrees
From 90 to 180 seconds	$A = 10$ degrees	13 degrees

Clearance for Tools

In laying out a set of cams it is sometimes found necessary to make allowance for one tool to clear another, the amount of clearance necessary being determined by the diameter or width of tool used in the turret and the position of the cross-slide tools relative to the work. When determining the amount of clearance necessary, the rise and drop on the lead cam is disregarded and the rises and drops on the front and rear cams are taken into consideration. To determine the rise and drop to use, make a rough lay-out of the various operations to be performed and also settle upon the approximate number of revolutions to complete one piece. The revolutions are then converted into seconds as was previously explained. To explain clearly the method used, we will take a practical example. Assume that it is required to make a brass screw as shown in Fig. 5. This screw is made from ¼-inch round brass rod, and can be made to advantage on the No. 00 Brown & Sharpe automatic screw machine, using a spindle speed of 2400 R. P. M. backward and forward. Assume that it is required to find the amount of clearance necessary for the die holder to pass the circular form and cut-off tools. Draw in the form tool in position on the screw as shown to the left in Fig. 5, and also an outline of the toolpost. Then lay out the die holder in position to start on the screw, as shown by the dotted lines. If a releasing die holder is used, take the diameter over the heads of the screws in the holder, but if a "draw-out" type is used, the diameter of the cap is taken. In this case, as the screw is threaded up to the shoulder, a releasing die holder will be used. In Fig. 5 it can be seen that the die holder cannot advance on the screw until the form tool drops back a distance *B*, but as *B* is the actual distance, it will be necessary to add an extra amount to insure that the die holder can advance without coming in contact with the circular form tool. The extra amount of clearance necessary varies with the type of tool used. The following dimensions give the approximate amounts that should be added to tne actual clearance for the type of tools specified:

Type of Tool	Extra Amount of Clearance
Drill holders	from 1/8 to 3/16 inch
Box-tools (with V-supports)	from 1/8 to 1/4 inch
Box-tools (with supporting bushing)	from 3/16 to 5/16 inch
Button die holders (draw-out type)	from 3/16 to 5/16 inch
Button die holders (releasing type)	from 1/4 to 1/2 inch

To find the amount necessary for clearance, make a diagram as shown in Fig. 6, laying out the drop on the front cam as shown. Then add, say, ¼ inch, to dimension *B* and measure down from the point where the lobe finishes, scribing an arc of a circle through the point

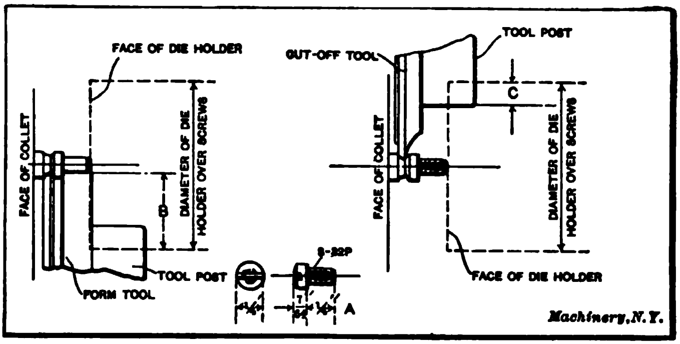


Fig. 5. Diagram Illustrating Method of Finding Clearance for Die Holder

thus located, as shown. Then with a radius equal to the radius of the cam roll, describe a circle touching the arc drawn and the drop on the cam. Join the center of the roll with the center of the cam circle by a straight line. The clearance is then measured off in hundredths as shown by dimension *H*. The starting point of the lobe on the lead cam for threading will be at the hundredth line *D* and the intervening space between the lines *D* and *E* will be the amount necessary for clearance.

When the cutting-off operation follows the threading operation it will also be necessary to allow for clearance. To find the amount of clearance necessary for the die holder to clear the circular cut-off tool, proceed as follows: Make a lay-out as shown to the right in Fig. 5 and measure off the distance C. Add ¼ inch to this and lay off this dimension from the starting point *A* of the rear cam as shown in Fig. 6, drawing an arc of a circle as before. Then draw a circle the diameter of which is equal to the diameter of the roll, touching the arc drawn and the rise on the cam, and measure off the clearance *H* as was previously explained. The thread lobe would finish at the hundredth line *F* and the cut-off tool start at the line *A*. Clearance should also be allowed between the dropping back of the cut-off tool and the feeding of the stock. To find the amount of clearance necessary add 1/8 inch to the largest radius of the stock used and proceed as previously explained.

To make this explanation more complete, the various steps followed when designing a set of cams will be given.

Designing and Laying out Cams

When designing a set of cams the speed of the spindle best suited for the size of stock and nature of material should first be decided upon.

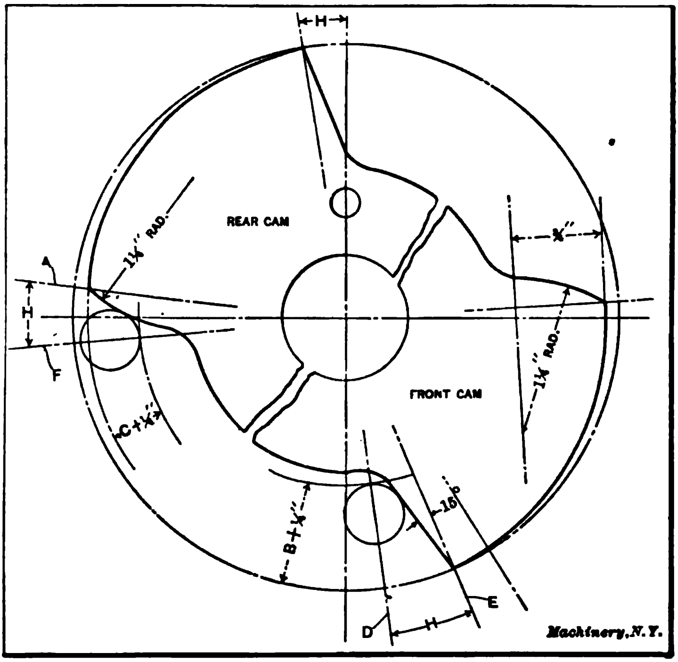


Fig. 6. Method of Determining Clearance on Cross-slide Cams

The tables for surface speeds given in MACHINERY's Reference Book No. 99, "Automatic Screw Machine Practice—Operation of the Brown & Sharpe Automatic Screw Machine," will be found convenient for this purpose. The quickest and best method of making the piece should next be considered, and a diagram made of the tools to be used in the turret as shown at *A*, Fig. 7, leaving from 1/8 to 3/16 inch clearance between the rear face of the tool-holder and the face of the turret. This amount, of course, varies to a considerable extent, depending on the length of the shank and body of the tool, and also on the distance that the work projects from the chuck. When the shank of the tool is short, care should be taken to see that the clamping devices in the turret have a good grip on the shank of the tool. The diagram of the circular tools applied to the work should also be made as shown at *B*, Fig. 7. The feeds for the various operations are then decided upon and divided into the length of cut which will give the number of revolutions required for the various operations. The total number of revolutions to complete one piece is found by adding together the number of revolutions for each cut, for revolving the turret, feeding the stock and, in some cases, reversing the spindle; an approximate number of revolutions should also be added for clearance. When the approximate number of seconds to complete one piece has been obtained we make a diagram of the rise and drop on the cam as shown in Fig. 6. To ascertain the exact number of revolutions required for clearance, if the approximate number of revolutions as allowed for

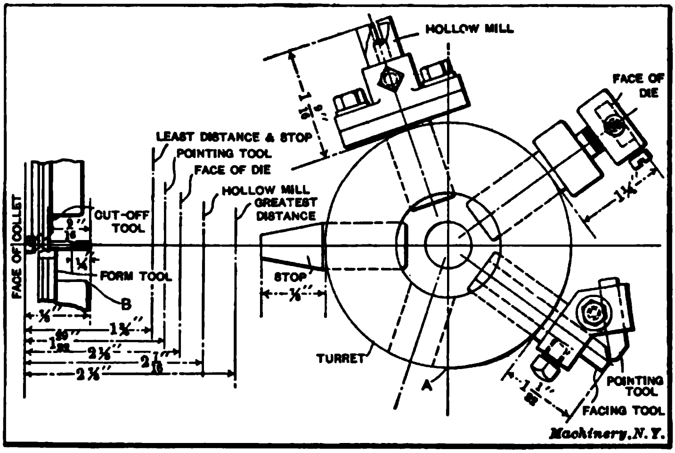


Fig. 7. Position of Tools in Turret, and Forming Tools applied to Work

clearance is not sufficient, the feed on some of the tools is increased, but if the maximum feed that the tools will stand has been used, the number of seconds to make one piece has to be increased. When the actual number of seconds has been obtained, we then convert the revolutions for each operation into hundredths of cam circumference, and proportion the different lobes on the cam to the number of revolutions for each operation. To explain the method adopted in laying out the cams, we will take a practical example.

Assume that it is required to make a screw as shown at *B*, Fig. 7. We first make the diagrams of the circular tools and the tools used in the turret as shown. Then to find the amount that the lead cam is to be cut down below the outer cam circle, measure the distance that the tools project out of the turret and add this amount to the distance that the piece projects from the face of the chuck. Then the least distance between the turret and the face of the chuck subtracted from this amount would give the distance down from the outer circle to where the lobe on the cam starts. For example, take the lobe for the hollow mill.

1 9/16 + 7/8 = 2 7/16 inch.

2 7/16 inch — 1 3/4 inch = 11/16 inch.

In Fig. 8 is given a method of laying out the cams for the screw shown in Fig. 7. This method is commendable, as it can be seen whether the tools will clear one another better than if the cams were drawn separately instead of one on top of the other. If the foregoing suggestions are followed, very little trouble will be encountered in designing a set of cams. The example as given is for making screws, but the same method can be followed in making any other class of work. After the cams have been designed, a tracing should be made and kept

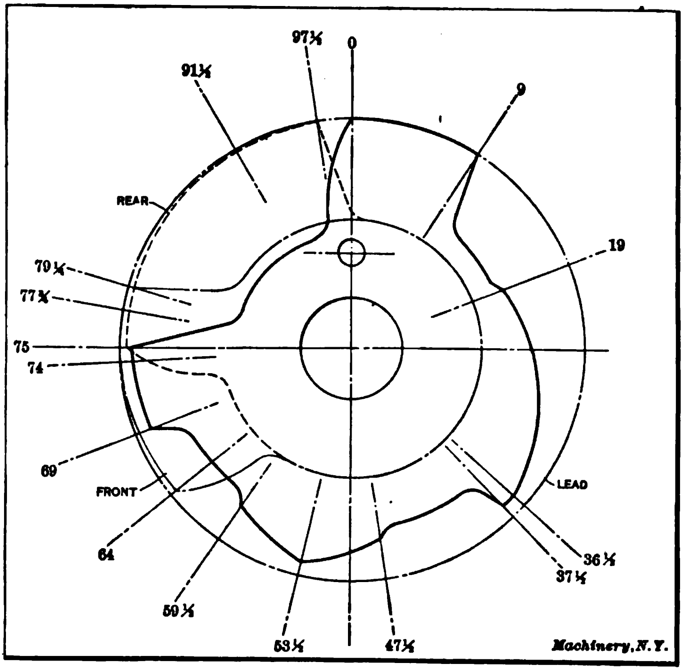


Fig. 8. Commendable Method of Laying out Cams

for reference. (See Fig. 40, Part I of this treatise, MACHINERY'S Reference Book No. 99.)

Practical Points in Designing Cams and Special Tools

1. Use the highest spindle speeds that the various tools will stand.
2. Use the arrangement of circular tools best suited for the class of work. (See Reference Book No. 101.)
3. Decide on the quickest and best method of arranging the operations before designing the cams.
4. Do not use turret tools for forming when the cross-slide tools can be used to better advantage.
5. Do not use a circular cut-off tool without top rake when cutting Norway iron, machine steel, etc.

6. Make the shoulder on the circular cut-off tool large enough so that the clamping screw will grip firmly.

7. When chips clinging to the work are objectionable, the circular form tool should be turned up-side-down and placed on the rear cross-slide.

8. Do not use too narrow a cut-off blade.

9. Allow 0.005 to 0.010 inch for the circular tools to approach the work and 0.003 to 0.005 inch for the cut-off tool to pass the center.

10. When cutting off work large in diameter, the feed on the cut-off tool should be increased until near the end of the cut where the piece breaks off. After it breaks off, the feed should again be increased until the tool has passed the center.

11. When a thread is cut up to a shoulder, the piece should be grooved or necked to make allowance for the lead on the die. This requires an extra projection on the form tool and also an extra amount of rise on the cam.

12. Use circular form and cut-off tools made from high-speed steel when cutting Norway iron, machine steel, etc.

13. Use a fine feed and high spindle speed for all cutting tools.

14. Allow sufficient clearance for tools to pass one another.

15. Always make a diagram of the cross-slide tools in position on the work when difficult operations are to be performed; it is also necessary to make a diagram of the tools held in the turret.

16. Do not drill a hole the depth of which is more than 2½ times the diameter of the drill, but use two or more drills as required. If there are not sufficient holes in the turret, drop the drill back clear of the hole, and advance it into the hole again.

17. Do not run a drill at a slow speed.

18. When the turret tools operate further in than the face of the chuck, see that tney will clear the chute when revolving the turret.

19. See that the body of all turret tools will clear the side of the chute when revolving the turret.

20. Do not use a box-tool for a roughing cut. Use a hollow mill.

21. Do not use a box-tool with soft supports. Use solid supports only on cold-drawn or finished stock.

22. The rise on the thread lobe should be reduced so that the spindle will reverse when the die or tap holder is drawn out.

23. When threading Norway iron, machine steel, etc., if the spindle speed used for the other tools is too high for threading, use a special threading attachment. (See MACHINERY's Reference Book No. 104.)

24. When bringing another tool into position after a threading operation, allow clearance before revolving the turret.

25. Make provision to revolve the turret rapidly, especially when pieces are being made in from three to five seconds and when only a few tools are used in the turret. It is sometimes convenient to use two sets of tools.

26. When using a belt-shifting attachment for threading, clearance should be allowed, as it requires extra time to shift the belt.

27. When laying out a set of cams for operating on a piece which requires to be slotted, cross-drilled or burred, allowance should be made on the lead cam so that the transferring arm can descend and ascend to and from the work without coming in contact with any of the turret tools.

28. Always allow a vacant hole in the turret when it is necessary to use the transferring arm.

29. Use standard tools whenever possible.

30. When designing special tools allow as much clearance as possible. Do not make them so that they will just clear, as errors sometimes turn up, causing trouble.

31. When designing special tools having intricate movements, avoid springs as much as possible, and use positive actions.

CHAPTER II

CAMS FOR SCREW-SLOTTING ATTACHMENTS

The Brown & Sharpe Mfg. Co., Providence, R. I., has designed a number of standard and special attachments for its automatic screw machines. These attachments are used for performing various second operations on a piece of work, such as slotting, milling, cross-drilling and burring, at the same time that another piece is being operated on by the cross-slide and turret tools. Thus extra operations are performed without taking additional time.

While the attachments—as such—are widely known, the methods of laying out the cams for operating them are no doubt unfamiliar to a large number of operators and mechanics in general, and, therefore, a description of the methods of laying out the cams for one of these attachments should be of general interest. The best known attachment designed by the Brown & Sharpe Mfg. Co. is its screw-slotting attachment, which is shown in Fig. 9.

Screw-slotting Attachment for the No. 00 Machine

The screw-slotting attachment is fastened to a boss, provided for this purpose on the machine, by two cap-screws. An apron, which is also an additional part, carries the arbor *C* to which the transferring arm *F* is attached. The transferring and advancing cam levers *D* and *E* are also fastened to bosses on this apron by cap-screws. These levers are operated by the advancing and transferring cams *J* and *K*. A block *H* is fastened to the arm *F*, and a slotting bushing or carrier for the screw is driven into it. This bushing grips the screw and holds it while the slotting saw, held on an arbor and driven by a pulley through bevel gears, mills the slot in the head.

The design and action of the device is, in detail, as follows: The transferring lever *D* is kept in contact with the cam by means of two

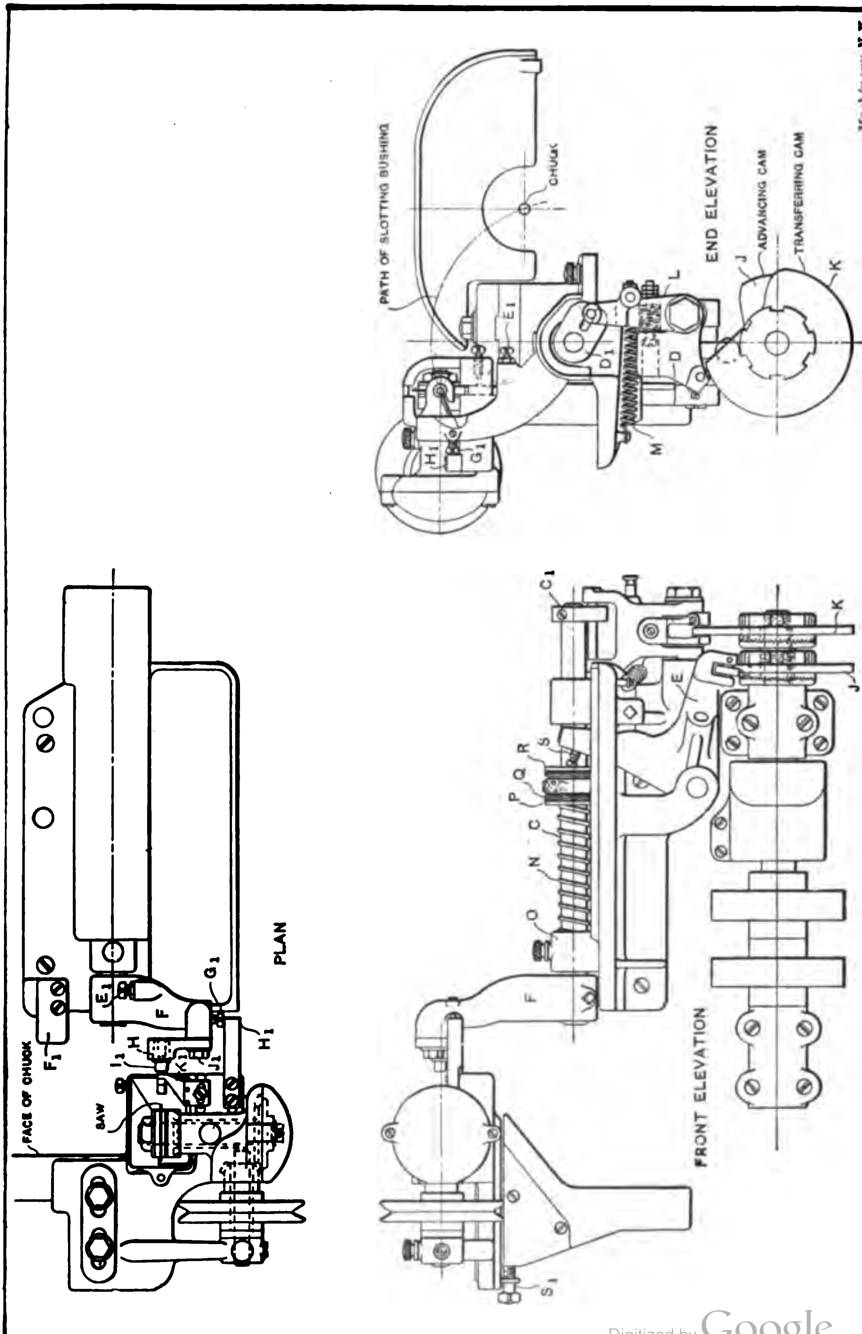


Fig. 9. Assembly Views of Screw-slotting Attachment for the No. 00 Brown & Sharpe Automatic Screw Machine

springs *L* and *M*. The advancing lever *E* is kept in contact with the advancing cam by the spring *N*, located on the transferring-arm rod *C*. This open-wound spring presses against the boss *O* on the attachment and the washer *P*, this latter being held up against a ball retainer *Q* which, in turn, is forced against a washer held to the arbor *C* by a cone-pointed screw. The lever *E* does not bear directly against the thrust-washer *R* to advance the arm, but holds a set-screw *S* which can be adjusted in and out and locked with a headless screw. This screw *S*, in conjunction with the screw S_1, is used for varying the depth of the slot in the head of the screw.

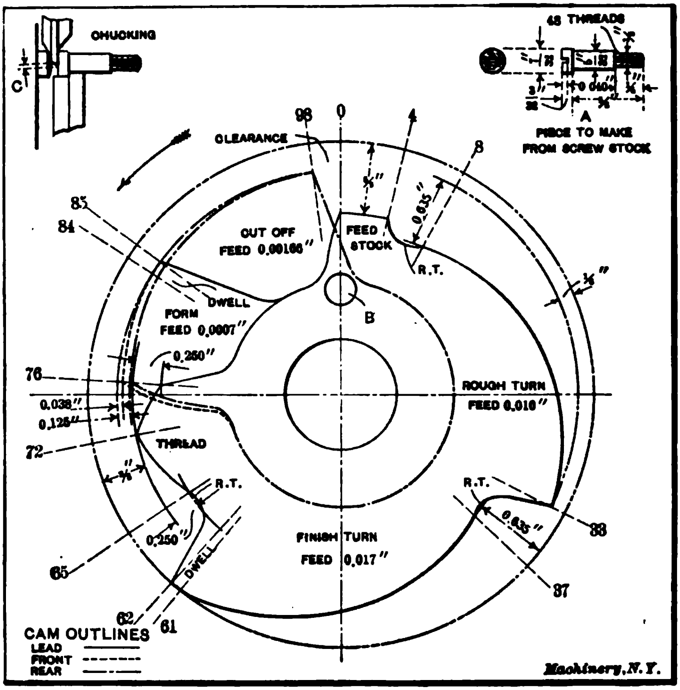


Fig. 10. Turret and Cross-slide Cams for Making a Steel Screw

The transferring lever *D* is connected to a block D_1, which is fastened to the rod *C* by a screw C_1. This block connects arm *F* with lever *D*. The arms of lever *D* and the arm *F* are so proportioned that a small rise of about 1⅛ inch on the cam in this case is sufficient to carry the slotting bushing from the chuck up to the saw through the path indicated in the engraving. When arm *F* drops down into a position in front of the chuck, it is stopped at the desired point by a set-screw E_1, which rests on a block F_1, attached to the machine. When the arm moves up into a position in front of the saw, it is stopped by a set-screw G_1, which bears against a block H_1, fastened to the attachment. The set-screws G_1 and E_1 are used for setting the slotting bushing accurately. The slotting bushing is shown at I_1 in position in block H. The shank of this bushing is tapered one-half inch to the foot and is driven into the block. Block H is held to the arm by a cap-screw J_1. When the slot in the screw has been cut and arm F drops back, the screw is removed from the bushing, which has a slot cut in it, by the ejector K_1, which is simply a piece of sheet steel fastened to the attachment.

Laying out a Set of Cams for a Screw-slotting Operation

Undoubtedly the method of setting and operating this screw-slotting attachment can best be described by taking a practical example. Suppose it is necessary to make the shouldered steel screw shown at A in Fig. 10 on a No. 00 Brown & Sharpe automatic screw machine. To proceed:

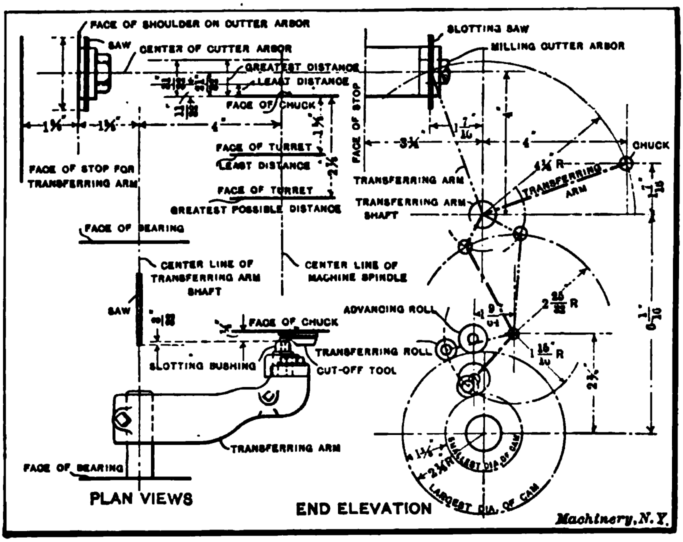


Fig. 11. Diagram used in determining the Rises on the Transferring and Advancing Cams

First design the cross-slide and turret cams, making allowance for one empty hole in the turret, thus enabling the transferring arm to drop down and pick up the screw while it is being cut off. It will not be necessary to describe the method of laying out the turret and cross-slide cams, as this has been described in the previous chapter, so we will confine our attention to the calculations necessary in laying out the transferring and advancing cams for removing and slotting the screw.

Before proceeding with the laying out of these cams, it is necessary to make a diagram such as is shown in Fig. 11. Here a diagrammatical view of the necessary movement of the transferring and advancing levers is shown. To the right of the illustration is a diagram of the movement of the transferring arm and lever. For the slotting attachment, the transferring arm does not have to dwell at any intermediate point between the chuck and the slotting saw, so that no calculation is necessary to find the rise on the cam—the full rise or 1⅛ inch being sufficient to lift the slotting bushing from the chuck to the slotting saw. To the left of the illustration is a diagram in which is indicated the least and greatest possible distances between the face of the turret and the chuck, and also the position of the screw-slotting arbor relative to the chuck. Below this, the transferring arm is shown in position on the screw. Here it can be seen that the lobes for placing the bushing on the work and advancing it to the saw will be of the same height, as the distance 3/32 inch is considerably less than the adjustment provided for the screw-slotting attachment; this adjustment is equal to 5/16 inch on each side of the center line.

When the rises or the heights of the various lobes on the cams have been determined, the next problem is to determine their relative positions, or, in other words, the starting and finishing points of the lobes on the transferring and advancing cams, respectively.

Laying out the Transferring and Advancing Cams

The location hole *B* in the cam shown in Fig. 10 is not used in the transferring and advancing cams, so that these cams, when made, can be shifted around to the desired position. However, it is best to start from some predetermined point when laying out the cams. The least confusion will result if the point at which the piece breaks off is used for the point at which the bushing is located on the work. This point, of course, cannot be determined exactly, but it is easy to locate it approximately.

The method of determining this is as follows: Taking the screw shown at *A*, in Fig. 10, as an example, we will assume that it will break off when the teat is 0.010 inch in diameter. (This screw is made in 9 seconds and requires 360 revolutions of the work spindle, which in this case is rotated at 2400 R. P. M.) Then assuming that the length of the bevel on the cut-off tool, or distance *C*, Fig. 3, equals 0.010 inch, and that the amount to pass the center of the work equals 0.005 inch, we find that the distance the point of the cut-off tool will have to travel after the piece breaks off equals $0.010 + 0.005 + 0.005 = 0.020$ inch. To find the hundredth line on the cam circle where the screw is supposed to break off, divide the travel (in inches) of the cut-off tool, still to be completed after the piece is cut-off, by the feed of the cut-off tool per revolution of the work. (See cut-off cam, Fig. 10.) Thus,

$$\frac{0.020}{0.00166} = 12.05 \text{ revolutions.}$$

In other words, it requires 12 revolutions of the spindle after the piece is cut off before the cut-off tool reaches the end of its travel. The hundredths of cam surface equivalent to 12 revolutions of the spindle are $\frac{12 \times 100}{360} = 3\frac{1}{3}$ hundredths, approximately. Therefore we assume that the screw will break off when the center of the cross-slide roll is at 94½ hundredths. As this is where the screw will break off, it is necessary to have the bushing on the work a moment previous to this. In this case we will allow 1/2 hundredth, but it is usually best to allow one hundredth of the cam surface to give the arm time to steady itself after forcing the bushing onto the work.

Having determined the point where the slotting bushing should be located on the work we can proceed to lay out the transferring and advancing cams. The method of laying out these cams is shown in Fig. 12. As previously determined, the advancing cam is not cut down below the outer circumference except for the rise for feeding the screw to the saw and dropping back, so a circle is drawn with a 2¼-inch radius as shown, which represents the largest diameter of the cams. A circle *A*, representing the path of the center of the transferring lever, is next drawn. Then a vertical line *B*, representing the path of the center of the advancing cam, is drawn. When this line and circle have been drawn, we have the relative positions of the transferring and advancing rolls. The transferring roll is ½ inch in diameter, while the advancing roll is ¾ inch, on the No. 00 machine only.

To find the starting and finishing points on the cams, proceed as follows: Draw a circle *C* representing the advancing roll on the hundredth line marked 94; then draw a quick-rise on the cam with a 1½-inch radius. As the screw will be severed from the bar at 97¼ hundredths, this is the finishing point of the lobe for placing the screw in the slotting bushing. Next construct the quick-drop on the cam and draw another circle *D*, 1/16 inch below the largest diameter of the cam, so that the arm will drop back from the chuck before it begins to rise.

Now, to determine the position of the transferring roll, draw two circles *E* and *F* of such diameters that the distance *G* equals the relative distance between the center of the transferring arm lever and the path of the center of the advancing lever; these levers swing through arcs in planes at right angles to each other.

To obtain the center of the transferring lever, relative to the path of the advancing lever, draw a line through the center of the circle *D* and tangent to the circle *F*. Then draw another line tangent to the circle *E* and parallel to the line which is tangent to the circle *F* and passes through the center of the circle *D*. The point where the last drawn line cuts the circle *A* will be the center of the transferring lever. With this point as center and the compasses set to the radius of the transferring lever, strike an arc, and with its center on this arc draw the transferring roll circle *H*, touching the smallest diameter of the cam. The quick-rise on the transferring cam is then constructed, and the finishing point of this rise is made with a ¼-inch radius, so that the speed at which the arm is traveling will be decreased as it approaches the top of its travel. If this is not done, the arm will hit the stop and rebound, which will have a tendency to knock the screw out of the slotting bushing. When the transferring roll is on the highest point of the cam, the advancing roll should be at the bottom. A clearance of

1/100 is allowed between the point when the transferring roll is on the top of the cam, and the point when the advancing roll begins to advance the screw to the saw. The starting and finishing points of the lobes on the advancing cam for advancing the screw to the saw are constructed in a manner similar to that just described.

Nothing will be gained by dropping the arm down to pick up another screw before the teat has been reduced sufficiently so that the screw can be removed; hence as much of the cam surface as possible is used for slotting, thus preventing forcing the feed too much. To find the

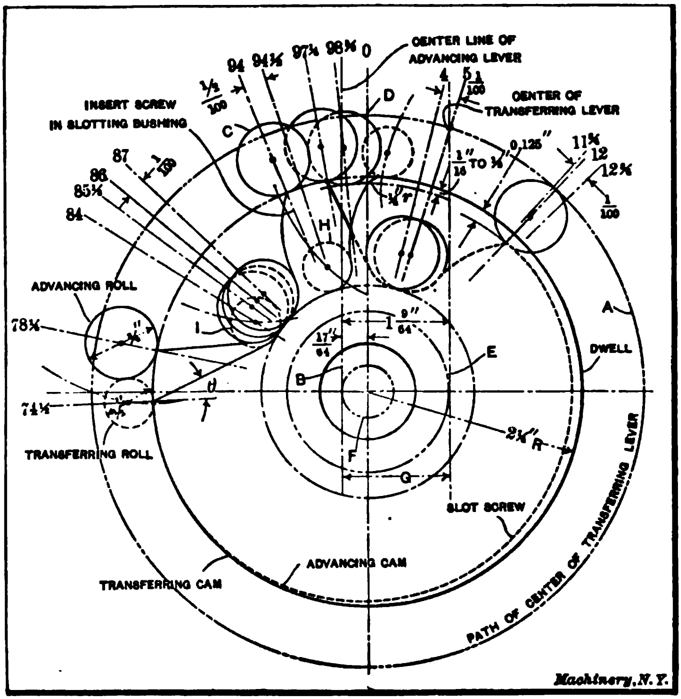


Fig. 12. Illustration showing Method of laying out Transferring and Advancing Cams

finishing point, we work backward, as it were, and locate the transferring roll at the base of the cam, as shown at *I*; then draw the quick-rise at an angle *θ*, which should be from 15 to 20 degrees for the No. 00 automatic screw machine. When this angle is drawn, we then have the finishing point on the transferring cam. The finishing point of the advancing cam is found by laying out the rolls in their respective positions, in the same manner as before, care being taken to retain the correct relations between the center of the transferring lever and the path of the advancing lever. This problem may seem to be rather complicated at first, but after some practice it will be found to be simple enough. A rise of 0.125 inch is generally allowed on the advancing

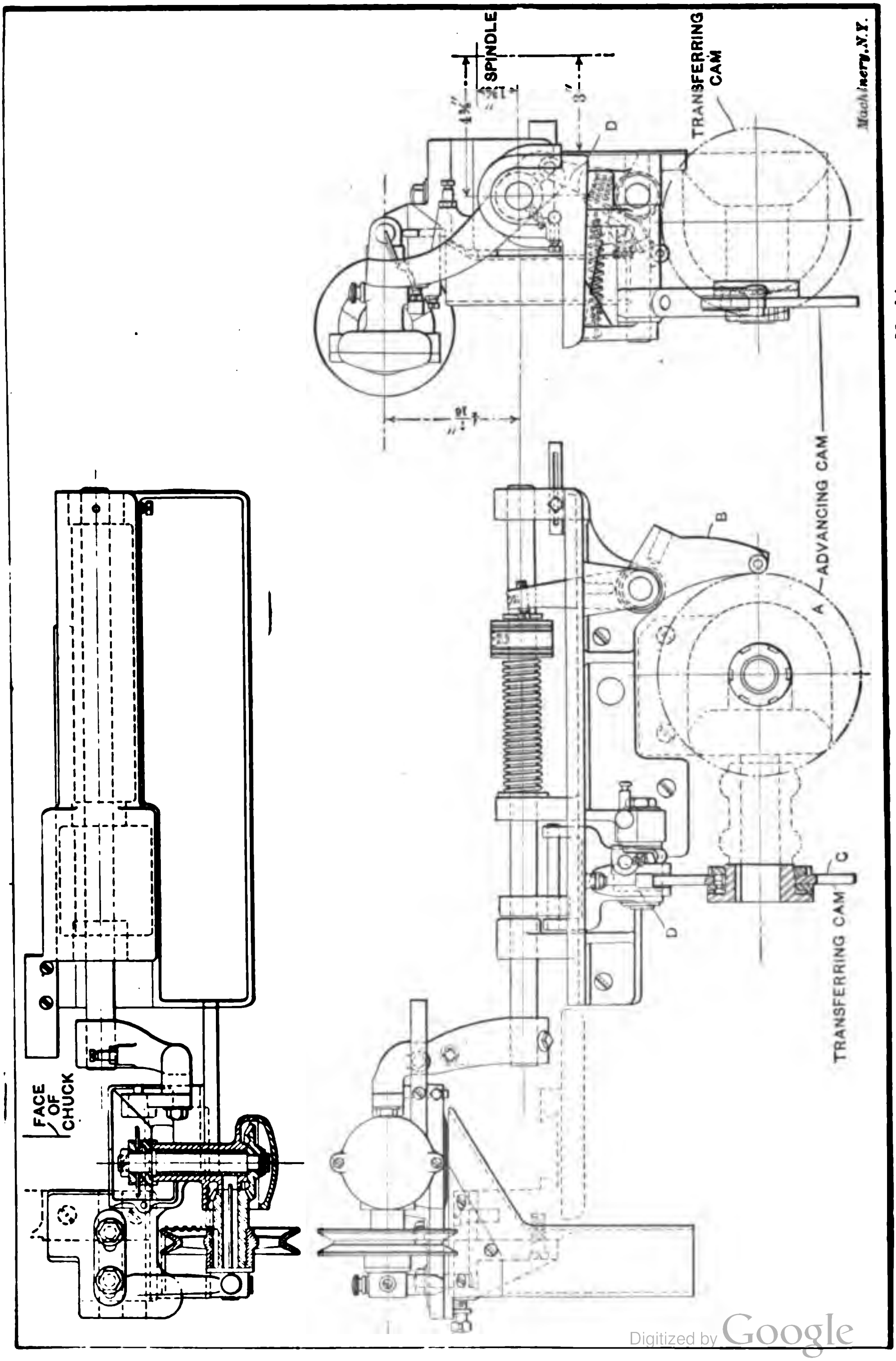


Fig. 13. Screw-slotting Attachment for the No. 0 Brown & Sharpe Automatic Screw Machine

cam, so that all sizes of screws within the range of the machine can be slotted with this same set of cams.

Screw-slotting Attachment for the No. 0 and No. 2 Machines

The principle on which the screw-slotting attachment for the No. 0 and No. 2 machines works does not vary from that used on the No. 00

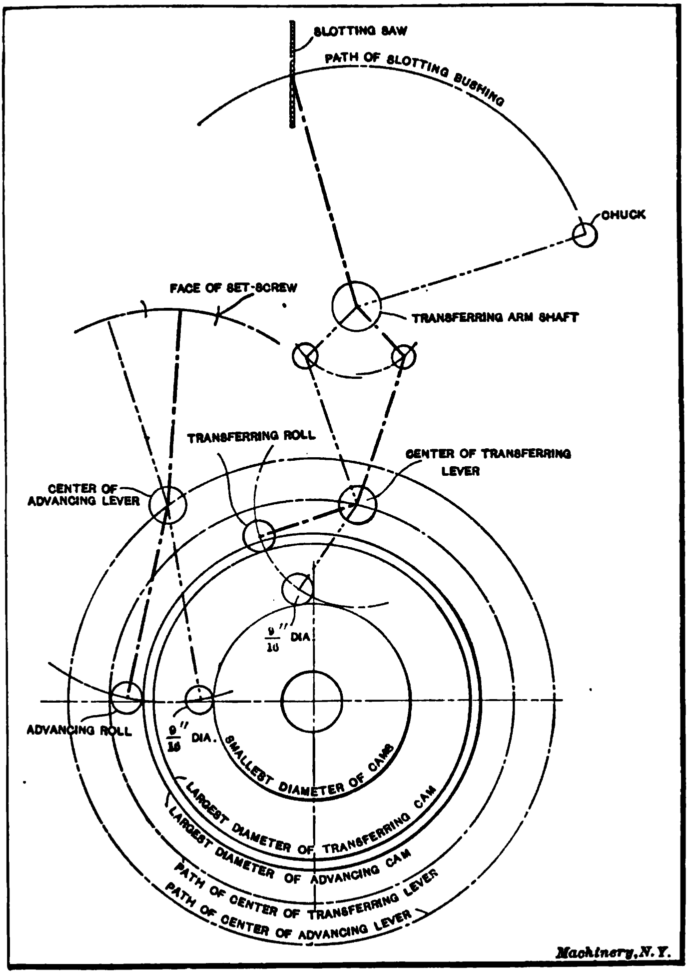


Fig. 14. Diagram used in laying out Transferring and Advancing Cams for the No. 0 Brown & Sharpe Automatic Screw Machine

machine, but the advancing and transferring cams are located differently. On the No. 00 machine, these cams are held side by side on the front cam-shaft, while in the No. 0 and No. 2 machines, the advancing cam is held on the stud which holds the lead cam, while the transferring cam is held on the front cam-shaft. The movement of the levers, of course, in this case differs from that on the No. 00 machine. Referring to the illustration Fig. 13, which shows the attachment used on the No. 0 machine, *A* is the advancing cam and *B* the advancing cam lever; *C* is the transferring cam, and *D* the transferring lever. The method of carrying the screw to the saw is similar to that on the No. 00 machine, as are also the other movements, so that this will not need further description. It is, however, necessary to describe the method of laying out the transferring and advancing cams.

The method of laying out the transferring and advancing cams is illustrated diagrammatically in Fig. 14 where the advancing and transferring levers, as well as the cams, are shown in the same plane. The method of finding the starting and finishing points of the lobes on the transferring and advancing cams is the same as that used for the ordinary cross-slide and lead cams. The only point to remember is to retain the proper distances between the centers of the levers, and to swing them into their proper positions. A templet could be made for these cams, which would simplify the problem of laying out the starting and finishing points. When a templet is not available, the method previously described for the No. 00 machine can be used; that is, keeping the center distances in the same relation, in their respective paths, and swinging the rolls into the desired position.

The screw-slotting attachment for the No. 2 Brown & Sharpe automatic screw machine does not differ from that for the No. 0 machine. The transferring cams in both these machines are made in two pieces, as it would be impossible otherwise to assemble them on the front camshaft. As there are no intermediate points at which the transferring arm is to dwell between the chuck and slotting saw, there are no calculations necessary for determining different heights on the transferring cam, the rise from the lowest to the highest point of the cam being sufficient to lift the screw from the chuck to the slotting saw.

The diagram shown in Fig. 11 should be laid out so that all the dimensions required for laying out the height of the lobes on the cams can be found. It is always advisable to allow at least one-hundredth of the cam surface for clearance, between the starting or finishing points of the lobes on the transferring or advancing cams. This allows the transferring arm to stop for a brief interval before the direction of its motion is changed.

APPENDIX

MILLING SCREW MACHINE CAMS

There are several methods used for finishing plate cams. Most methods require that the outline be accurately laid out, after which the stock is removed, generally by drilling a series of holes around the outline and breaking away the outer part. The cam is then finished to the scribed lines by milling and filing. This method, however, is slow, and the highest accuracy is not obtainable in this way.

Another method which is applicable to all cams with a constant rise is illustrated and described in the following: A diagrammatical view of the relative positions of the compound vertical milling attachment and the index head used in this method, is shown in Fig. 15. By this method constant-rise cams may be milled, so to speak, automatically, by placing the cam blank on the index head spindle, and gearing the head for spiral milling. An end-mill is held in the compound vertical milling attachment, which is adjustable to any angle in the vertical plane, as indicated. The milling attachment and the spiral head are set at a certain angle with the table surface, this angle being determined by the rise of the cam and the forward feed of the milling machine table for one turn of the index head spindle; this forward feed is usually called the spiral lead for which the machine is geared. It will be clear even to persons unfamiliar with this method, that when the table is feeding forward, the slowly revolving cam blank is fed against the cutting edge of the end-mill, and as this latter is stationary, the radius of the cam will be constantly decreased. It is the object of this article to describe a method for finding the angle to which the spiral head is to be set, and the lead for which the spiral head is to be geared, so as to obtain very accurate results when milling constant-rise cams. The formulas given below and the accompanying tables of leads obtainable on the Brown & Sharpe milling machines, and their logarithms, are used for facilitating the necessary calculations. In order to carry out the calculations by the method outlined, a table of logarithms of numbers (MACHINERY'S Reference Book No. 53) and a table of logarithms of angular functions (MACHINERY'S Reference Book No. 55) are required. In order to find the gears to be used for any spiral lead obtainable on the machine, a book entitled "Tables of Leads for Use with Universal Milling Machines," published by the Brown & Sharpe Mfg. Co., Providence, R. I., should be used.

General Formulas for the Calculations

In the following formulas let

l = lead of the cam lobe to be milled; the lead of the cam lobe is the rise of the cam if the given rate of rise were continued for one whole revolution or 360 degrees

R = rise of the cam in a given part N of the circumference,
N = the part of the circumference in which a given rise takes place; N is expressed as a decimal in hundredth of the cam circumference,
L = spiral lead for which the milling machine is geared,
α = angle to which the index head and milling attachment are to be set.

The finding of the angle α to which the index head is to be set for any specific case is most easily explained by reference to Fig. 16. In the right-angle triangle shown, the hypotenuse L represents the distance that the milling machine table will be fed forward while the

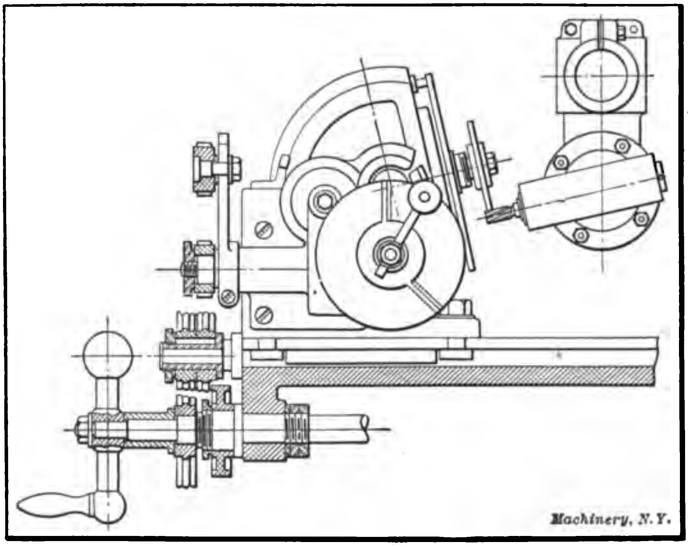


Fig. 15. Diagrammatical View showing Method of Milling Cams on the Milling Machine

index head spindle makes one complete revolution, or, in other words, L is the spiral lead for which the machine is geared. The side l in the triangle represents the rise that the cam to be milled would have in 360 degrees, or in one complete revolution; hence, this side represents the lead of the cam. It is then clear that

$$\sin = \frac{l}{L} \qquad (1)$$

$$\text{But } l = \frac{R}{N}, \text{ hence: } \sin \alpha = \frac{R}{N \times L} \qquad (2)$$

It is apparent from Formula (2) that when R, N and L are known angle α can be determined. As it is not practicable, however, to set either the index head or the vertical milling attachment closer than to whole or half degrees, the lead L must be so selected that the angle

a will be within 5 minutes either way of a whole or a half degree. Hence trial calculations must be made, and it is for the purpose of facilitating these calculations that the tables on pages 36 to 38 have been prepared.

Practical Use of Tables and Formulas

The practical use of the formulas given and of the tables can be best explained by means of an example. Assume that a set of cams is designed and drawn as shown in Fig. 17, and that the toolmaker is to be given the necessary data for milling the lobes on these cams. The milling is to be done according to the method illustrated in Fig. 15. The calculations should be made by the draftsman or whoever designs the cams, and it is recommended that the results of the calculations

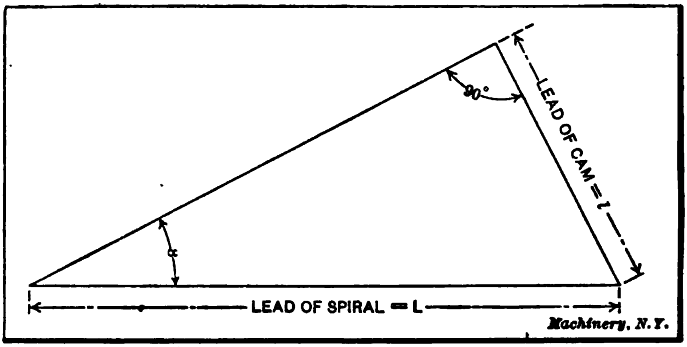


Fig. 16. Relation between Setting Angle of Index Head, Spiral Lead and Lead of Cam Lobe

be tabulated as shown in the table. Referring to the cam drawings in Fig. 17, let us first take the first lobe on the front-slide cam. Here the rise $R = 0.155$ inch and this rise takes place in 0.24 of the whole cam circumference. Hence $N = 0.24$. We have further:

$$l = \frac{R}{N} = \frac{0.155}{0.24} = 0.6458$$

and, from Formula (1):

$$\sin a = \frac{l}{L} = \frac{0.6458}{L} \qquad (3)$$

As already mentioned we must now find a lead L so selected that angle a will be within 5 minutes either way of a whole or half degree. In order to accomplish this result proceed as follows:

First find the logarithm of 0.6458:

$$\log 0.6458 = \bar{1}.81010$$

Now turn to the accompanying tables on pages 36 to 38 (Tables XI to XII). Beginning with any lead L that is *larger* than the numerator 0.6458, subtract the logarithms of the leads, as found in the tables, from the logarithm of the numerator 0.6458 until, by repeated trials,

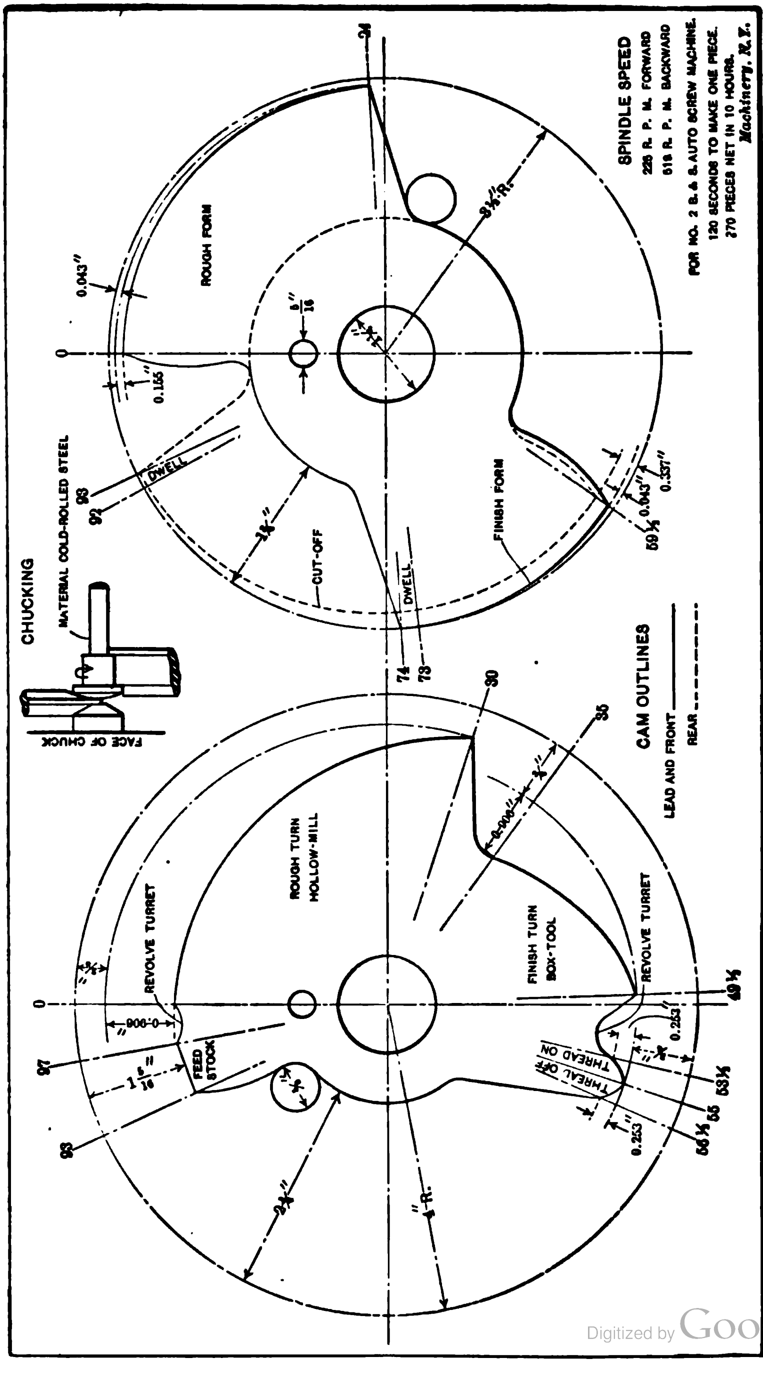


Fig. 17. Cams used as Examples in the Calculations

TABLE XI. DATA FOR MILLING SCREW MACHINE CAMS

Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm
0.900	$\bar{1}$.95424	1.776	0.24944	2.333	0.36791	2.894	0.46150	3.429	0.53517
0.930	$\bar{1}$.96848	1.778	0.24993	2.338	0.36884	2.909	0.46374	3.438	0.53631
0.933	$\bar{1}$.96988	1.786	0.25188	2.344	0.36996	2.917	0.46494	3.488	0.34258
1.029	0.01242	1.800	0.25527	2.368	0.37438	2.924	0.46598	3.491	0.54295
1.042	0.01787	1.809	0.25744	2.381	0.37676	2.933	0.46731	3.492	0.54307
1.047	0.01995	1.818	0.25959	2.386	0.37767	2.934	0.46746	3.500	0.54407
1.050	0.02119	1.823	0.26079	2.392	0.37876	2.946	0.46923	3.520	0.54654
1.067	0.02816	1.860	0.26951	2.400	0.38021	2.950	0.46982	3.535	0.54839
1.085	0.03543	1.861	0.26975	2.424	0.38453	2.977	0.47378	3.552	0.55047
1.116	0.04766	1.867	0.27114	2.431	0.38578	2.984	0.47480	3.556	0.55096
1.196	0.07773	1.875	0.27300	2.442	0.38775	3.000	0.47712	3.564	0.55194
1.200	0.07918	1.886	0.27554	2.445	0.38828	3.030	0.48144	3.565	0.55206
1.221	0.08672	1.905	0.27989	2.450	0.38917	3.044	0.48344	3.571	0.55279
1.228	0.08920	1.919	0.28307	2.456	0.39023	3.055	0.48501	3.572	0.55291
1.240	0.09342	1.920	0.28330	2.481	0.39463	3.056	0.48515	3.582	0.55413
1.244	0.09482	1.925	0.28443	2.489	0.39602	3.070	0.48714	3.588	0.55485
1.250	0.09691	1.944	0.28870	2.500	0.39794	3.080	0.48855	3.600	0.55630
1.302	0.11461	1.954	0.29092	2.514	0.40037	3.086	0.48940	3.618	0.55847
1.309	0.11694	1.956	0.29137	2.532	0.40346	3.101	0.49150	3.636	0.56062
1.333	0.12483	1.990	0.29885	2.537	0.40433	3.111	0.49290	3.637	0.56074
1.340	0.12710	1.993	0.29950	2.546	0.40586	3.117	0.49374	3.646	0.56182
1.371	0.13704	2.000	0.30103	2.558	0.40790	3.125	0.49485	3.655	0.56289
1.395	0.14457	2.009	0.30298	2.567	0.40943	3.126	0.49499	3.657	0.56312
1.400	0.14613	2.030	0.30750	2.571	0.41010	3.140	0.49693	3.663	0.56384
1.429	0.15503	2.035	0.30856	2.593	0.41380	3.143	0.49734	3.667	0.56431
1.433	0.15625	2.036	0.30878	2.605	0.41581	3.150	0.49831	3.673	0.56502
1.440	0.15836	2.045	0.31069	2.618	0.41797	3.175	0.50174	3.684	0.56632
1.447	0.16047	2.047	0.31112	2.619	0.41814	3.182	0.50270	3.686	0.56656
1.458	0.16376	2.057	0.31323	2.625	0.41913	3.189	0.50365	3.704	0.56867
1.467	0.16643	2.067	0.31534	2.640	0.42160	3.190	0.50379	3.721	0.57066
1.488	0.17260	2.083	0.31869	2.658	0.42455	3.198	0.50488	3.733	0.57206
1.500	0.17609	2.084	0.31890	2.667	0.42602	3.200	0.50515	3.750	0.57403
1.522	0.18241	2.093	0.32077	2.674	0.42716	3.214	0.50705	3.763	0.57553
1.527	0.18384	2.100	0.32222	2.678	0.42781	3.225	0.50853	3.771	0.57646
1.550	0.19033	2.121	0.32654	2.679	0.42797	3.241	0.51068	3.772	0.57657
1.556	0.19201	2.133	0.32899	2.700	0.43136	3.256	0.51268	3.799	0.57967
1.563	0.19396	2.143	0.33102	2.718	0.43425	3.267	0.51415	3.809	0.58081
1.595	0.20276	2.171	0.33666	2.727	0.43569	3.273	0.51495	3.810	0.58092
1.600	0.20412	2.178	0.33806	2.743	0.43823	3.275	0.51521	3.818	0.58184
1.607	0.20602	2.182	0.33885	2.750	0.43933	3.281	0.51601	3.819	0.58195
1.628	0.21165	2.188	0.34005	2.778	0.44373	3.300	0.51851	3.822	0.58229
1.637	0.21405	2.193	0.34104	2.791	0.44576	3.308	0.51957	3.837	0.58399
1.650	0.21748	2.200	0.34242	2.800	0.44716	3.333	0.52284	3.840	0.58433
1.667	0.22194	2.222	0.34674	2.812	0.44902	3.345	0.52440	3.850	0.58546
1.674	0.22376	2.233	0.34889	2.828	0.45148	3.349	0.52492	3.876	0.58838
1.680	0.22531	2.238	0.34986	2.843	0.45378	3.360	0.52634	3.889	0.58984
1.706	0.23198	2.240	0.35025	2.845	0.45408	3.383	0.52930	3.896	0.59062
1.711	0.23325	2.250	0.35218	2.849	0.45469	3.403	0.53186	3.907	0.59184
1.714	0.23401	2.274	0.35679	2.857	0.45591	3.409	0.53263	3.911	0.59229
1.744	0.24155	2.286	0.35908	2.865	0.45712	3.411	0.53288	3.920	0.59329
1.745	0.24180	2.292	0.36021	2.867	0.45743	3.422	0.53428	3.927	0.59406
1.750	0.24304	2.326	0.36661	2.880	0.45939	3.428	0.53504	3.929	0.59428

TABLE XII. DATA FOR MILLING SCREW MACHINE CAMS

Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm
3.977	0.59956	4.573	0.66011	5.160	0.71265	5.848	0.76701	6.548	0.81611
3.979	0.59977	4.582	0.66106	5.168	0.71332	5.861	0.76797	6.563	0.81710
3.987	0.60065	4.583	0.66115	5.185	0.71475	5.867	0.76842	6.578	0.81809
4.000	0.60206	4.584	0.66124	5.186	0.71483	5.893	0.77034	6.600	0.81954
4.011	0.60325	4.651	0.66755	5.195	0.71559	5.912	0.77173	6.645	0.82249
4.019	0.60412	4.655	0.66792	5.209	0.71675	5.920	0.77232	6.667	0.82393
4.040	0.60638	4.667	0.66904	5.210	0.71684	5.926	0.77276	6.689	0.82536
4.059	0.60842	4.675	0.66978	5.226	0.71817	5.952	0.77466	6.697	0.82588
4.060	0.60853	4.687	0.67089	5.233	0.71875	5.954	0.77481	6.698	0.82595
4.070	0.60959	4.688	0.67099	5.236	0.71900	5.969	0.77590	6.719	0.82730
4.073	0.60991	4.691	0.67127	5.238	0.71917	5.972	0.77612	6.720	0.82737
4.074	0.61002	4.714	0.67339	5.250	0.72016	5.980	0.77670	6.735	0.82834
4.091	0.61183	4.736	0.67541	5.256	0.72066	6.000	0.77815	6.750	0.82930
4.093	0.61204	4.762	0.67779	5.280	0.72263	6.016	0.77931	6.757	0.82975
4.114	0.61426	4.773	0.67879	5.303	0.72452	6.020	0.77960	6.766	0.83033
4.125	0.61542	4.778	0.67925	5.316	0.72558	6.061	0.78254	6.784	0.83149
4.135	0.61648	4.784	0.67979	5.328	0.72656	6.077	0.78369	6.806	0.83289
4.144	0.61742	4.785	0.67988	5.333	0.72697	6.089	0.78455	6.818	0.83366
4.167	0.61982	4.800	0.68124	5.347	0.72811	6.109	0.78597	6.822	0.83391
4.186	0.62180	4.813	0.68242	5.348	0.72819	6.112	0.78618	6.825	0.83410
4.200	0.62325	4.821	0.68314	5.357	0.72892	6.122	0.78689	6.857	0.83613
4.242	0.62757	4.849	0.68565	5.358	0.72900	6.125	0.78711	6.875	0.83727
4.253	0.62870	4.861	0.68673	5.375	0.73038	6.137	0.78796	6.880	0.83759
4.264	0.62982	4.884	0.68878	5.400	0.73239	6.140	0.78817	6.944	0.84161
4.267	0.63012	4.889	0.68922	5.418	0.73384	6.143	0.78838	6.945	0.84167
4.278	0.63124	4.898	0.69002	5.426	0.73448	6.160	0.78958	6.968	0.84311
4.286	0.63205	4.900	0.69020	5.427	0.73456	6.171	0.79036	6.977	0.84367
4.300	0.63347	4.911	0.69117	5.444	0.73592	6.172	0.79043	6.982	0.84398
4.320	0.63548	4.914	0.69144	5.455	0.73679	6.202	0.79253	6.984	0.84410
4.341	0.63759	4.950	0.69461	5.469	0.73791	6.222	0.79393	7.000	0.84510
4.342	0.63769	4.961	0.69557	5.473	0.73822	6.234	0.79477	7.013	0.84590
4.361	0.63959	4.978	0.69705	5.486	0.73926	6.250	0.79588	7.040	0.84757
4.363	0.63979	4.984	0.69758	5.500	0.74036	6.255	0.79623	7.071	0.84948
4.364	0.63988	5.000	0.69897	5.556	0.74476	6.279	0.79789	7.104	0.85150
4.365	0.63998	5.017	0.70044	5.568	0.74570	6.286	0.79837	7.106	0.85163
4.375	0.64098	5.023	0.70096	5.581	0.74671	6.300	0.79934	7.111	0.85193
4.386	0.64207	5.029	0.70148	5.582	0.74679	6.343	0.80229	7.130	0.85309
4.400	0.64345	5.040	0.70243	5.600	0.74819	6.350	0.80277	7.143	0.85388
4.444	0.64777	5.074	0.70535	5.625	0.75012	6.364	0.80373	7.159	0.85485
4.465	0.64982	5.080	0.70586	5.657	0.75259	6.379	0.80475	7.163	0.85509
4.466	0.64992	5.088	0.70655	5.698	0.75572	6.396	0.80591	7.167	0.85534
4.477	0.65099	5.091	0.70680	5.714	0.75694	6.400	0.80618	7.176	0.85588
4.479	0.65118	5.093	0.70697	5.730	0.75815	6.417	0.80733	7.200	0.85733
4.480	0.65128	5.105	0.70800	5.733	0.75838	6.429	0.80814	7.268	0.86141
4.500	0.65321	5.116	0.70893	5.756	0.76012	6.450	0.80956	7.272	0.86165
4.522	0.65533	5.119	0.70919	5.759	0.76035	6.460	0.81023	7.273	0.86171
4.537	0.65677	5.120	0.70927	5.760	0.76042	6.465	0.81057	7.292	0.86285
4.545	0.65753	5.133	0.71037	5.788	0.76253	6.482	0.81171	7.310	0.86392
4.546	0.65763	5.134	0.71046	5.814	0.76448	6.512	0.81371	7.314	0.86415
4.548	0.65782	5.142	0.71113	5.818	0.76477	6.515	0.81391	7.326	0.86487
4.558	0.65877	5.143	0.71122	5.833	0.76589	6.534	0.81518	7.330	0.86510
4.567	0.65963	5.156	0.71231	5.847	0.76693	6.545	0.81591	7.333	0.86528

TABLE XIII. DATA FOR MILLING SCREW MACHINE CAMS

Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm	Spiral Lead	Logarithm
7.334	0.86534	8.081	0.90747	8.953	0.95197	9.828	0.99247	10.800	1.03342
7.347	0.86611	8.102	0.90859	8.959	0.95226	9.844	0.99317	10.853	1.03555
7.371	0.86753	8.119	0.90950	8.960	0.95231	9.900	0.99564	10.859	1.03579
7.373	0.86759	8.140	0.91062	8.980	0.95328	9.921	0.99656	10.909	1.03778
7.400	0.86923	8.145	0.91089	9.000	0.95424	9.923	0.99664	10.913	1.03794
7.408	0.86970	8.148	0.91105	9.044	0.95636	9.943	0.99752	10.937	1.03890
7.424	0.87064	8.149	0.91110	9.074	0.95780	9.954	0.99800	10.945	1.03922
7.442	0.87169	8.163	0.91185	9.091	0.95861	9.967	0.99856	10.949	1.03937
7.465	0.87303	8.167	0.91206	9.115	0.95976	9.968	0.99861	10.972	1.04029
7.467	0.87315	8.182	0.91286	9.134	0.96066	10.000	1.00000	11.000	1.04139
7.500	0.87506	8.186	0.91307	9.137	0.96080	10.033	1.00143	11.021	1.04222
7.525	0.87651	8.212	0.91445	9.143	0.96109	10.046	1.00199	11.057	1.04364
7.543	0.87754	8.229	0.91535	9.164	0.96209	10.057	1.00247	11.111	1.04575
7.576	0.87944	8.250	0.91645	9.167	0.96223	10.078	1.00337	11.137	1.04677
7.597	0.88064	8.306	0.91939	9.210	0.96426	10.080	1.00346	11.160	1.04766
7.601	0.88087	8.312	0.91971	9.214	0.96445	10.101	1.00436	11.163	1.04778
7.611	0.88144	8.333	0.92080	9.260	0.96661	10.159	1.00685	11.169	1.04801
7.619	0.88190	8.334	0.92085	9.302	0.96858	10.175	1.00753	11.198	1.04914
7.620	0.88195	8.361	0.92226	9.303	0.96862	10.182	1.00783	11.200	1.04922
7.636	0.88287	8.372	0.92283	9.333	0.97002	10.186	1.00800	11.225	1.05019
7.639	0.88304	8.377	0.92309	9.334	0.97007	10.209	1.00898	11.250	1.05115
7.644	0.88332	8.400	0.92428	9.351	0.97086	10.228	1.00979	11.313	1.05358
7.657	0.88406	8.437	0.92619	9.375	0.97197	10.233	1.01000	11.314	1.05362
7.674	0.88502	8.457	0.92722	9.382	0.97230	10.238	1.01022	11.363	1.05549
7.675	0.88508	8.484	0.92860	9.385	0.97243	10.267	1.01144	11.401	1.05694
7.679	0.88530	8.485	0.92865	9.406	0.97340	10.286	1.01225	11.429	1.05801
7.680	0.88536	8.506	0.92973	9.428	0.97442	10.312	1.01334	11.454	1.05896
7.700	0.88649	8.523	0.93059	9.429	0.97447	10.313	1.01338	11.459	1.05915
7.714	0.88728	8.527	0.93080	9.460	0.97589	10.320	1.01368	11.467	1.05945
7.752	0.88941	8.532	0.93105	9.472	0.97644	10.336	1.01435	11.512	1.06115
7.778	0.89087	8.534	0.93115	9.524	0.97882	10.370	1.01578	11.518	1.06138
7.792	0.89165	8.552	0.93207	9.545	0.97978	10.371	1.01582	11.520	1.06145
7.813	0.89282	8.556	0.93227	9.546	0.97982	10.390	1.01662	11.574	1.06348
7.815	0.89293	8.572	0.93308	9.547	0.97987	10.417	1.01774	11.629	1.06554
7.818	0.89310	8.594	0.93420	9.549	0.97996	10.419	1.01783	11.638	1.06588
7.838	0.89421	8.600	0.93450	9.556	0.98028	10.451	1.01916	11.667	1.06696
7.855	0.89515	8.640	0.93651	9.569	0.98087	10.467	1.01982	11.688	1.06774
7.857	0.89526	8.681	0.93857	9.598	0.98218	10.473	1.02007	11.695	1.06800
7.872	0.89609	8.682	0.93862	9.600	0.98227	10.476	1.02020	11.719	1.06889
7.875	0.89625	8.687	0.93887	9.625	0.98340	10.477	1.02024	11.721	1.06896
7.883	0.89669	8.721	0.94057	9.643	0.98421	10.500	1.02119	11.728	1.06922
7.920	0.89873	8.727	0.94086	9.675	0.98565	10.558	1.02358	11.733	1.06941
7.936	0.89960	8.730	0.94101	9.690	0.98632	10.571	1.02412	11.757	1.07030
7.954	0.90059	8.750	0.94201	9.697	0.98664	10.606	1.02555	11.785	1.07133
7.955	0.90064	8.772	0.94310	9.723	0.98780	10.631	1.02657	11.786	1.07137
7.963	0.90108	8.800	0.94448	9.741	0.98860	10.655	1.02755	11.825	1.07280
7.974	0.90168	8.838	0.94635	9.763	0.98961	10.659	1.02773	11.852	1.07379
7.994	0.90276	8.839	0.94640	9.773	0.99003	10.667	1.02804	11.905	1.07573
8.000	0.90309	8.889	0.94885	9.778	0.99025	10.694	1.02914	11.938	1.07693
8.021	0.90423	8.909	0.94983	9.796	0.99105	10.713	1.02991	11.944	1.07715
8.035	0.90499	8.929	0.95080	9.818	0.99202	10.714	1.02995	11.960	1.07773
8.063	0.90650	8.930	0.95085	9.822	0.99220	10.750	1.03141	12.000	1.07918

a remainder is obtained which is the logarithm of the sine of an angle which is within 5 minutes of a whole or a half degree. The angle thus found is the setting angle for the index head and the lead giving this angle is the one for which the head is to be geared. Proceeding according to the directions given above we have:

$$\begin{array}{rl} & \log 0.6458 = \bar{1}.81010 \\ \text{(Subtract)} & \log 0.900 \;\; = \bar{1}.95424 \\ \hline & \log \sin a = \bar{1}.85586 \end{array}$$

From a table of logarithms of sines we find that a = 45 degrees 51 minutes. As this angle is not within 5 minutes of a whole or a half degree, try the next lead in Table XI, as follows:

$$\begin{array}{rl} & \log 0.6458 = \bar{1}.81010 \\ \text{(Subtract)} & \log 0.930 \;\; = \bar{1}.96848 \\ \hline & \log \sin a = \bar{1}.84162 \end{array}$$

Hence a = 43 degrees 59 minutes.

This angle fills the requirements. No more trials are, therefore, required, and the index head and the compound vertical milling attachment are to be set to 44 degrees; the gears to use for gearing the spiral head for 0.930 inch lead are found from Brown & Sharpe Mfg. Co.'s book "Table of Leads for Use with Universal Miling Machines," as aready mentioned.

In using this method, the following conditions must be taken into consideration:

If a spiral lead can be found in the accompanying tables which is exactly equal to the numerator l in the fraction giving sin a in Formula (1), then this lead is the lead for which the spiral head is to be geared. It will be seen that sin a in this case becomes equal to 1, which is the sine of 90 degrees. This indicates that the compound vertical milling attachment and the index head are to be set in a vertical position. The calculations required for this case then become very simple, as no further trials are necessary.

Especial attention should be given to the fact that the spiral leads L used in the trial calculations must be larger than the numerator l in the fraction giving sin a in Equation (1). If the number expressing the lead were not greater than the numerator, the value of the fraction would be greater than 1, but as the sines of all angles are smaller than 1, this would be an impossible condition.

In finding the lead corresponding to a suitable angle, a simple way is to write the logarithm of the lead L on the upper edge of a second sheet of paper and to hold this under the originally written value of the logarithm of the numerator l in Formula (1), putting the difference on the second sheet of paper until a logarithm of sin a is found, giving a suitable angle, as explained above. This saves repeating the writing down of the logarithm of the numerator l for each trial subtraction.

As another example illustrating what has been said, we may calculate the first lobe on the lead cam. Here $L = 0.906$, $N = 0.30$. Hence $l = \frac{0.906}{0.30} = 3.02$. It is found by repeated trials, starting with $L = 3.03$, that no lead gives an angle a even approximately within the given requirements, before we come to the lead 3.111:

$$\begin{aligned} &\log 3.02 = 0.48001 \\ \text{(Subtract)}\quad &\log 3.111 = 0.49290 \\ \hline &\log \sin a = \bar{1}.98711 \end{aligned}$$

Hence $a = 76$ degrees 6 minutes.

TABLE XIV. RESULTS OBTAINED BY THE CALCULATIONS FOR ANGLE AND LEAD

Piece No. 4-817
Computed by H. W. E.
Checked by W. W. J.
Date: Nov. 17, 1910

Name of Cam	Rise on Cam in Inches	Number of Hundredths	Angle a in Degrees	Lead in Inches	Gear on Worm	First Gear on Stud	Second Gear on Stud	Gear on Screw
Lead cam	0.906	30	76	3.111	40	72	56	100
Lead cam	0.906	14½	80	6.348	100	44	24	86
Front cam	0.155	24	44	0.930	24	72	24	86
Front cam	0.048	18½	20	0.930	24	72	24	86
Rear cam	0.837	82½	82	1.047	24	64	24	86

While the angle 76 degrees 6 minutes is not quite within the limits that we have specified, it is so nearly so that it is safe enough to assume the setting angle to be 76 degrees, the corresponding lead being 3.111. We can calculate the actual rise of the cam with this lead and angle and compute the error resulting in the rise. From Formula (2) we have:

$$R = \sin a \times N \times L \qquad (4)$$

Inserting $a = 76$ degrees, $N = 0.30$, and $L = 3.111$, we obtain $R =$ 0.9056 inch.

The error in the rise thus is 0.0004 inch, which for all practical purposes can be disregarded. The same method is employed for the other lobes. With a little practice, the work can be carried on rapidly, and the method is very simple to remember.

While it is the best practice always to use a spiral lead which corresponds to an angle within 5 minutes of a whole or half degree, as stated, yet a considerable amount of time may be saved in milling cam lobes with several leads, when the greatest accuracy may not be required. by gearing the machine for the greatest lead of lobe and changing the setting angle of the head for the other leads.

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