PLANING AND MILLING

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A TREATISE ON THE USE OF PLANERS, SHAPERS, SLOTTERS, AND VARIOUS TYPES OF HORIZONTAL AND VERTICAL MILLING MACHINES AND THEIR ATTACHMENTS

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PREFACE

THIS book deals with the practical problems connected with the adjustment and use of planers, shapers, slotters and milling machines of standard and special designs. Each subject is treated from the standpoint of the man in the shop, and a special effort has been made to present needed information pertaining to problems which the practical man often finds difficult to solve. Many operations from actual practice are illustrated and described to show the adaptability of different machines for certain classes of work, and the relation between various designs and types. Examples and operations have been selected that would not only show how a specific result is obtained, but illustrate fundamental principles and serve as a general guide. Descriptions of methods involving mathematical calculations contain the necessary rules or formulas and are accompanied by examples illustrating the problems which arise in actual practice.

While some of the material is rather elementary, many of the more advanced and difficult operations are explained, so that the book is not only a general treatise but contains much useful information of value even to experienced machinists. Detailed descriptions of different classes of planing and milling machines are given to show, in a general way, how modern machine tools are constructed and controlled, but, as far as possible, the practical application or use of the machine has been emphasized rather than its constructional details. The machines illustrated were selected as designs typical of different types, and not necessarily because they were considered superior to other machines of the same class.

Readers of mechanical literature are familiar with MACHINERY'S 25-cent Reference Books, of which one hundred and twenty-five different titles have been published during the past six years. As many subjects cannot be covered adequately in all their phases in books of this size, and in response to a demand for more comprehensive and detailed treatments of the more important mechanical subjects, it has been deemed advisable to publish a number of larger volumes, of which this is one. This work includes MACHINERY's Reference Books Nos. 93, 96 and 97, together with a large amount of additional information on modern planing and milling practice. In the preparation of the subject matter, many practical methods and interesting operations were obtained from the columns of MACHINERY and represent approved machine-shop practice.

As the illustrations in a book of this kind constitute a very important feature, they have received particular attention. Practically all of the drawings are original and most of them are simple diagrams which can easily be understood, even by those not accustomed to "reading" drawings. Care was taken also to secure photographs which would clearly illustrate the different subjects presented. The coöperation of the machine tool manufacturers who generously supplied many of these views is greatly appreciated.

F. D. J.

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CHAPTER I

PLANING MACHINES AND THEIR APPLICATION

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 tool-head *T* 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 while cutting, and when the platen is near the end of the return stroke, the tool-head and tool feed slightly for taking 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.

Planer 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*, meshing with a large gear *g*. This large gear, which is called the "bull-wheel," 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

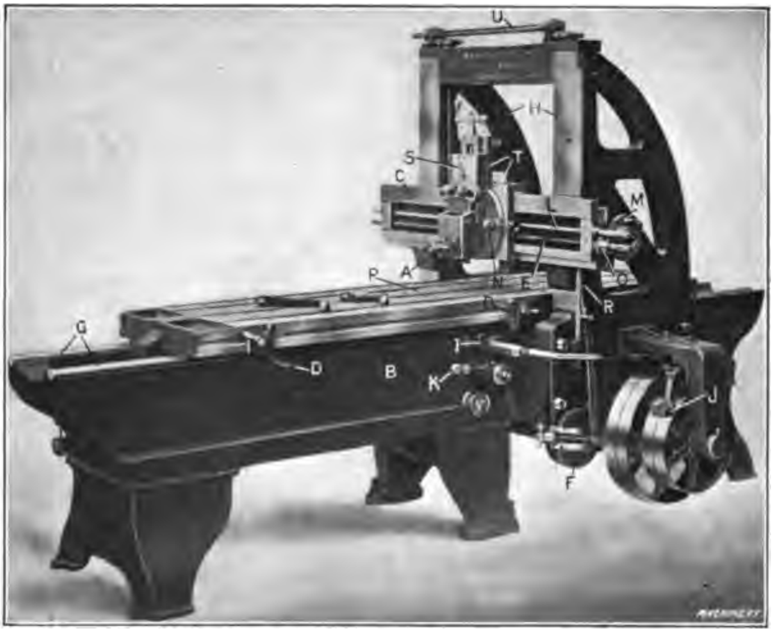


Fig. 1. Single-head Planing Machine

revolves freely. The belt operating on the large pulleys *f* and f_1 is crossed, whereas the belt for the smaller pulleys *r* and r_1 is "open," 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 crossed 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 crossed belt on loose pulley f_1 and the open 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 open 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

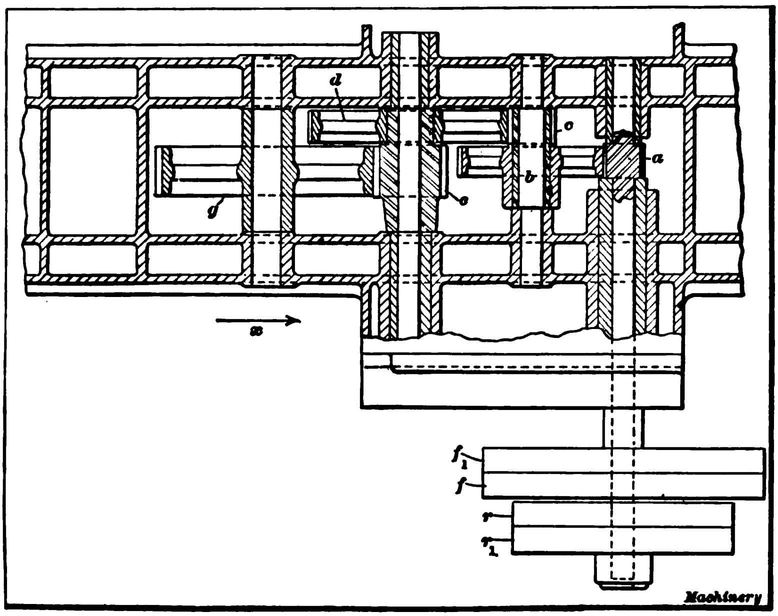


Fig. 2. Driving Mechanism of a Spur-geared Planer

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 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 tool is cutting than when the table is on the return movement. 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.—As previously mentioned the feeding movement of the tool takes place on the return stroke and before the tool begins to cut. 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 tool-head *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 cross-wise position of the tool and head can be varied by turning horizontal feed-screw *E*.

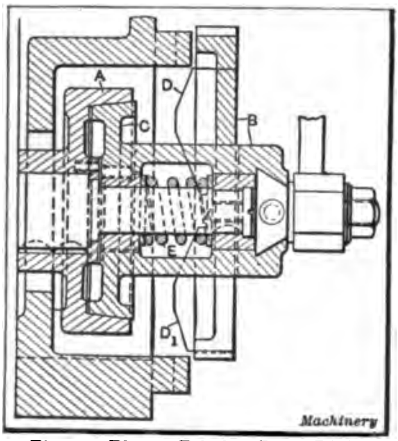


Fig. 3. Planer Friction Feed Disk

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* which 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 tool-head feed-screw through gearing. This shaft is also driven by gear O which is removable and is placed on shaft L when an automatic vertical feed is desired.

The friction disk F is turned by pinion shaft e (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. 3. 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.

Spiral-geared Planer.—There are two general methods of driving a planer table. The most common form of drive is that in which the motion is transmitted from the belt pulleys through spur gearing to a "bull-wheel" or spur gear, which meshes with a rack attached to the under side of the planer table, as described in connection with Figs. 1 and 2. A planer driven in this way is known as a "spur-geared" type to distinguish it from the "spiral-geared" planer. With a spiral-gear drive (sometimes known as the Sellers drive) the motion is transmitted from the belt pulleys through bevel gears to a shaft which extends under the bed diagonally and carries a spiral pinion or worm which meshes with the table rack. The belt pulleys are mounted on a shaft that is parallel to the table, instead of being at right angles as with a spur gear drive. Smoothness of action is the principal advantage claimed for the spiral gear drive.

Example of Planer Work. — A simple example of planing is illustrated in Fig. 4. The work *W* is a base casting, the top surface of which is to be planed true. The casting is first fas-

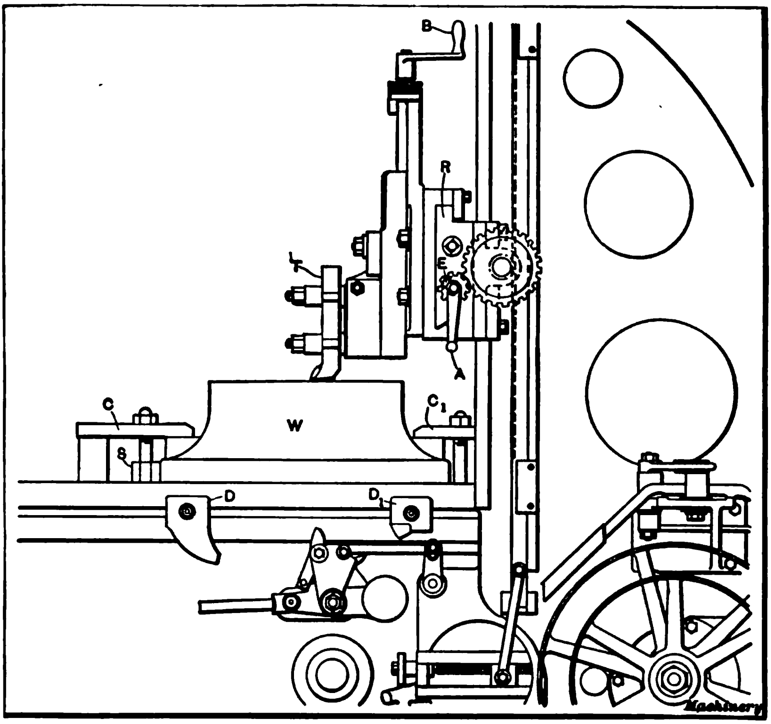


Fig. 4. Side View of Planer with Work in Position

tened 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 reception of clamping bolts and stop-pins. When the casting is securely attached to the platen, a planing tool *T* is clamped in the tool-post, 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 casting and are set far enough apart to give the platen 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. 5, 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

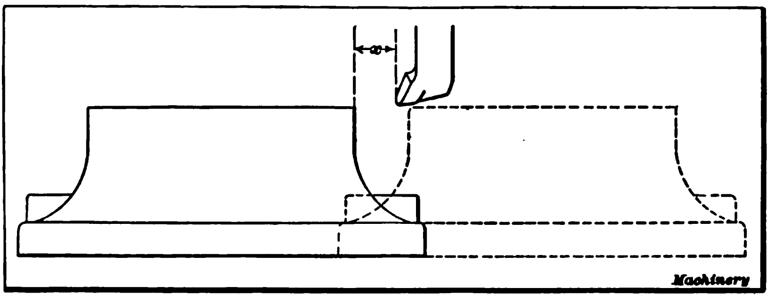


Fig. 5. Movement of Work with Relation to Planing Tool

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 a small handle *E*. The tool planes the surface of the casting by feeding horizontally across it and removing a chip during each forward stroke. 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 will be referred to later.

Position of the Tool and Cross-rail. — The tool should be set about square with the surface to be planed, as shown at *A*, Fig. 6, 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.

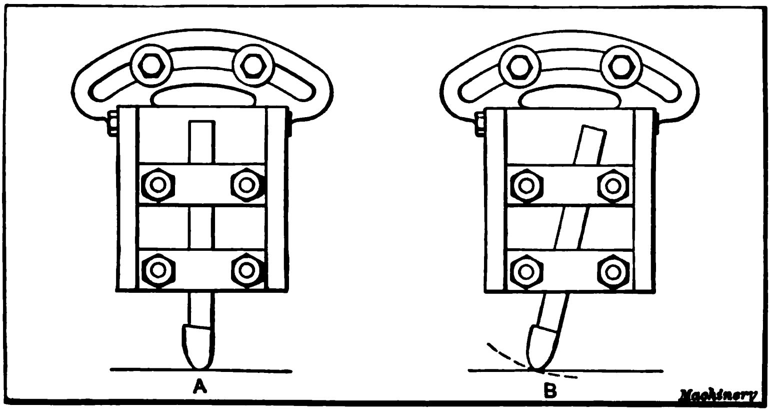


Fig. 6. Correct and Incorrect Positions for Tool when Planing a Horizontal Surface

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

Alignment of Cross-rail. — 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 position of the cross-rail.

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 position of the cross-rail. The parallelism of the cross-rail can also be tested accurately by clamping an ordinary dial indicator to the tool-head, and noting the readings when the indicator is moved from one side of the platen to the other. If the cross-rail is not parallel, the low side should be raised by adjusting the elevating screw.

Planing Work held in a Chuck. — Another planing operation is illustrated in Fig. 7. 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 were used, they would interfere with the movement of the tool. This chuck, an end view of which is shown at *A* in Fig. 8, 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. 7), the casting is turned to bring its finished face against the stationary jaw *J* as shown at *A*, Fig. 8. A finished or planed surface should always be located against the fixed or stationary jaw of the vise,

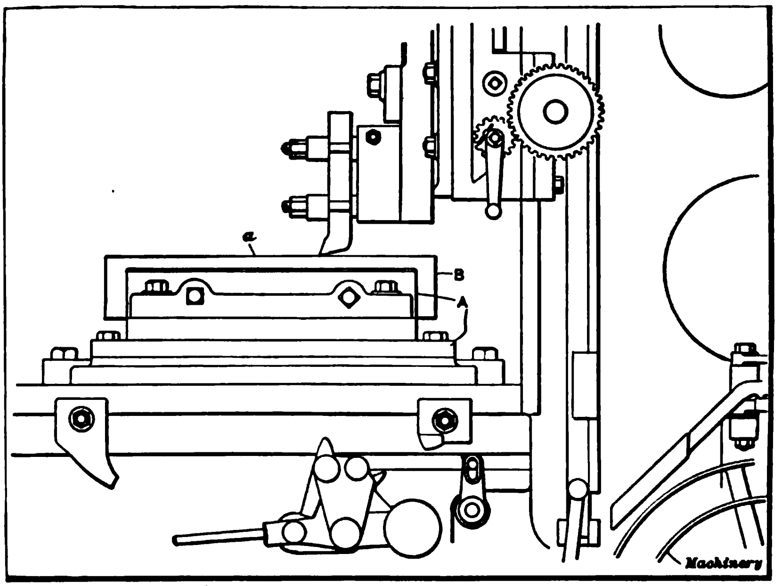


Fig. 7. Planing Work held in a Chuck

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 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

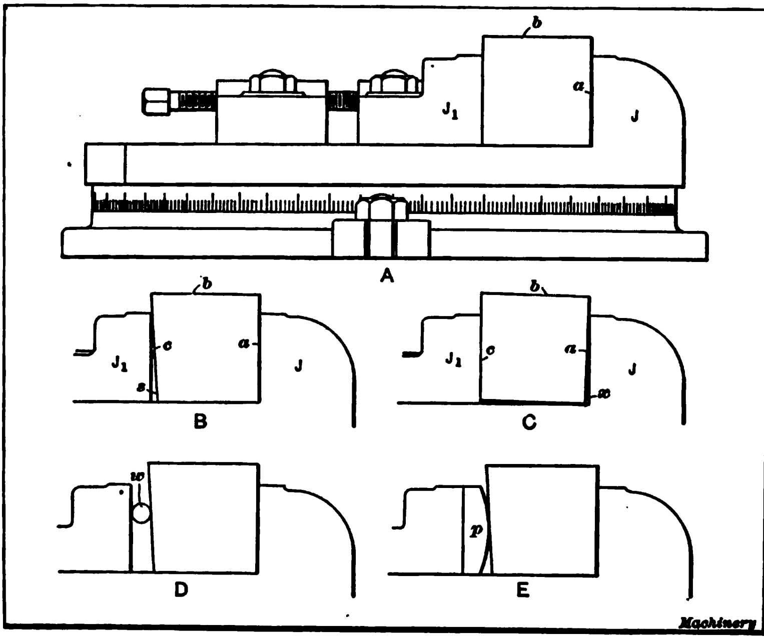


Fig. 8. Planer Chuck — Diagrams showing how Work is Tilted, and Methods of Holding it Square

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 clamping work in a planer chuck. If considerable accuracy were required, the block could be held to better advantage by fastening it directly to the table with special

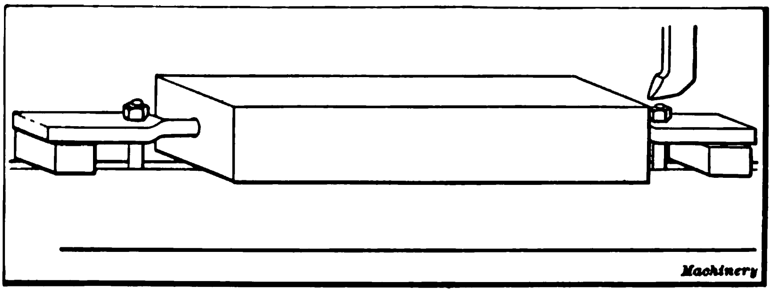


Fig. 9. Holding Block directly against Platen by Finger-clamps

clamps, as indicated in Fig. 9. 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.

Double-head Planers — Use of Side-heads.— Modern planers, with the exception of comparatively small sizes, are ordinarily equipped with two tool-heads on the cross-rail, as shown in Fig. 10, 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

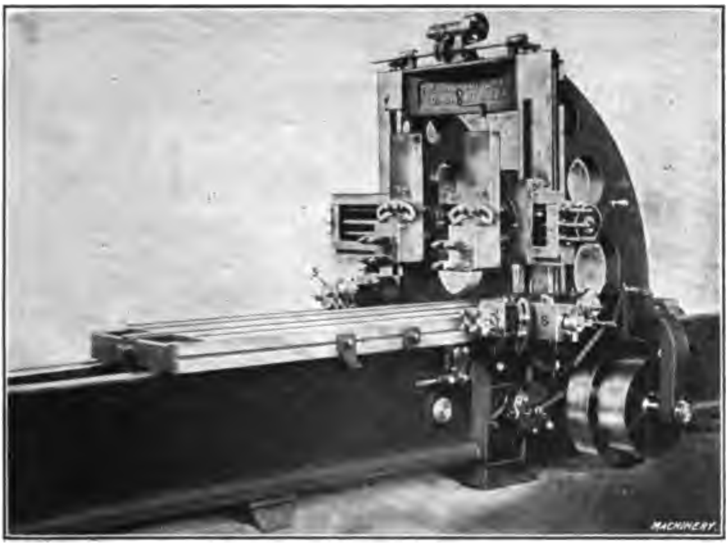


Fig. 10. Cincinnati Four-head Planer

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, etc., the planing would be done first on one side, and then on 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.

Application of Two-head Planer. — Two or more tools can be used at the same time in connection with many planing operations. Fig. 11 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

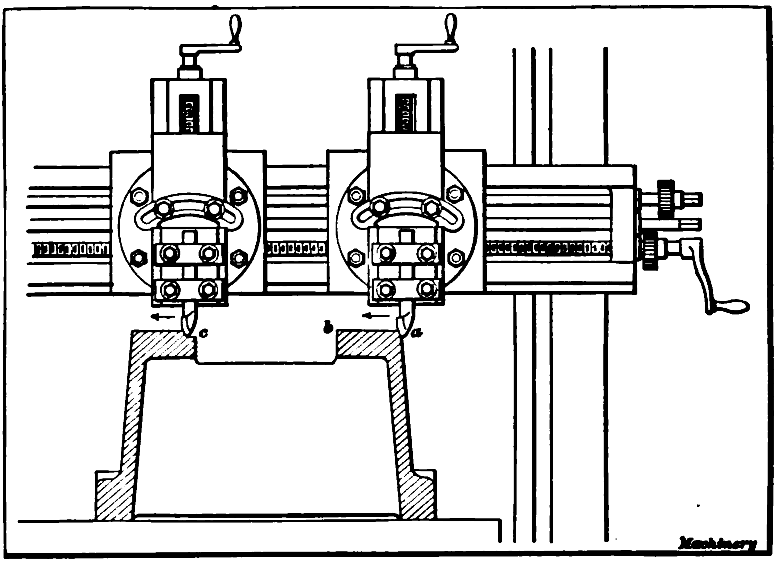


Fig. 11. Planing Two Surfaces Simultaneously with Two-head Planer

the *leading* tool, as determined by the direction of the feed. This is a good rule to follow, especially when the tool-heads are quite close to each other on the cross-rail, 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 $\frac{1}{2}$ or $\frac{3}{4}$ 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 $\frac{1}{4}$ 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.

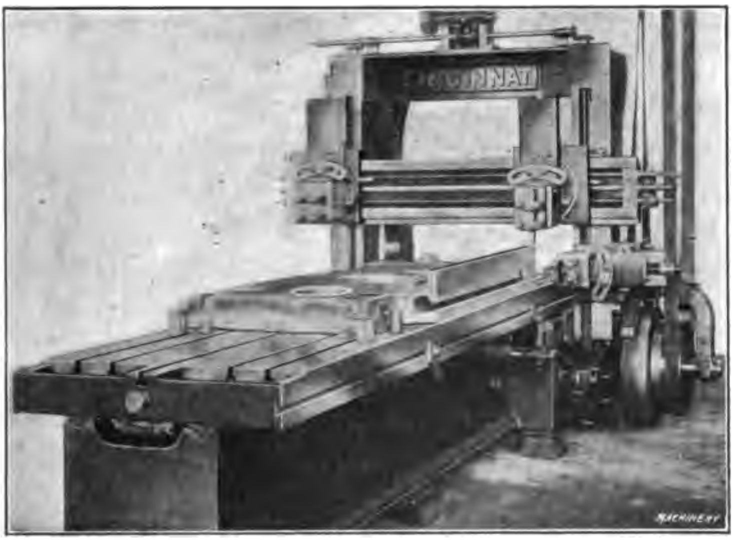


Fig. 12. Planing Top Edge and Side of Casting—Illustrating use of Side-head

Application of Side-head. — A typical example of the class of planer work on which a side-head can be used to advantage is shown in Fig. 12. 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 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

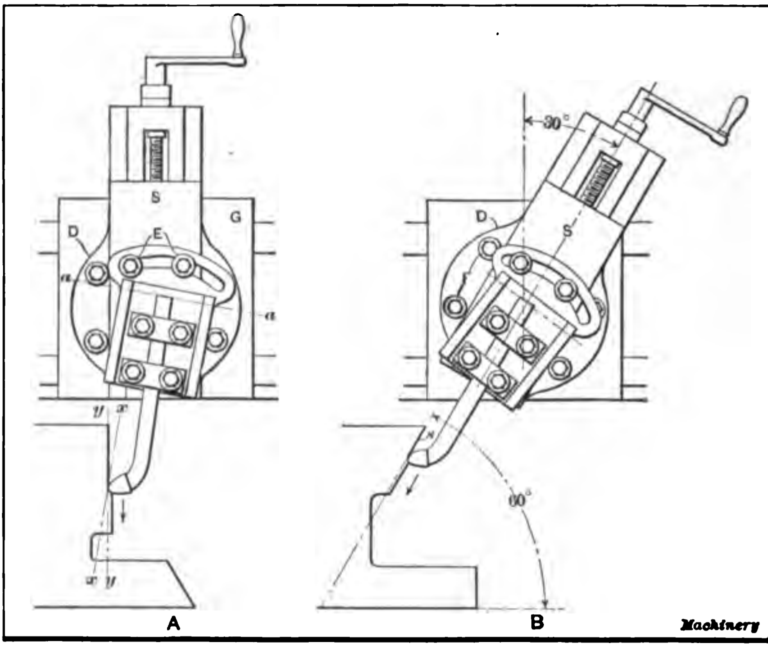


Fig. 13. Positions of Tool and Head for Planing Vertical and Angular Surfaces

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.

Planing Vertical 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. 13 is ordinarily used, unless the planer has side-heads, in which case a straight tool held in the side-head can often be used to advantage. 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 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 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.

Fig. 14. Tool-heads set for Planing Angular Surfaces

Planing Angular Surfaces. — The planing of an angular surface is illustrated at *B*, Fig. 13. 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. 14, 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 platen are also planed at the same setting by tools held in the side-heads.

Holding 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 parts on a planer and clamping them in the best manner. There are three important points 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 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. — Much of the work done on a planer is clamped directly to the platen although in many cases special fixtures are used. A form of clamp that is often used is shown at A in Fig. 15, 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 of the clamp or at the edge of the casting. Packing blocks are made of either hard wood or cast iron.

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

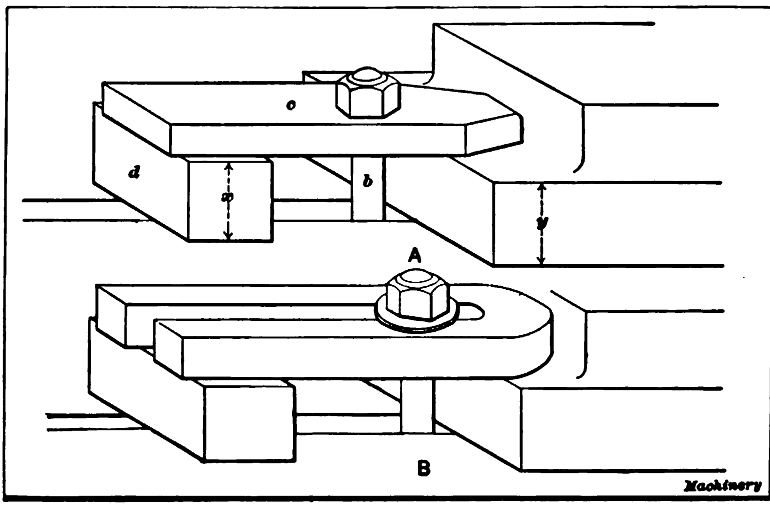


Fig. 15. Clamps for Attaching Work to Planer Platen

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. 16 shows an off-set clamp applied to a casting which, we will assume, is to be planed on the top. If, in this 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. 17 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.

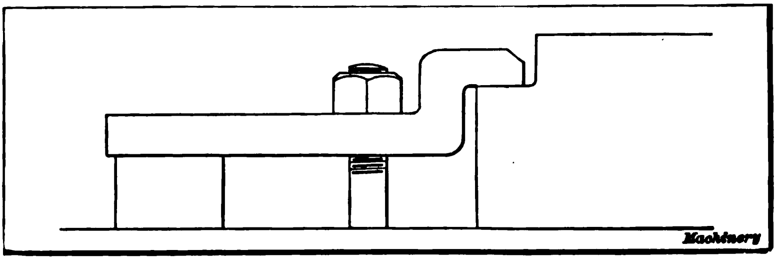


Fig. 16. Off-set Clamp

An illustration of the use of finger clamps is given in connection with Fig. 9. 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

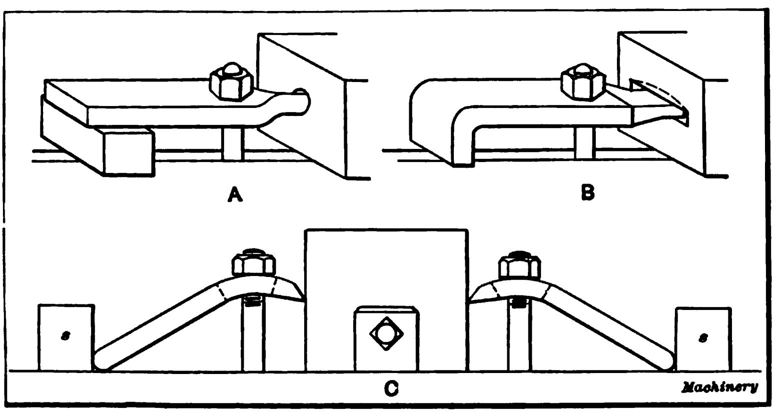


Fig. 17. Methods of Clamping Work which cannot be held by Ordinary Means

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.

Three styles of bolts that are generally used for planer work are shown at *A*, Fig. 18. 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

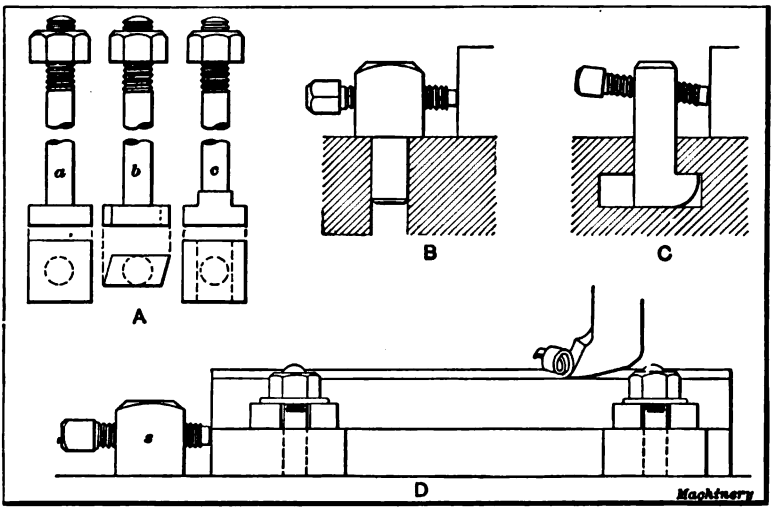


Fig. 18. Planer Clamping Bolts — Stop-pins — Use of Stop-pins

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. 18. 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 in-

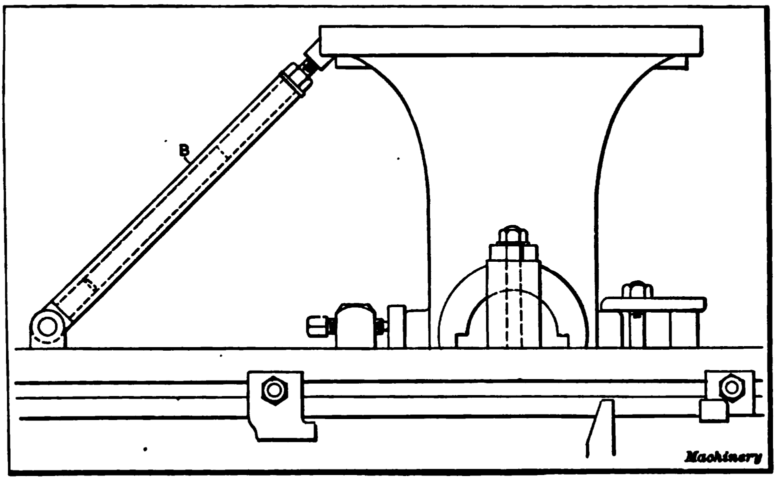


Fig. 19. High Casting supported by Brace which takes Thrust of Cut

clined, as shown at *C*, in order to force the work down against the platen. Stop-pins are also made without adjusting screws.

Some castings have surfaces to be planed that are a considerable distance above the platen, as shown in Fig. 19, 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 pin 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 depend 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.

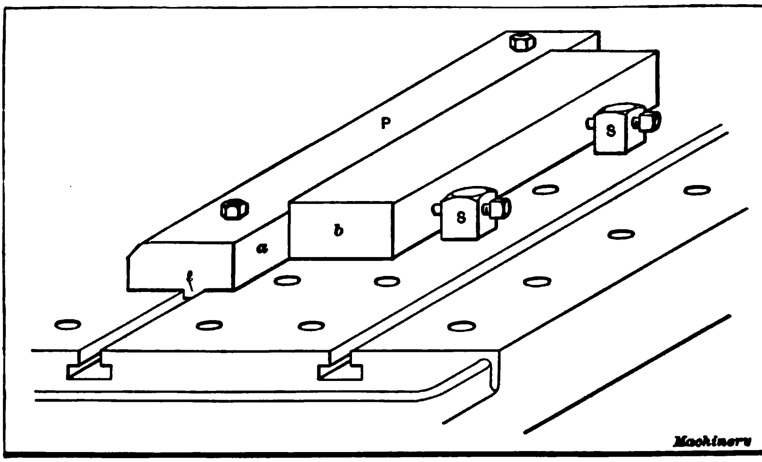


Fig. 20. Work held between Stop-pins and Strip Bolted to Platen

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. 20. The part to be planed is held between ordinary 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 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

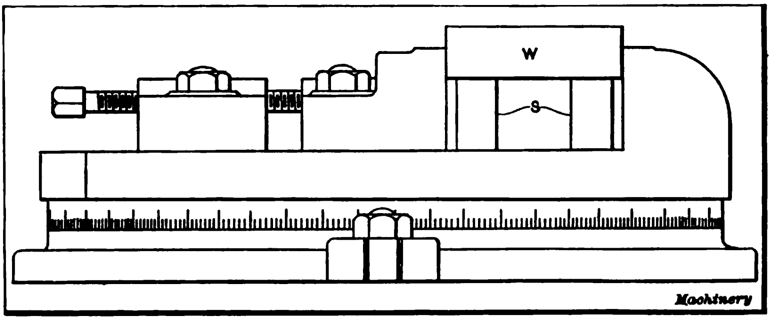


Fig. 21. Illustration showing use of Parallel Strips

in Fig. 21. 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

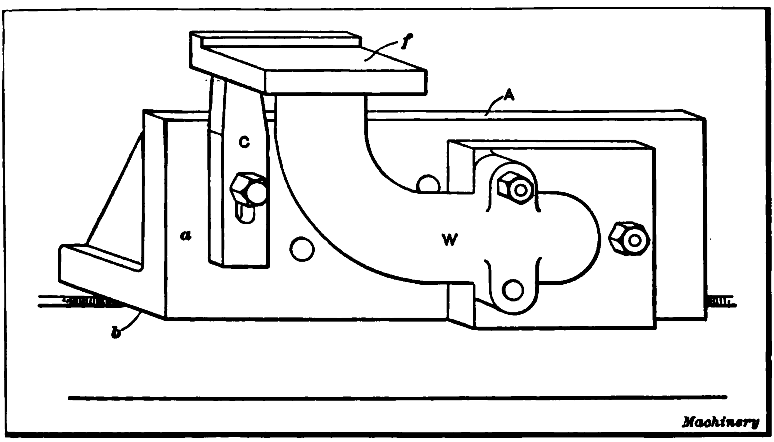


Fig. 22. Odd-shaped Casting attached to Angle-plate

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. — The method of holding an odd-shaped casting on an angle-plate is illustrated in

Fig. 22. The angle-plate *A* has two faces *a* and *b* 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. 23. In this

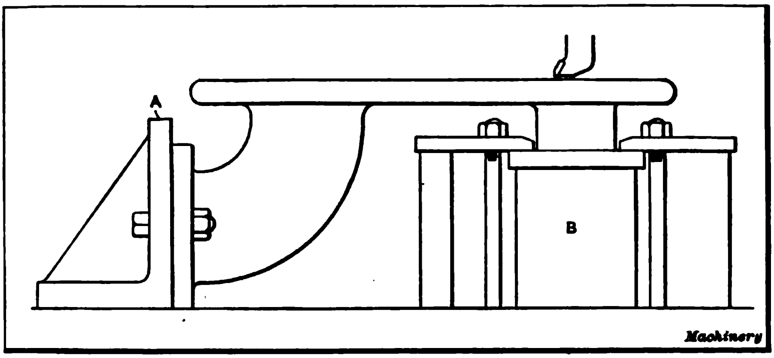


Fig. 23. Use of Angle-plate in Conjunction with Clamps for Holding Work

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.

Holding Thin Plates for Planing. — 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. 24, are used. These are known as "spuds" or "toe-dogs," and one way in which they are applied 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.

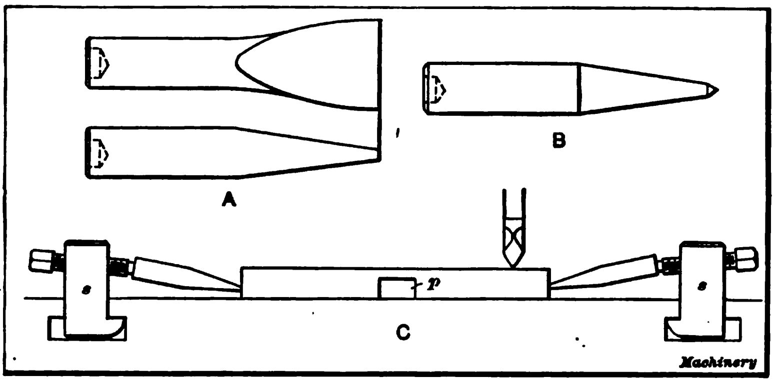


Fig. 24. Method of Holding Thin Flat Plates while Planing

Use of Magnetic Chucks on Planer. — Magnetic chucks, such as are used on surface grinding machines, can also be applied to planing and milling operations, especially for holding thin parallel parts that are difficult to hold by other means. Fig. 25 shows how a magnetic chuck of rectangular shape is used for holding three castings while the upper surfaces are being planed. The current (which must be direct and not alternating) is supplied by a cable *A* which passes under the cross-rail to a plug above the machine. The chuck is magnetized by closing switch *B* which is a duplex type. In order to demagnetize the chuck face, open the switch and move the handle until the switch bars nearly come into contact with the posts on the opposite end; then quickly move the switch bars in and out of contact with the posts. This movement, if timed correctly, will remove the magnetism left by the previous magnetic charge. If the contact should be too long, the chuck will simply become oppositely

Fig. 25. Walker Magnetic Chuck applied to Planing Operation

charged and in such a case, it can be discharged again by moving the switch in and out of contact with the opposite posts.

The castings are held against end-wise movement by the strip *C* which takes the thrust of the cut. Slotted clamps *D* are also used to stay the work laterally. When a number of pieces are held on the chuck at one time, it is advisable to separate them with strips of non-magnetic material. Iron or steel parts can be held on magnetic chucks, and the gripping power depends upon the amount of surface in contact with the chuck face.

Imbedding Work in Plaster of Paris or Wax. — Sometimes it is necessary to plane thin parts which cannot be held on magnetic chucks because they are made of some non-magnetic material, such as bronze, or because they are so irregular in shape that there is not sufficient surface in contact with the chuck face to hold the work securely. In such cases, it may be advisable to imbed the work in plaster of Paris, especially if the parts are flexible and liable to be sprung out of shape and it is impossible to use ordinary clamps. A mixture of melted bees-wax and rosin in about equal proportions is also used for this purpose. One or more pieces are placed in a box-shaped enclosure and

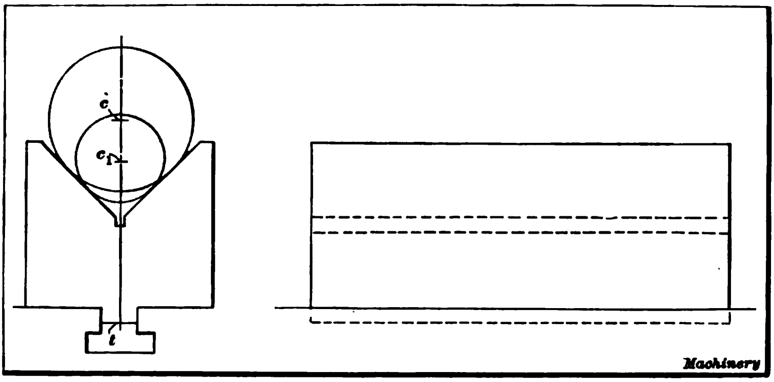


Fig. 26. V-block for Holding Cylindrical Parts in Alignment with Machine Table

plaster of Paris or wax is poured around them and allowed to set, thus holding the parts for planing and supporting them in every direction. This method of clamping work is rarely necessary.

Holding Cylindrical Parts for Planing. — The planer is sometimes used for cutting keyways or splines in shafts, and, occasionally, other cylindrical work requires a planing operation. In order to hold and at the same time align round work with the platen, V-blocks (Fig. 26) are used. These blocks have a tongue piece *t* at the bottom which fits into a T-slot 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. 27 illustrates how V-blocks are used in locomotive shops for holding a piston-rod while the cross-head, which is mounted on the end, is being planed. The bearing surfaces of the cross-head must be in line with the rod which fits a tapering hole in

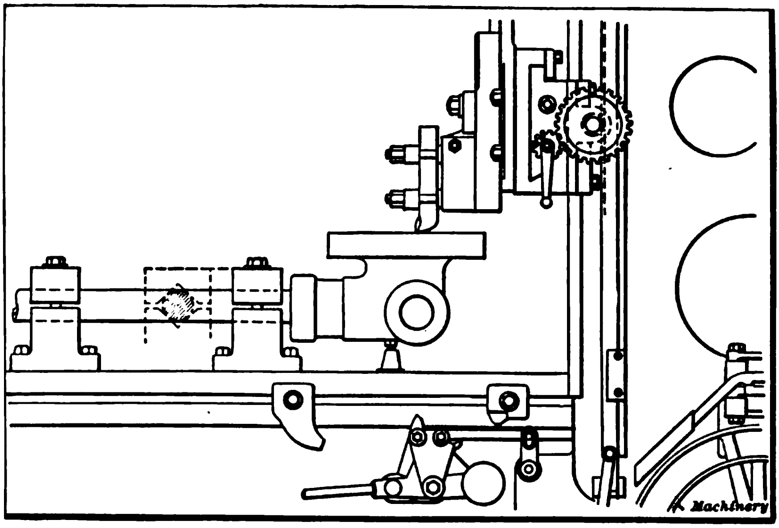


Fig. 27. Piston-rod and Attached Cross-head Mounted in V-blocks for Planing

one end of the cross-head. 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 special planer strip which is used in conjunction with screw-stops for holding round parts is illustrated in Fig. 28. The strip has an angular face f so that pressure from the screws s tends to force the 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.

Method of Planing Accurate V-blocks. — 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. 26, 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 an angle of 45 degrees and one side of the vee is rough planed. The blocks are then reversed or turned "end for end" and the opposite side is rough planed without disturbing the angular setting of the head. These operations are then repeated for the finishing cuts. This method of reversing the work, instead of setting the head to the opposite

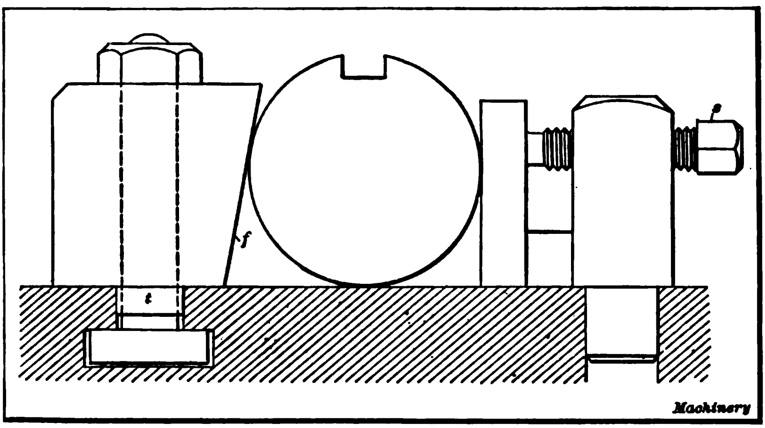


Fig. 28. Method of Holding Shaft for Splining or Keyseating

angle, insures equal angles for both sides and a vee that is exactly central with the tongue piece.

Distortion of Work by Clamping. — 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. 29, 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

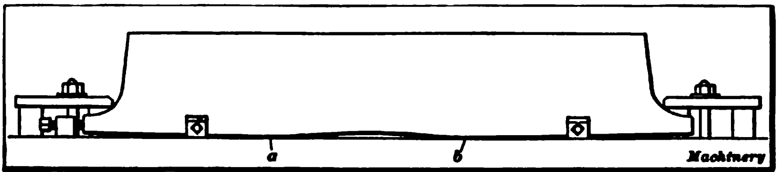


Fig. 29. Class of Work which is sometimes Distorted by Clamping

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 removed.

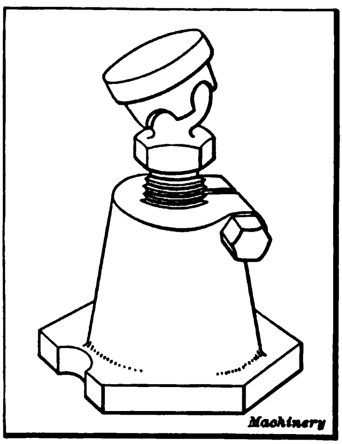


Fig. 30. Planer Jack

Very long castings or those which are rather frail but quite large and 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. When setting such castings on the planer, jacks, such as the one illustrated in Fig. 30, 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. 27 shows 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.

Distortion Caused by Internal Stresses. — 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

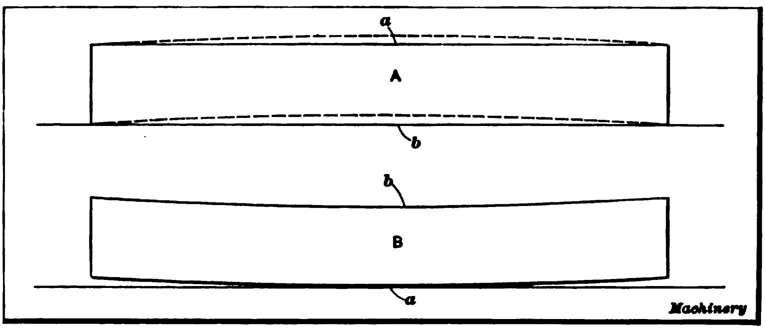


Fig. 31. Diagrams Illustrating, on Exaggerated Scale, Distortion Caused by Internal Stresses in Castings

side, a slight distortion takes place. This is illustrated on an exaggerated scale in Fig. 31. 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. When great accuracy is required, it is the practice in some shops to rough plane the casting and then allow it to "season" for several weeks before taking the finishing cuts. This seasoning period is to allow the stresses

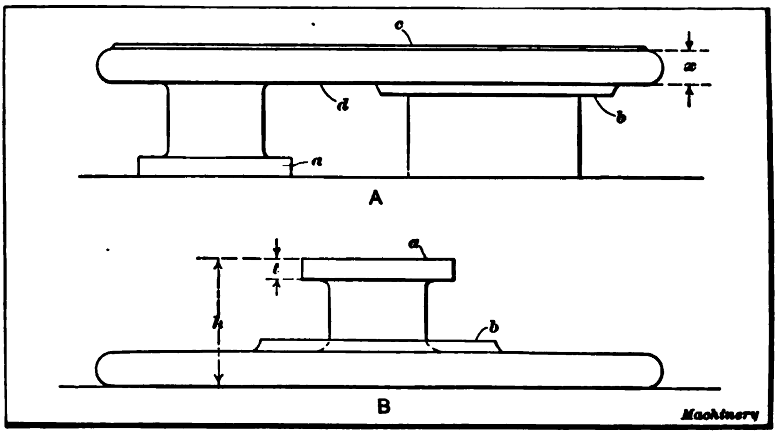


Fig. 32. Diagram Illustrating Points Relating to Position of Work

to become adjusted so that little or no change will occur after all the surfaces are finished.

Locating Work with Relation to Surfaces to be Planed. — 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. 32, is to be planed so that the distance between these surfaces corresponds to the dimensions given on a 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. 33. Surface Gage

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 to show the location of finished surfaces, and also for setting parts parallel with the platen. This tool, which is shown in Fig. 33, has a rather heavy base on which is mounted a rod *R* 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. 34. The scriber *s* is first set

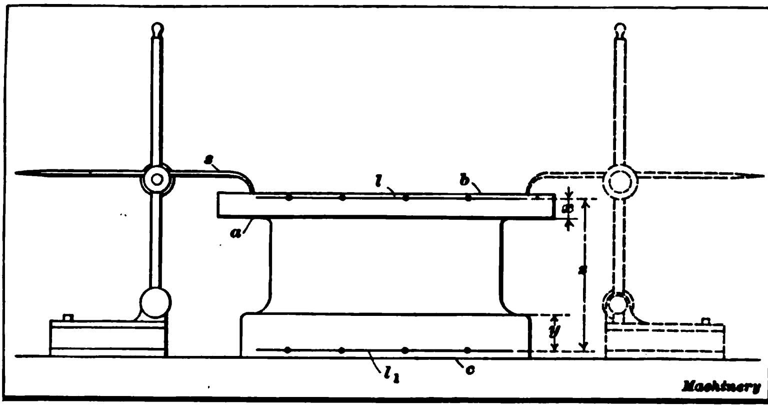


Fig. 34. Testing Alignment by Using Surface Gage

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 heights at various points are compared.

The surface gage is also used extensively for laying out work. As a simple illustration, suppose the sides *b* and *c* (Fig. 34) 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.

Various Forms of Planer Tools. — The number and variety of cutting tools used on a planer depend upon 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 duplicate parts do not need a large tool equipment. In Figs. 35 and 36, 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. 35 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 metal. This style of tool is also made to the opposite hand, as at *B*, because 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. (See "Feeds for Planing.") Wide finishing tools for cast iron are sometimes ground so that the cutting edge, instead of being parallel with the front side of the tool, slopes back at an angle to give a shearing cut. A plain round-nose tool is shown at *D*. This style is often used for rough planing steel or wrought

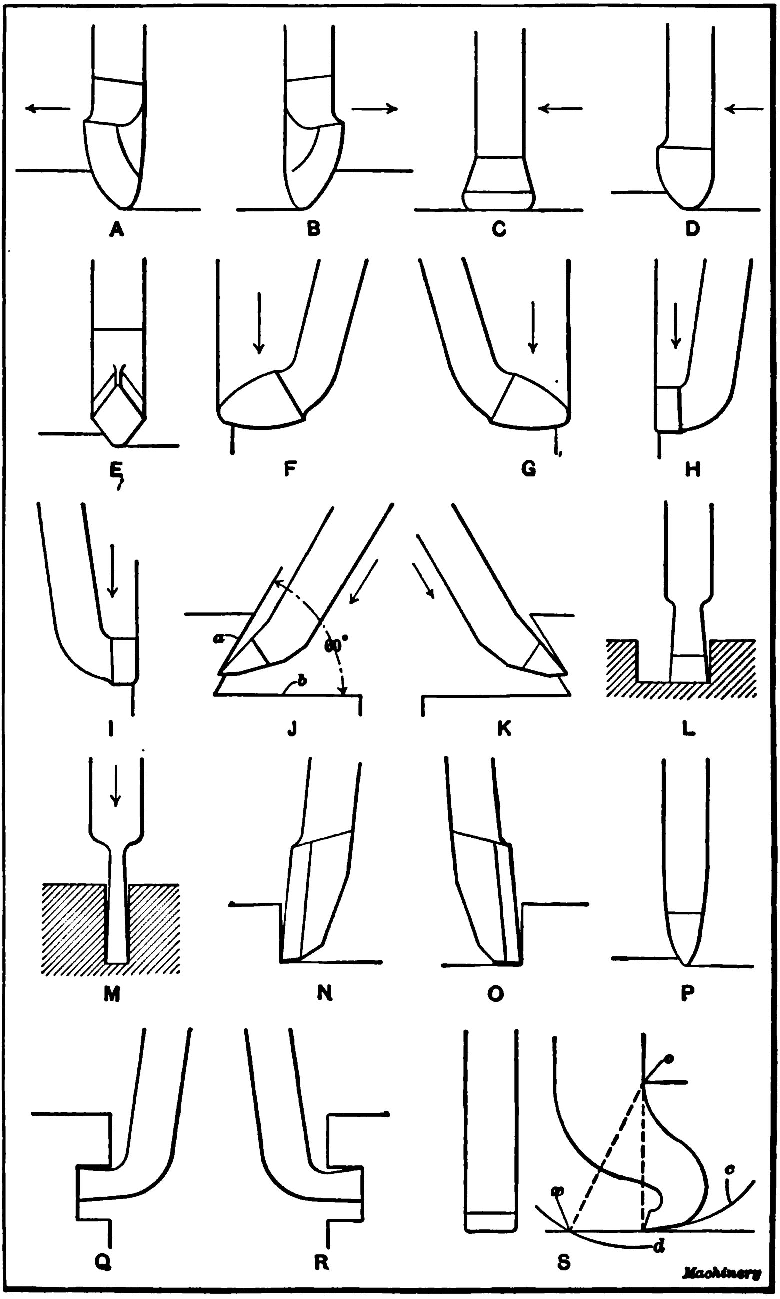


Fig. 35. Planer Tools of Different Form and Operations for which They are Adapted

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 and for taking light cuts.

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*. 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 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

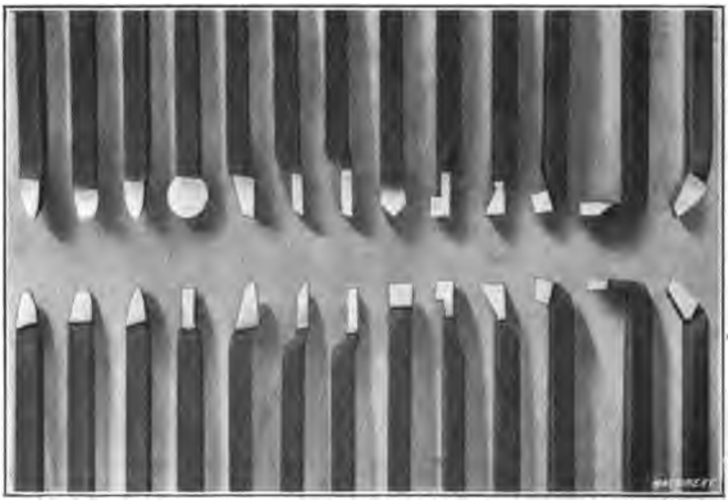


Fig. 36. Set of Planer Tools Ground on Sellers Tool-grinding Machine

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 gouge 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. 35 are forged from a solid bar of steel, the cutting end being forged to about the right shape, after which the end is correctly formed by grinding. After the tool has been worn away considerably by repeated grindings, the end has to be reforged 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. 37. This particular style is so

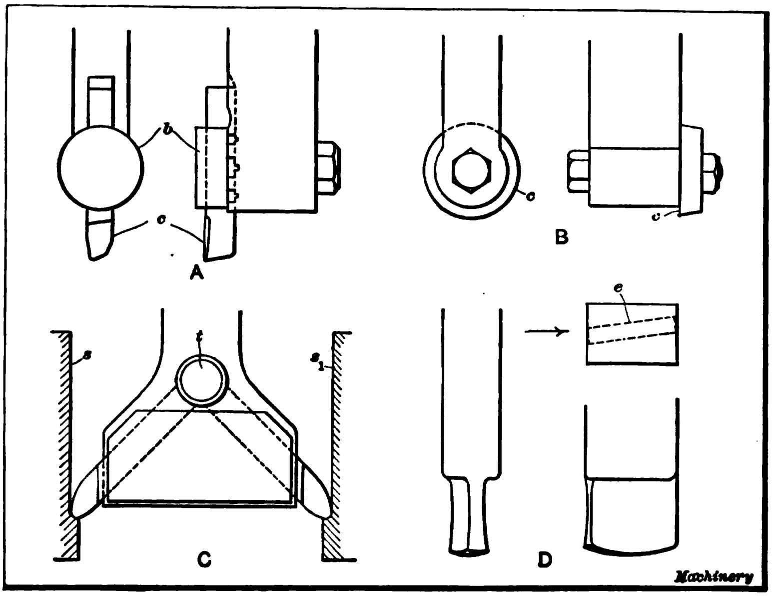


Fig. 37. (*A*) Planing Tool with Inserted Cutter. (*B*) Radius Tool. (*C*) Tool having Two Cutters. (*D*) Finishing Tool

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.

The tool shown at *B* has a circular cutter *c* which is held to the shank by a bolt as shown. This style of tool is used for finishing round surfaces, the cutter being made to the required diameter. It is also used for finishing the upper sides of T-slots as illustrated at *A* in Fig. 38, the diameter *d* of the cutter being equal to the width of slot required. When the cutter becomes dull, its retaining bolt is loosened and the cutter is turned around far enough to bring a new edge in the working position. Form tools are sometimes used on planers for finishing surfaces of irregular form, the cutter being made to correspond in shape to the form required.

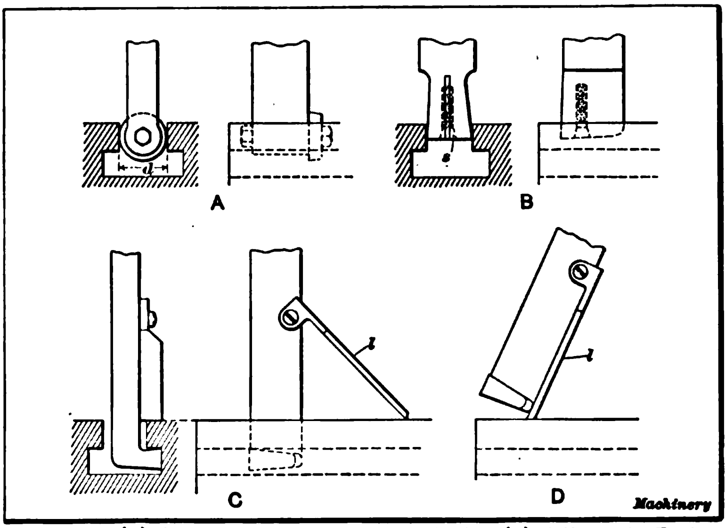


Fig. 38. (*A*) Sizing T-slot with Circular Tool. (*B*) Adjustable Tool. (*C*) Undercutting Tool with Lifting Latch

A tool having two cutters is shown at *C*, Fig. 37. 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 tool shown at *D* is a solid forged type, that is adapted 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.

Another form of tool for finishing the sides of T-slots is illustrated at *B* in Fig. 38. The cutting end is slotted through the center and a small conical headed screw *s* is used to spread the two sections when the width of the end has been reduced by repeated grinding.

Sketches *C* and *D* show how a latch is sometimes applied to an under-cutting tool such as is used on planers for machining the

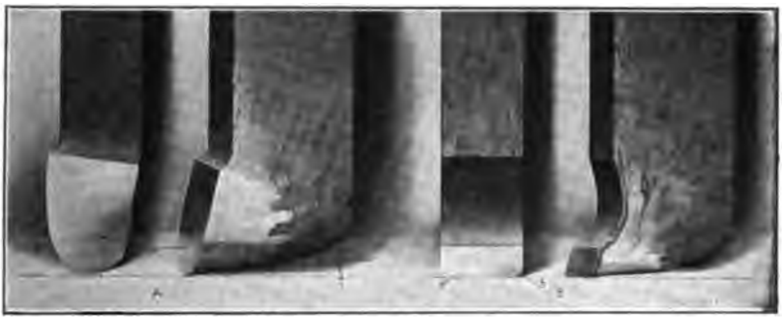


Fig. 39. Roughing and Finishing Tools for Planing

bottoms of T-slots. The stroke of the planer is adjusted so that the hinged latch *l* which drags over the upper surface on the cutting stroke drops down and, when the tool returns, prevents it from entering the slot. The position of the tool on the return stroke is illustrated at *D*. When a lifting latch is not used, it is necessary to block the tool so that it cannot rise against the upper part of the slot. Blocking the tool is objectionable, because the cutting edge drags back over the planed surface and is dulled quickly.

Points on Grinding Planer Tools. — While the action of a planer is entirely different from that of a lathe, many of the principles which govern the shape of turning tools also apply in the grinding of tools for planing. Front and side views of a planer roughing tool are shown at *A*, Fig. 39. 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 slope being away from the *working part* of the cutting edge. 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, whereas a planer tool is stationary during the cut, the

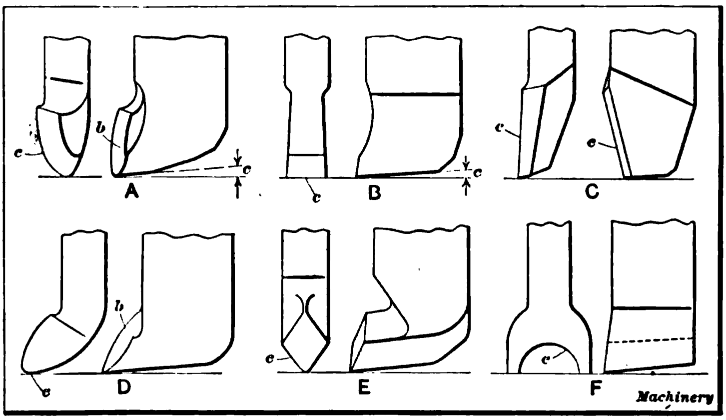


Fig. 40. Different Types of Planing Tools

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 stronger. When tools are ground by hand, the angles of slope and clearance are not ordinarily measured, the workman being guided by experience. By grinding a flat spot on the nose or lower end, this tool can be used for taking finishing cuts in steel. Finishing cuts are also taken with a round nose tool by using a fine feed.

The edge *e* of the cast-iron finishing tool *B* should be ground straight by testing it with a small straight edge 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 shape of the tool. Tool *A*, Fig. 40, is shaped somewhat like a side tool except that cutting edge *e* is curved. The face *b* slopes away from edge *e* and the end is given a slight clearance *c*. The square-nose tool, seen at *B*, cuts along its lower edge *e*, and is given clearance *c* 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 *C* 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 greater shock. As tool *D* is used for vertical planing, the cutting is done by edge *e*; hence face *b* should slope back from edge *e*. The diamond point *E* is ground with a narrow rounded point; this type of tool is useful when a light cut is necessary, either because the work cannot be held securely for planing or for some other reason. The form tool *F* is used for rounding edges. Tools of this type are sharpened by grinding on the front face only, in order to retain the curved edge. When sharpening other than formed tools, the grinding is done both on the face and end, because a sharp edge can be secured more quickly by this method.

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 grinding wheel, as is often done in attempting to sharpen the tool 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 plenty of cooling water.

Multiple or Gang Planing. — 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 possi-

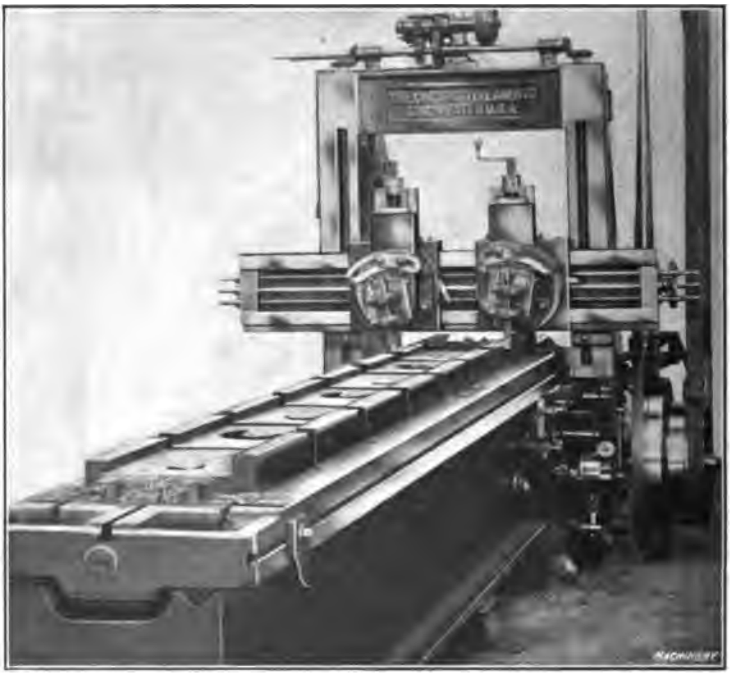


Fig. 41. An Example of Gang Planing

ble by machining them separately, and it also insures duplicate work. An example of multiple or gang planing is shown in Fig. 41. The particular castings illustrated are the "saddles" of planer tool-heads and eight are being planed at the same time. Both tool-heads are in use, and the top surfaces 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

Fig. 42. Twenty Connecting-rods being Planed Simultaneously

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, the gang method of planing insures a uniform product and greatly reduces the time required for machining.

Another example of gang planing is shown in Fig. 42. Twenty engine connecting-rods are clamped to the platen and the two heads of the planer are working on the bosses at each end of the rod, the operation being that of planing the sides. The rods are placed against one another, with every alternate rod reversed, to bring a large and small end together, in order to make a straight line of castings. The entire string of castings is prevented from shifting along the table by two stop-pins at the end, and they are held down on the platen by a series of straps or clamps along the center. These connecting-rods are steel castings; the planer has a cutting speed of 40 feet per minute with a $\frac{1}{8}$ inch depth of cut and a transverse feed of $\frac{3}{32}$ inch per stroke.

Castings that are finished by gang planing are often held in special fixtures, especially if they are of irregular shape and not readily clamped directly to the planer table.

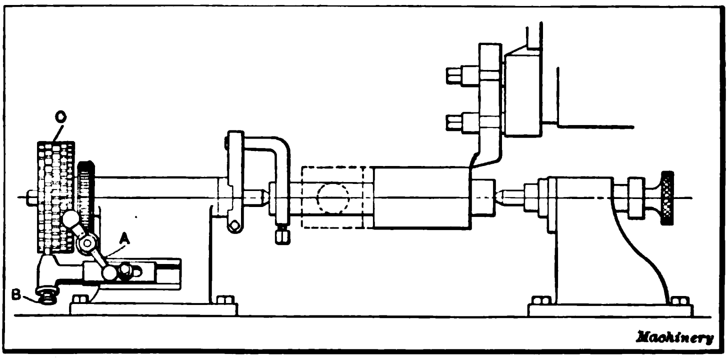


Fig. 43. Illustrating Use of Index Centers as Applied to Planer Work

Use of Planer Index Centers. — Centers are sometimes used on the planer to support work that must be indexed or rotated part of a revolution between successive operations. Fig. 43 shows a set of planer centers and illustrates their application. The centers are bolted to the table and are aligned with each other by tongues on the base which fit into one of the T-slots. The example of work shown has been turned in a lathe, and the operation is that of planing the enlarged part square. The sides of the square section must be parallel with the cylindrical ends. The piece is held by the same center-holes that were used for turning it, and a dog is attached to one end. This dog engages the slotted arm of the headstock center, all play between the dog and arm being eliminated by adjusting a set-screw provided for this purpose.

The work is first tested for alignment with a table, by using a surface gage. The curved point of the gage is then set above the cylindrical end a distance equal to one-half the width of the square, minus the radius of the end. The surface gage is then used to test each side as it is planed. The headstock spindle is revolved for indexing, by turning the handle *A*, which connects with the spindle through worm-gearing. The indexing is done on this particular headstock, by engaging pin *B* with one of the series of notched plates *C*. (Some planer centers have a number of concentric rows of holes which are engaged by a round pin.) There are five plates having 44, 52, 56, 90 and 96 divisions,

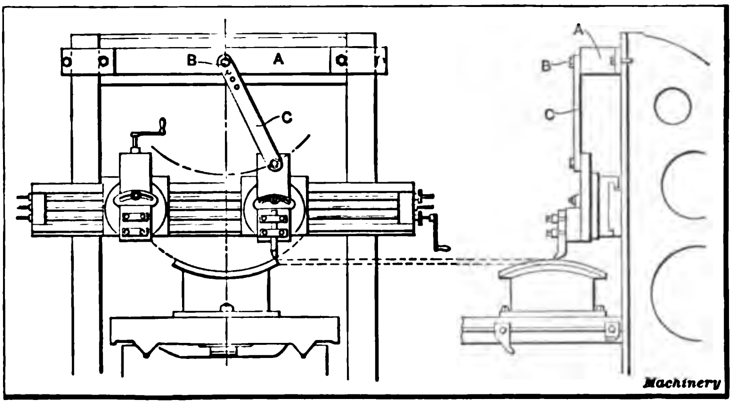


Fig. 44. Planer Equipped with Attachment for Circular Planing

respectively, and pin *B* is aligned with any one of these plates by adjusting the arm which holds it along a groove in the base.

The plate to use, in any case, must have a number of notches evenly divisible by the number of divisions required on the work. When planing a square section, the plate having 44 notches could be used ($44 \div 4 = 11$), eleven spaces being indexed for planing each side. The tailstock center of this attachment can be adjusted vertically in order to hold parts at an angle, when planing bevels or tapering surfaces.

Planing Curved Surfaces. — Curved surfaces that are either circular or of irregular form are sometimes finished by planing, especially when the work is too large to be milled with formed cutters. A simple method of planing an irregular shape is to first make a cast-iron or sheet-steel templet corresponding to the curvature required. This templet is then clamped against one end of the work (usually the end at the beginning of the cutting stroke) and the planing is done by manipulating the horizontal and cross-feeds so that the tool follows the outline of the templet. If the hand feeding is done carefully and the finishing tool is ground to correspond in a general way with the curvature to be planed, fairly accurate results can be obtained by this method. Special attachments are commonly used for planing curved surfaces, especially when duplicate parts are required. Some of the attachments that have been used for circular planing are described in the following:

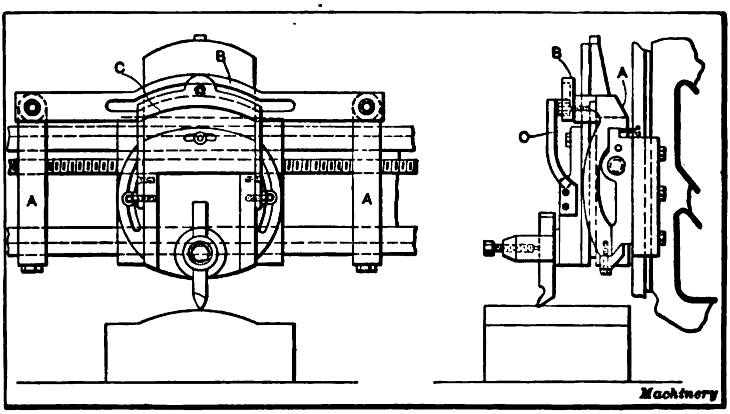


Fig. 45. Templet Type of Curve Planing Attachment

Attachment for Circular Planing. — A very simple form of radial planing attachment is shown in Fig. 44. A bracket *A* is bolted across the housing and carries a pin *B* upon which the radial arm *C* swings. The lower end of arm *C* is pivoted to the tool-slide, the feed-screw of which is removed, thus allowing it to move freely. The casting shown in the illustration is the steam dome of a boiler and the operation is that of planing it to the radius of the boiler shell. After the tool is properly set, the planing is done by simply feeding the saddle along the cross-rail. This horizontal movement causes the tool point to follow an arc equal to the radius of arm *C* which is made to suit the curvature required.

Templet Type of Curve Planing Attachment. — An attachment for planing work of a convex or concave shape is shown in Fig. 45. This attachment consists principally of four parts; namely, the two side brackets *A*, a templet *B* which conforms to the curvature to be planed, and the double-armed leader *C* which is attached to the tool-slide. The side brackets are provided with bosses at the top in order to hold the templet so that it will clear the planer head (see end view), thus allowing the

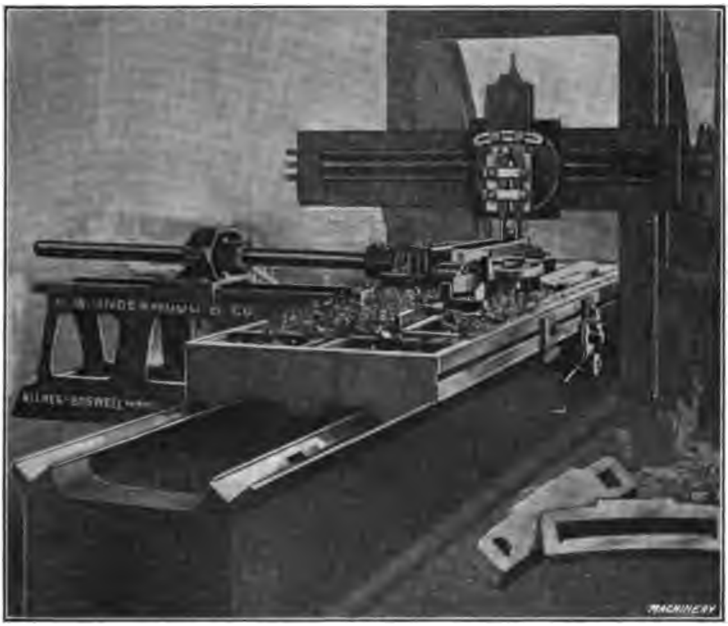


Fig. 46. Aliner-Boswell Radius Planing Attachment for Machining Links, etc.

saddle to be moved along the cross-rail. The templet, which is machined to the required form on a profile or slotter, is attached to the brackets *A* by bolts. The double-armed leader *C* has a roller at the top which engages a slot in the templet, thus imparting a vertical movement to the tool-slide when the saddle is fed horizontally along the cross-rail.

When using this attachment, the power feed may be engaged, and as the tool is automatically raised or lowered, obviously it will plane a surface corresponding to the curvature of the slot in the templet. As will be seen by referring to the end view, the brackets *A* fit over the top guide on the cross-rail and are fastened in position by set-screws at the rear. Separate retaining pieces are fitted to the bottom of each bracket, these being bolted in place after the fixture is mounted on the rail. This attachment, or some modification of it, is especially adapted for planing a number of duplicate parts.

Radius Planing Attachment. — In locomotive shops where the curved links for the valve mechanisms have to be machined, a planer is often used, and various attachments have been designed

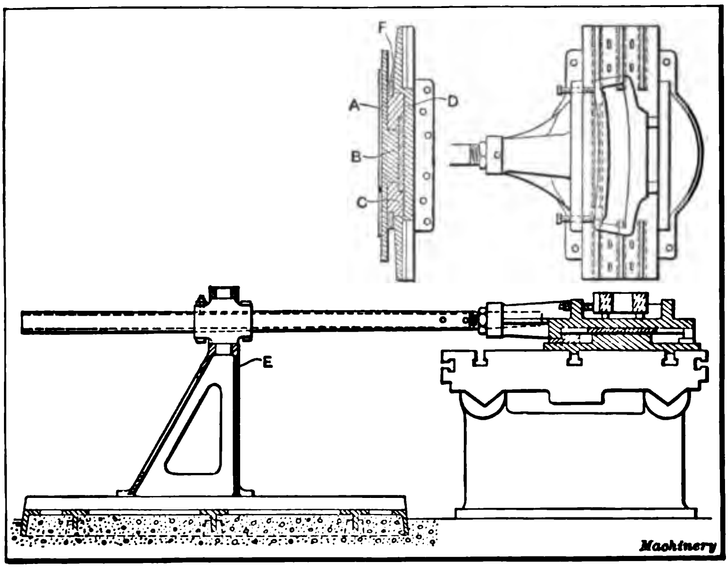


Fig. 47. Elevation and Plan of Radius Planing Attachment

for this purpose. One of these, known as the Aliner-Boswell radius planing attachment, is illustrated in Figs. 46 and 47.

This attachment has a plate *A* which is fixed to the planer table and on this plate there is a square projecting block *B*. This block fits into a cross slot in the ring *C*, which has an annular bearing in the top plate *D*. The latter forms the work table, and it is attached to a radial bar that passes through a double-trunnioned bearing mounted in an adjustable stand *E*. The ring *C* is kept down by a central plate, as shown, and the work table is provided with a retaining ring *F*.

The movement of the planer table is transmitted by the square block *B* to ring *C*, which, in turn, imparts a circular movement to the work table; this is accompanied by a lateral movement of ring *C* with relation to the square driving block. With this arrangement the driving power is transmitted to the work table in the direction of the reciprocating movement of the planer, and the thrust of the tool's cut is also along parallel lines. Owing to the small amount of stress imposed on the radial bar, the latter is made of tubing and is comparatively light. The attachment is adjusted for planing different radii by shifting stand *E* and its bearing along the bar at right-angles to the planer table. The link to be planed can quickly be located in the fixture by a center-line marked upon the chuck.

Prior to planing the curved slot, the sides of the link are planed, the edges milled, and the clearances for the planing tools drilled and slotted. The work is then placed on the attachment and the slot is rough planed by using two parting tools simultaneously. These tools cut narrow slots on each side, and the central part of the slot is removed in the form of a solid block. After the link is roughed out in this manner, the slot is finished by side tools. This attachment can also be used for planing quadrants, dies, etc.

Attachments for Planing Spiral Flutes. — The spirally-fluted or corrugated rolls, such as are used in flour mills, rubber mills, etc., are often machined on the planer by the use of special attachments such as are illustrated in Figs. 48, 49 and 50. The attachment shown in Fig. 48 is a simple design that is often used, the construction being modified somewhat in different shops to suit the nature of the work. The journals of the roll to be fluted are mounted in special V-blocks held in a T-slot of the planer table. Straps or clamps are bolted across the top of each journal, tightly enough to eliminate all play but still permit the roll to revolve. Attached to the end of the roll shaft there is an index plate *B* containing as many equally-spaced notches as there are flutes to be cut. At the side of the index plate there is an arm *C* that is connected to the index plate by plunger *D*. An extension of this arm rests upon the inclined bar *E* which is attached to a bracket bolted to the planer base. The arm is held in contact with bar E by a weight F suspended at the end.

When cutting a spiral flute, the arm ascends the inclined bar, thus rotating the work part of a revolution, the amount of rotation and the angle of the spiral generated depending upon the inclination of bar E. After one flute is cut, plunger D is withdrawn, the work is rotated one tooth and the next groove is cut. By repeating this operation, the entire roll is corrugated or fluted.

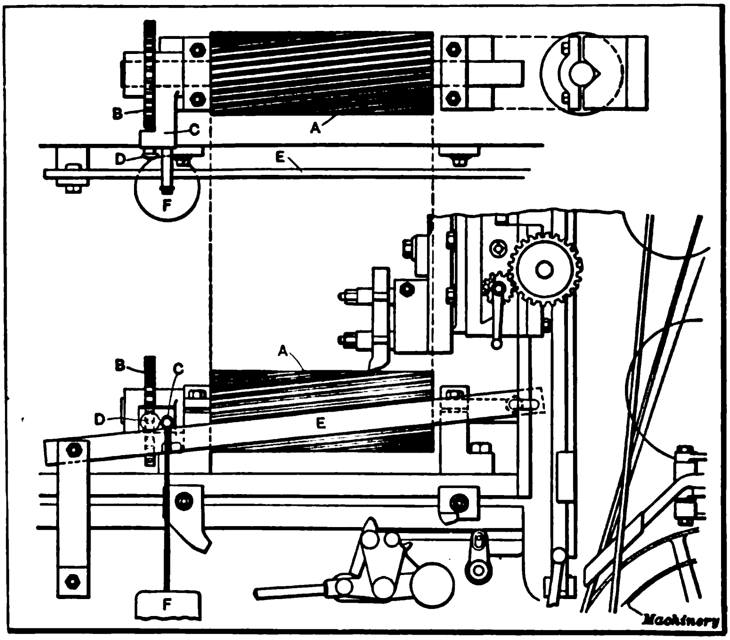


Fig. 48. Attachment for Planing Helical or "Spiral" Flutes

The flutes generated in this way are not true helices, but when the helix angle is small the inaccuracy is negligible for most work.

Angle of Guide Bar for Spiral Planing. — The angle at which bar E should be set for planing a given spiral can be determined approximately by the following formula in which β = angle to which bar E should be set; l = one-half length of work; angle $\theta = \frac{l}{L} \times 360$; L = lead of spiral; R = horizontal distance from center of work to center of bar E.

$$\tan \beta = \frac{\tan \theta \times R}{l}$$

Example. — Grooves or flutes are to be planed in a roll, the diameter of which is 5 inches and the length 20 inches. The spiral angle α between the flutes and the axis is to be 4 degrees.

The first step is to find the lead of the spiral flutes or the distance they would advance in one complete revolution. The lead L equals the circumference C of the work divided by the

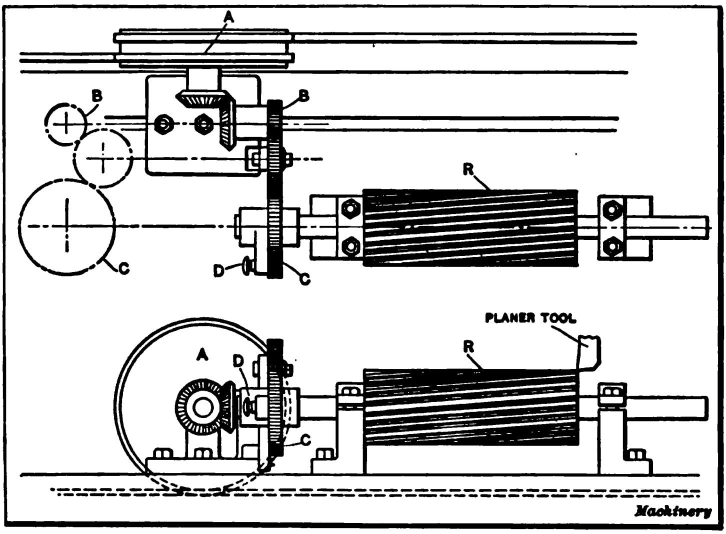


Fig. 49. Spiral Planing Attachment Operated by Chain Drum and Gearing

tangent of the spiral angle α, or $L = \frac{C}{\tan \alpha} = \frac{15.708}{0.06993} = 224.6$ inches. Angle $\theta = \frac{l}{L} \times 360 = \frac{10}{224.6} \times \frac{360}{1} = 16$ degrees. The tangent of 16 degrees = 0.28675.

Assuming that the horizontal distance R from center of work to center of bar E is 6 inches, then,

$$\tan \beta = \frac{0.28675 \times 6}{10} = 0.1720$$

which is the tangent of $9\frac{3}{4}$ degrees, approximately. The bar, therefore, would be set to an angle of $9\frac{3}{4}$ degrees from the horizontal. The angular position could be gaged quite accurately either by using an ordinary protractor placed on parallels extending from the planer table, or by using a graduated protractor head and level such as are provided with "combination" squares.

Spiral Planing Attachments of the Geared Type. — The attachment shown in Fig. 49 is given a rotary movement for spiral planing by means of a drum *A* around which chains are wound. One of these chains is fastened to a support at the left and the other to a support at the right, and as the table reciprocates,

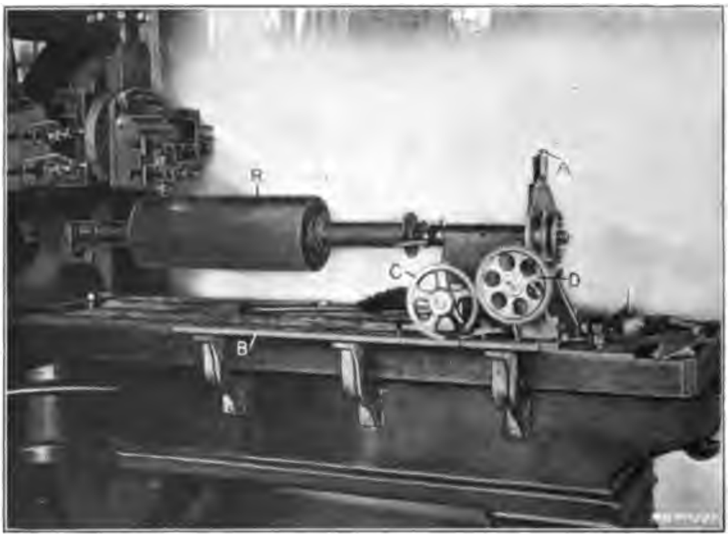


Fig. 50. Planing Spiral Corrugations in Flour Mill Roll by Use of Geared Attachment

the drum is rotated part of a revolution, first in one direction and then in the other. This rotary movement is transmitted to the roll *R*, through the bevel and spur gearing shown in the plan view. The journals of the roll to be fluted are held in V-blocks fitted with straps or clamps adjusted to eliminate play but allow a free rotary movement. The spur gear *C* attached to the end of the work arbor or journal, as the case may be, has concentric rows of holes drilled in the side and the work is indexed after each successive groove is cut, by withdrawing plunger *D* and engaging it with the next succeeding hole. The angle of the spiral can be varied by using different size driving gears at B.

Another spiral planing attachment of the geared type is illustrated in Fig. 50. The roll R shown in this illustration is for a flour mill and the operation is that of replaning the flutes or corrugations. This roll, which is of chilled cast iron, weighs about 400 pounds; it is held while being planed between centers as the illustration shows. On the outer end of the headstock spindle is keyed a disk carrying an index pin A. Outside of this disk and loose on the spindle is a worm gear, to which is fastened the index plate. To prevent undue strain on the index pin, when a cut is being taken, binder bolts pass through the worm gear and engage a circular T-slot cut in the disk. It is necessary to loosen these bolts when indexing the roll for planing the next groove or corrugation. The rotary movement necessary for generating the spiral is obtained through the gearing shown. Gear C meshes with a stationary rack B and as the table moves to and fro, the work spindle is rotated through the connecting gear D and the worm gearing. The intermediate gear D was used, in this particular instance, to change the direction of the roll's movement. Owing to the hardness of the roll, it was necessary to reduce the speed of the planer to about one-third its normal speed, when cutting the grooves.

Rack Cutting on the Planer. — When rack teeth are formed by planing, the usual method is to first rough out the teeth by cutting plain rectangular grooves with a square-nosed tool as indicated at A, Fig. 51. A form tool is then used to finish the teeth to the required angle. The included angle between the sides of the teeth (according to the B. & S. system for involute gears) equals 29 degrees, as shown at C. The proportions of a rack tooth are the same as for a gear of corresponding pitch. The whole depth d equals the linear pitch p (or the circular pitch of the meshing gear) multiplied by 0.6866. The width w at the pitch line equals one-half the linear pitch. The distance h from the top of the tooth to the pitch line (which would be required when setting a vernier gear-tooth caliper for measuring width w) equals the linear pitch multiplied by 0.3183. The width of the point or end of the rack tool (before the corners are rounded) equals the linear pitch multiplied by 0.31.

Expressing these rules as formulas,

$$d = 0.6866\,p \qquad h = 0.3183\,p$$
$$w = 0.5\,p \qquad t = 0.31\,p$$

The radius r of the corners of the tool equals one-seventh the width x of the space between the rack teeth at the top or along the addendum line.

Indexing the Tool when Planing Racks. — When planing the teeth, the tool is indexed a distance equal to the linear pitch p,

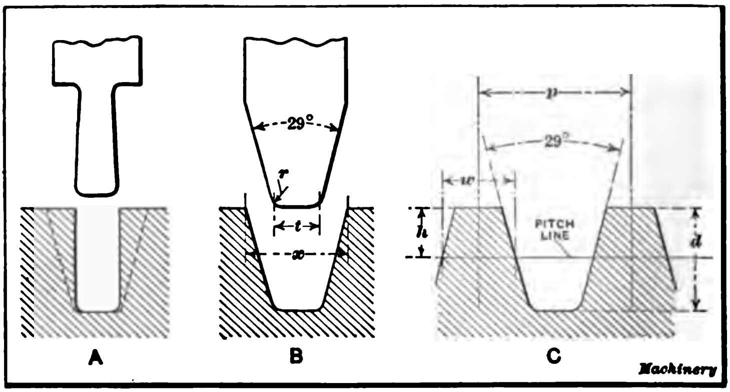


Fig. 51. Diagrams showing Rack Planing Tools and Formation of Rack Teeth

either by means of a micrometer dial and the cross-feed screw or by the use of a positive locating device attached to the cross-rail. Some planers have micrometer dials on the feed-screw for adjusting the tool by direct measurement, and if the planer is in good condition, quite accurate results can be obtained by this method of spacing the tool when cutting rack teeth, although care should be taken to avoid errors due to lost motion between the screw and feed-nut, by moving the tool continuously in one direction when making an adjustment. When using the micrometer dial, it is well to set it to zero before making each adjustment. The distance that the tool is indexed can then be read direct from the zero mark, which tends to prevent mistakes that might otherwise be made. When a planer is not equipped with feed dials, special dials are sometimes applied for rack cutting.

To avoid the possibility of error when measuring the indexing movement of the tool by using the cross-feed screw, a special indexing bar is sometimes attached to the cross-rail, especially when a number of duplicate racks are to be planed. This bar has notches or teeth of the same pitch as the rack teeth to be cut, and the planer tool-head is located positively by a pin or plunger on the saddle which engages the notches in the fixed indexing bar.

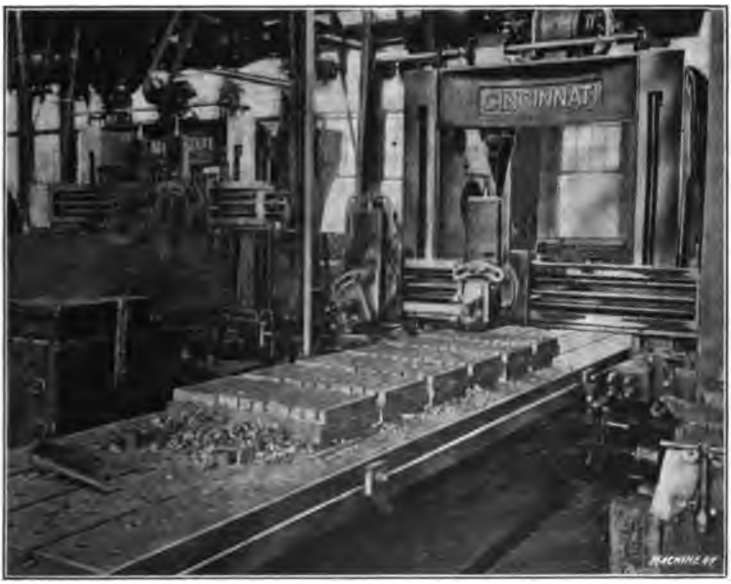


Fig. 52. Planing Teeth in Steel Racks for Frog and Switch Planers

Another very simple but positive method of indexing the tool is to clamp a stop on the cross-rail in such a position that when the saddle is against the stop the tool will be set for planing the first tooth space; when the first space is cut, the stop is set ahead of the saddle a distance equal to the pitch of the rack, by using a gage. The saddle is then moved up to this stop for planing the next tooth space, and this operation of adjusting the stop by the gage and locating the saddle against it is repeated for each successive tooth.

It is advisable when cutting rack teeth on the planer to have an adjustable screw stop for down feed; then when the stop is set correctly, all of the teeth can easily be planed to a uniform depth. If the automatic down feed is used, it should be disengaged before the full depth is reached so that the tool-slide can be fed against the stop by hand.

To avoid making a form tool for finishing rack teeth, a circular cutter, such as is used when milling racks, is sometimes employed when planing the teeth. The cutter is bolted to a shank held in the tool-holder, with one of the teeth in the lowest position to act as a planer tool. Of course, this cutter must

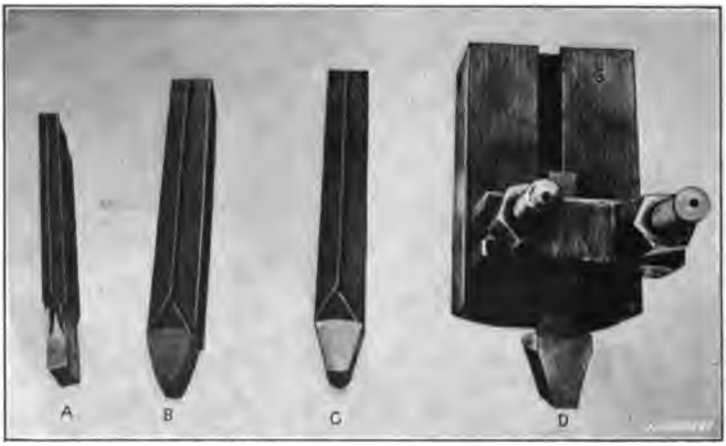


Fig. 53. Successive Tools Used in Cutting Steel Rack Teeth

correspond to the pitch of the rack teeth, and, according to the B. & S. system for involute cutters, it should be a No. 1 form, as this number is adapted for cutting gearing varying from a 135-tooth gear to a rack.

Planing Steel Racks. — A practical example of rack cutting on a planer is shown in Fig. 52. These racks are used on the Cincinnati frog-and-switch planers, and are made of steel forgings instead of cast iron, because of the heavy class of work done on a planer of this type. The rack is made in sections and when the teeth are being cut, these sections are clamped to the planer table as shown in the illustration. The racks are made from

0.40 per cent carbon steel forgings and the linear pitch of the teeth is about 2 inches.

The successive tools used are shown in Fig. 53. The first roughing tool, which is similar in shape to a wide parting tool, is shown at *A*. This tool is used to rough out the teeth and it takes a cut 0.040 inch deep per stroke, at a cutting speed of 40 feet per minute. After all the teeth have been roughed out to within about $\frac{1}{8}$ inch of the proper depth, tool *B* having a stepped face is used to rough out the angular sides of the teeth. Tool *C* is then put in the tool-holder and all of the teeth are

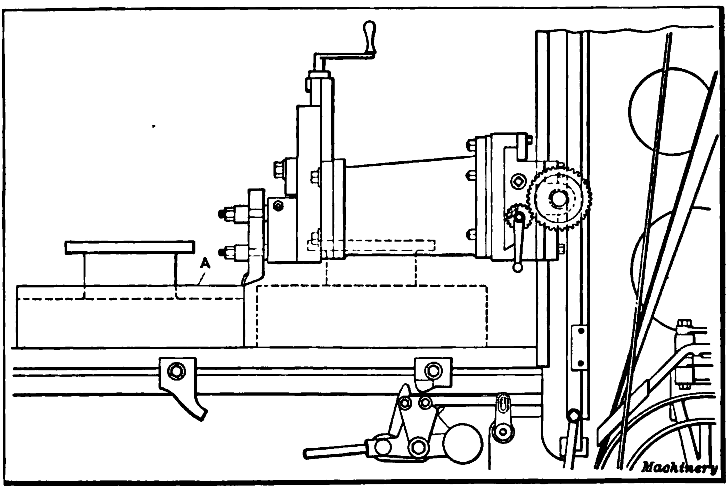


Fig. 54. Extension Head Used for Planing Parts which are too Wide to Pass between Housings

finished to within about $\frac{1}{64}$ inch of the proper depth. The final shape is given to the teeth by the formed cutter *D*. This is held by a strap, bolts and nuts in a slot in the special block *G*, the latter fitting snugly into the clapper box. The finishing tool is held in this manner to insure accurately formed teeth of the proper angle. The spacing or indexing of the tools is done by means of the micrometer dial or collar on the cross-feed screw.

While the planer is often used for this work, most rack cutting is done either on a milling machine by the use of an attachment or on special rack-cutting machines. These machines vary greatly as to size and design although most of them form the teeth by a milling process.

Extension Tool-head. — When a great variety of work is done on a planer, special attachments are occasionally needed. Fig. 54 shows how a planer can be arranged for machining a casting *A* that is too wide to pass between the housings when placed lengthwise across the table, for planing the end. The tool is held in an extension head to locate it far enough forward to prevent the work from striking the housings when at the extreme end of

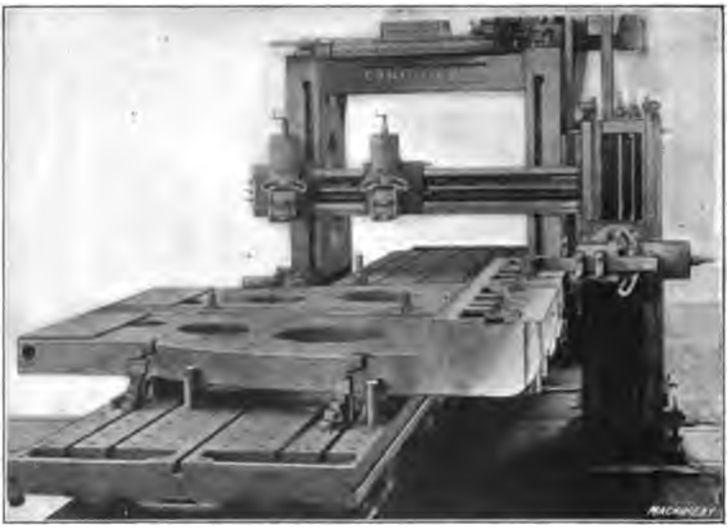


Fig. 55. Floor Stand or Independent Housing for Special Planing Operations

the cutting stroke. This extension is fastened to the saddle in place of the swiveling base, and the regular tool-slide is attached to its outer end.

Extension tools that are long enough to reach across the work are also used for planing parts that will not pass between the housings, but the more rigid extension head, shown in the illustration, is preferable.

Floor Stand or Independent Housing. — Another method of planing a casting that is too large to pass between the housings is illustrated in Fig. 55. The surface to be planed is too wide to use an extension head, and the tool is held on a special floor stand that is bolted to a T-slotted base-plate secured to the foundation. The stroke of the planer (as far as its position is concerned) is adjusted with reference to the tool of this auxiliary floor stand, the latter being set far enough forward to provide room for the work between the tool and planer housing. The floor stand or "independent housing," shown in the illustration, has an automatic feed operated from the planer feed mechanism. Auxiliary equipment of this kind makes it possible to handle a large range of work on one or two planers, which is especially desirable in some shops.

Open-side Planers. — The open-side type of planer has a massive column on only one side of the table so that the opposite side is open and unobstructed, which greatly increases the range of the machine. The cross-rail or beam upon which the tool-heads are mounted is of very rigid design and has a broad bearing surface on the column to prevent deflection due to the thrust of the cut. The chief advantage of an open-side planer is that it can be used for machining large castings which could not be handled on a two-housing planer of ordinary size, as well as for general planing operations.

Fig. 56 shows a typical example of open-side planer work. The large casting being planed is the vertical column for another open-side planer. The operation is that of machining a pad on top for the motor bracket, and planing the end. The pad is finished by a tool held in one of the cross-rail tool-heads *A*, and the end surface is planed by a tool held in side-head *B*. If a casting of this size were machined on a two-housing type of planer, the distance between the housings would have to be 8 feet 8 inches, but with the open-side design, the end of the work simply projects beyond the table as the illustration shows.

When an exceptionally long casting must be held at right angles to the table, the outer or overhanging end is generally supported on an auxiliary rolling table which is supplied with some open-side planers. This table is set parallel with the planer and consists of a series of rollers upon which is mounted an I-beam that supports the work and travels to and fro with the planer table.

The driving and feeding mechanism of an open-side planer is similar to that used on other types and the stroke is also controlled by the position of dogs or tappets attached to the side of the platen. The particular planer shown in Fig. 56 is driven by a motor *C*, which is connected by belts with countershaft *D*. The latter transmits the motion by open- and cross-belts to the planer driving shaft at the base of the column. The cross-rail

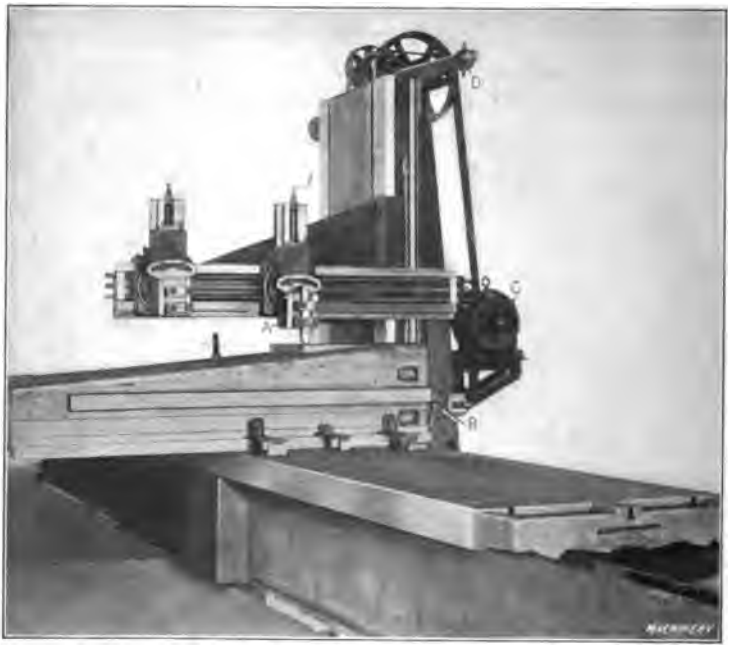


Fig. 56. Cleveland Open-side Planer and Example of Work for which this Type of Planer is Adapted

can be adjusted vertically by power to suit the height of the part being planed.

Planing Cast-steel Locomotive Frames. — The machining of a locomotive frame is a good example of the application of the planer to large heavy parts requiring rapid machining rather than skillful and accurate work. Fig. 57 shows how two cast-steel frames are planed at the same time, in the Juniata shops of the Pennsylvania Railroad. These shops have, under normal conditions, a capacity for building a complete locomotive every

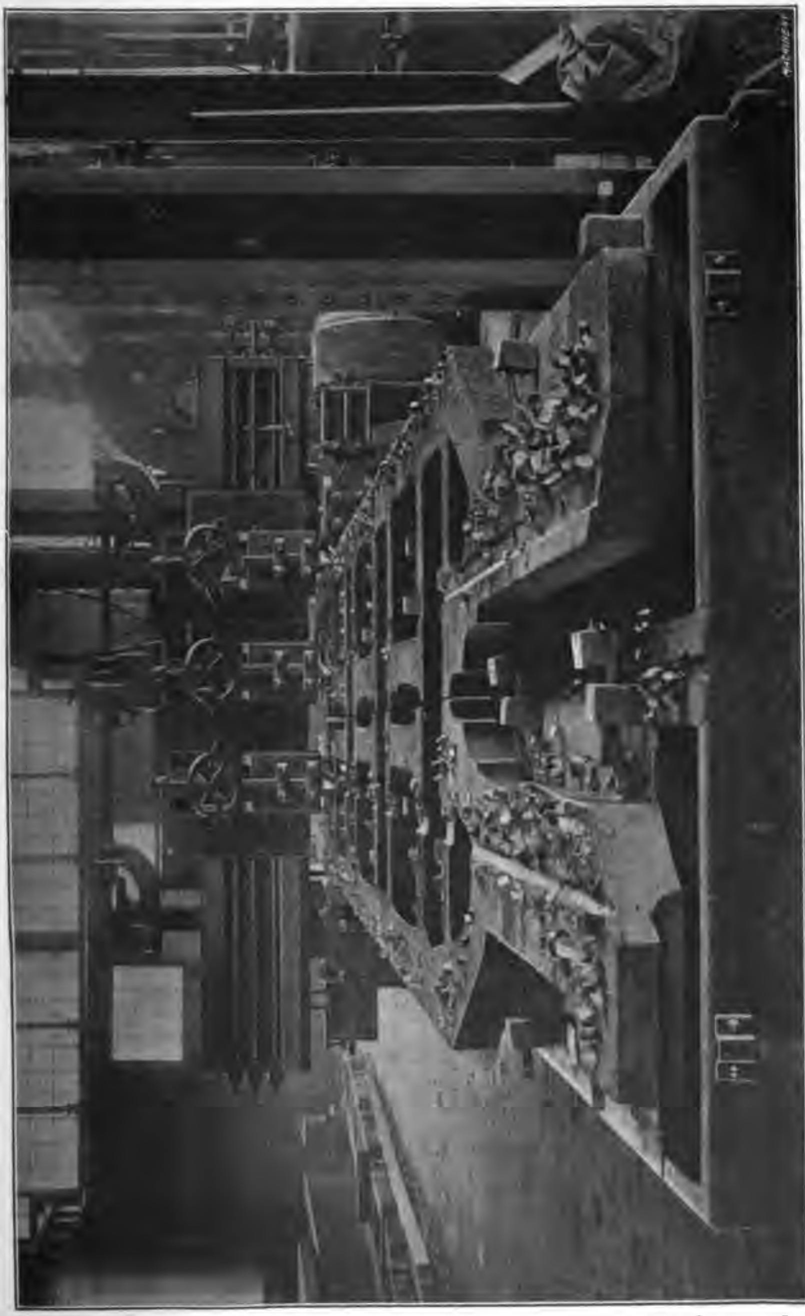


Fig. 57. Planing Two Cast-steel Frames Simultaneously on a Powerful Planer Equipped with Five Tools

day, and this rate is sometimes exceeded, so that the machining of frames is an everyday occurrence. Practically all of the locomotives built in these shops at the present time are equipped with cast-steel frames instead of wrought-iron frames, which were used almost exclusively a few years ago. Frames that are cast are much cheaper than the forged type and another advantage of using cast steel is that pads or other projections can be easily and neatly formed on the frame pattern.

The cast-steel frames are usually warped more or less as they come from the foundry, owing to unequal cooling, and it is necessary to straighten them prior to machining. This straightening is done under a large steam hammer. The frame is heated sufficiently to insure a permanent "set" when straightened, and it is made approximately straight by giving it a few blows with the hammer. The work is then ready for the first machining operation which is that of planing the sides and edges.

Two frames or sections are planed simultaneously on a very rigid planer having five tool-heads. Fig. 57 shows this machine taking a roughing cut over the sides of two frames. The work is held on the platen by screw-stops and toe-dogs or "spuds" which are placed in an inclined position to force the work down. Stops are also set against the frames at the most advantageous positions to take the longitudinal thrust of the cut. Part of the time, all five planing tools are at work, the three tool-heads on the cross-rail being used to plane the sides of the two sections, while the right and left side-heads plane the edges. The three upper tools are started so that each rough planes about one-third of the surface formed by the two castings. In this way the roughing is, of course, done in much less time than would be required if an ordinary two-head machine were employed. As many of these castings have spongy, sandy spots, blow-holes or similar defects on the cope side, a generous allowance is left for planing in order to remove all porous material.

Owing to the power of this machine, very heavy cuts can be taken, as indicated in the illustration. The planer is motor-driven, and momentarily as much as 90 horsepower is required for driving, owing to the heavy "hogging" cuts which are taken in the tough cast steel. When roughing, the tools frequently cut to a depth of from $\frac{1}{2}$ to $\frac{3}{4}$ inch with a feed of $\frac{3}{16}$ inch. The average depth of cut for the five tools, however, would be somewhat less than the figures given. After the three heads on the cross-rail are started, the right and left side-heads are set for planing the edges. The work is set up for rough-planing the first side, with the top edge of each section outward. This is done so that the top edges can be finished with reference to pads for braces or brackets which are located on the inside of the top and bottom rails of the frames.

After the roughing cuts on one side are completed, the finishing cuts are taken with broad flat tools which are given a feed varying from 1 inch to $1\frac{1}{4}$ inch per stroke. Only two of the cross-rail heads are used for finishing, so that each frame can be planed by a continuous cut in order to obtain a smooth surface free from ridges. The frames are next turned over for roughing and finishing the opposite side. The bottom edge of each frame is now in the outward position, thus permitting the ends of the pedestals to be rough-planed. The finishing tools are set for planing the second side by means of a post or height gage to which the cutting edges are adjusted. In this way the proper thickness is quickly obtained, although a fixed caliper gage is used to check this dimension. After the sides and edges have been planed, the inside faces of the jaws are finished in a large slotting machine.

Planing Locomotive Cylinders. — The cylinders of locomotives vary considerably in their general arrangement, and the exact method of planing them depends, of course, upon the design. The various operations referred to represent the practice at the Juniata shops of the Pennsylvania Railroad. The style of cylinder now used almost exclusively on the new locomotives built by this company is the single-expansion piston-valve type. The first machining operation on a cylinder casting is that of boring the cylinder proper. After the cylinder is bored, the various surfaces on the saddle are planed.

By the use of an ingenious set of fixtures, the castings are

Fig. 58. Planing Three Locomotive Cylinders Simultaneously in Juniata Shops of Pennsylvania Railroad

quickly and accurately set up for the planing operations. Figs. 58 and 59 show different views of the work mounted on the fixtures. Three cylinders are placed in a row and planed simultaneously, and the fixtures are so arranged that the bores of the various cylinders are aligned with one another and with the planer platen. These fixtures consist of heavy brackets or standards *B* (see Fig. 60) having flanges as shown. The end brackets have a single flange, whereas the two which come between the cylinders are double flanged. There is a central pocket *A* in each flange face, and the distance from these pockets to the base is exactly the same for each bracket. Each of the conical disks *C* which engage the counterbores of the cylinders has a cylindrical boss on the rear side which fits into any of the central pockets *A*.

When a cylinder is to be set up for planing, one of these conical disks is clamped in each end of the counterbore by a bolt passing from one disk to the other. The brackets are also bolted to the planer platen in the proper position. The distance between the brackets is governed by the length between the outer faces of the disks after the latter are bolted in place, and the central pockets *A* are all brought into alignment, laterally, by tongue-pieces on the base of each bracket. The cylinder is next picked up by a crane and lowered until the disks have entered between the brackets. The temporary holding bolt for the disks is then removed and the work is lowered until the cylindrical bosses on the disks, which slide through the vertical slots *D*, rest in the central pockets *A* of the fixtures. When three cylindrical castings have been set up in this way, the center line or axis of each cylinder bore will be in alignment.

The valve chamber is next set vertically with relation to the center of the cylinder. To obtain this setting, a spider *F*, Fig. 59, is placed in the valve chamber and its hub is centered with the bore of the valve chamber by using hermaphrodite calipers. The casting is then adjusted vertically by the small supporting jacks seen in Fig. 58, until this center is the required distance below the center of the cylinder, as shown by an ordinary surface gage. The height from the platen to the center of the cylinder bore is accurately ascertained beforehand and remains constant for a given size fixture.

After the three castings are set as described, clamping pieces which fit in the slots *D*, Fig. 60, are tightened against the hubs of the conical disks by clamps *E*. The cylinders are further secured by a long tie-bolt *G* which extends through the three castings and holds both the work and fixtures rigidly together.

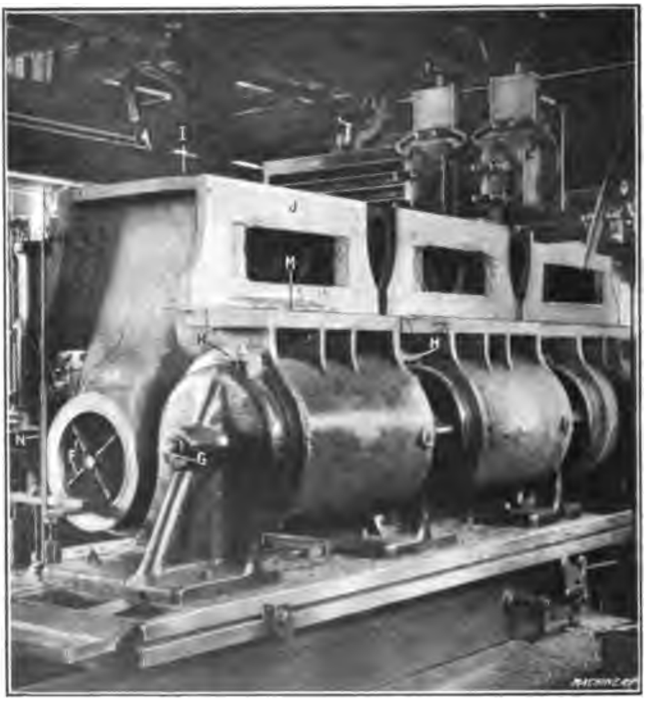


Fig. 59. Another View of Cylinder Planing Operation Illustrated in Fig. 58

By referring to the illustrations, it will be seen that these fixtures make it possible to hold the three cylinders with very few clamps. These fixtures have not only effected a considerable reduction in the time required for setting the cylinders prior to planing, but they also insure accurate and uniform work.

After the cylinders are set as described, the top surface *I* (Fig. 59) which forms the joint between the right- and left-hand cylinders is rough-planed by using the two tool-heads. This surface is then finished with a broad tool which is set to the right height for the final cut by a special micrometer gage *N*. The cutting edge is adjusted to coincide with the top of this gage, which is graduated with reference to the centers of the fixtures so that heights from the center of the cylinder bore can be read directly. The side *J* is next roughed out and finished by using a side-head, and while this surface is being planed, the seats *K* and *L* (Fig. 58) for the steam and exhaust pipes are rough-planed with the opposite side-head. Side *J* is finished to a certain distance from the planer housing, the measurement being taken with a special vernier gage. By measuring directly from the housing, duplicate work is assured and the liability of mistakes

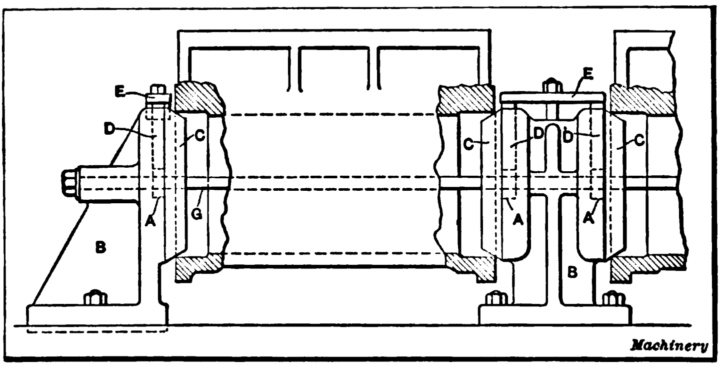


Fig. 60. Fixtures for Holding Locomotive Cylinders while Planing

is lessened. This method of measuring is made practicable by the improved fixtures, which are always located in the same lateral position on the platen and, consequently, hold the finished cylinder bores in the same vertical and cross-wise position.

The face *M*, against which the frame is bolted when the locomotive is assembled, is planed at the same time the seats *K* and *L* are finished. The half-seat *K* for the exhaust pipe is gaged from the finished side *J* and the steam pipe seat *L* is finished with reference to the exhaust seat. The distance between surfaces *I* and *M* is measured by a special height gage. This practically completes the planer work. Of course, the order of the operations is governed entirely by the shape of the cylinder casting, and differs from that described in the foregoing, for other types of cylinders.

Planing Speeds. — The speeds for planing usually vary from 30 to 50 feet per minute on the cutting stroke, with a return speed three or four times as great. A general idea of planer speeds may be obtained from the following figures given by the Cincinnati Planer Co., which represent the practice in some of the best machine shops: Cast iron, roughing, 40 to 50 feet per minute; cast iron, finishing, 20 to 25 feet per minute; steel castings, roughing, 30 to 35 feet per minute; wrought iron, roughing, 30 to 45 feet per minute; steel castings, finishing, 20 feet per minute; wrought iron, finishing, 20 feet per minute; bronze and brass, 50 to 60 feet per minute; machinery steel, 30 to 35 feet per minute. When high-speed steel tools are used, a speed of 55 feet per minute is given as about the maximum that ordinarily can be used to advantage.

Actual Cutting Speeds of Planers

Cutting Speed, Feet per Minute	Return Speed, Feet per Minute							
	50	60	70	80	90	100	120	150
	Actual Number of Feet Traversed on Cutting Strokes per Minute							
20	14.3	15.0	15.5	16.0	16.4	16.7	17.1	17.6
25	16.7	17.6	18.4	19.0	19.6	20.0	20.7	21.4
30	18.7	20.0	21.0	21.8	22.5	23.1	24.0	25.0
35	20.6	22.0	23.3	24.3	25.2	25.9	27.1	28.4
40	22.2	24.0	25.4	26.7	27.7	28.6	30.0	31.6
45	23.7	25.7	27.4	28.8	30.0	31.0	31.1	34.6
50	25.0	27.3	29.2	30.8	32.1	33.3	35.3	37.5
	Actual Number of Feet Traversed on Cutting Strokes per Hour							
20	857	900	933	960	981	1000	1028	1058
25	1000	1058	1105	1142	1173	1200	1241	1285
30	1125	1200	1260	1309	1350	1384	1440	1500
35	1235	1321	1400	1460	1512	1555	1625	1702
40	1333	1440	1527	1600	1661	1714	1800	1894
45	1421	1542	1643	1728	1800	1862	1863	2076
50	1500	1636	1750	1846	1928	2000	2117	2250

The Net or Actual Cutting Speed. — When installing a planer, the net or actual cutting speed should be considered. For example, if a planer has a cutting speed of 30 feet per minute and a return speed of 90 feet per minute (3 to 1), 1 minute would be required for a forward movement of 30 feet and $\frac{1}{3}$ minute for the return stroke or $1\frac{1}{3}$ minute for a complete cycle of movement. The *actual* cutting speed or number of feet traversed by the tool while cutting is, of course, less than 30 feet per minute, owing to the idle return period. The actual speed may be determined by dividing the forward cutting speed by the total time required for the forward and return movement. Thus, $30 \div 1\frac{1}{3} = \frac{30}{1} \div \frac{4}{3} = \frac{30}{1} \times \frac{3}{4} = 22.5$ feet per minute.

Now, if the return speed were increased to 150 feet per minute (5 to 1), the actual cutting speed would equal $30 \div 1\frac{1}{5} = 25$ feet per minute which is a gain of only 2.5 feet for a return speed increase of approximately 66 per cent. On the other hand, if the cutting speed were increased from 30 to 45 feet (the return speed remaining at 90), then the actual cutting speed would equal $45 \div 1\frac{1}{2} = 30$ feet per minute. In this instance, the actual cutting speed was increased from 22.5 to 30 feet by increasing the forward cutting speed 50 per cent, whereas a return speed increase of 66 per cent only resulted in a gain of 2.5 feet. From the foregoing it will be seen that a slight increase in the forward speed has a much greater effect on the net cutting speed and rate of production than a comparatively high increase of the return speed, and for that reason it is important to have the cutting speed as high as the conditions will permit.

Belt-driven planers are sometimes speeded up by increasing the speed of the countershaft, both forward and return speeds being increased in proportion. This method may not give very efficient results, especially if the return speed reaches its limit before the cutting speed is as high as it should be. In such cases, a larger pulley for the cutting stroke should be placed on the countershaft, in order to increase the cutting speed as much as possible. In actual practice, the speeds will be somewhat less than the theoretical values given in the foregoing, because of the momentary delay at each end of the stroke, due to the shifting of the belts and the time lost before full speed is obtained after reversal. This loss is much less on planers having aluminum driving pulleys because the principal power loss at reversal is due to the energy stored in the revolving pulleys; hence when lighter pulleys are used, there is less kinetic energy for a given speed and less power is required at the point of reversal.

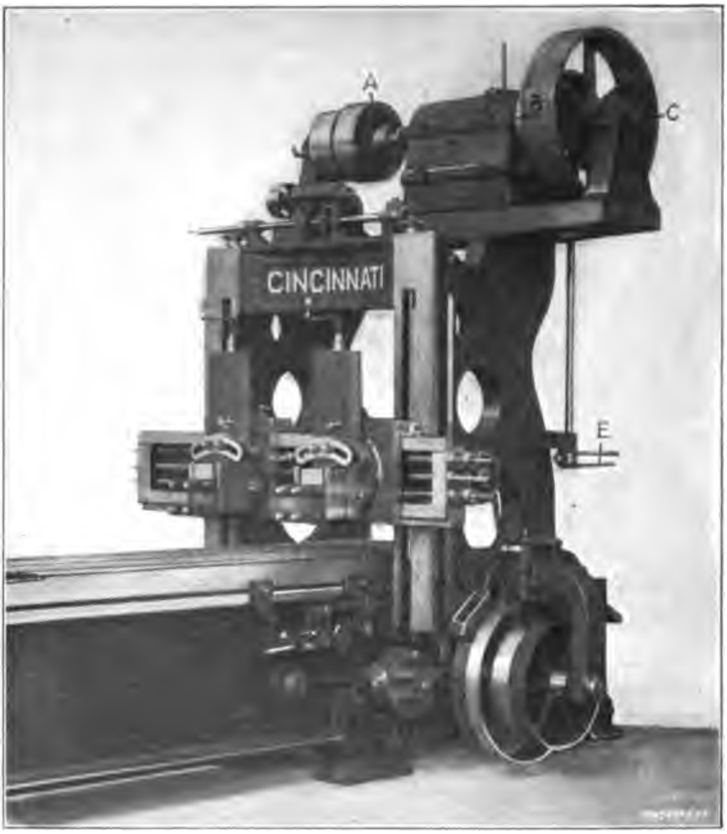


Fig. 61. Cincinnati Variable-speed Belt-driven Planer

Feeds for Planing. — The feed of a planing tool varies widely for different kinds of material and classes of work. It is also governed by the depth of cut, the nature of the cut (whether roughing or finishing), and by the rigidity of the work when clamped in position for planing. Feeds ordinarily vary from $\frac{1}{16}$ to $\frac{1}{8}$ inch when taking deep roughing cuts in steel, and from $\frac{1}{8}$ to $\frac{3}{16}$ inch for rough-planing cast iron. When taking light finishing cuts in cast iron, a broad tool having a flat edge is commonly used and the feed ordinarily varies from $\frac{1}{4}$ to $\frac{1}{2}$ inch per stroke. When planing large, rigid castings a feed as coarse as $\frac{3}{4}$ or 1 inch per stroke is often used.

Variable-speed Drives for Planers. — Many planers can only be operated at one cutting speed, the driving pulleys being proportioned to give a speed that will be about right for average conditions. A change of two or more speeds, however, is very desirable, because the cutting speed should be varied to suit the material being planed or the nature of the cut. Many modern planers have a variable-speed driving mechanism.

A planer of the variable-speed type is shown in Fig. 61. The belt pulley *A* transmits power to the driving pulleys *B* and *C*, through gearing enclosed in speed-box *D*. The speeds are changed by levers *E* which control the position of the sliding gears in the speed-box. This particular machine has four speed changes. The speed variator is also used on motor-driven planers, the motor being mounted on top of the housing. When a variety of speeds is unnecessary, a two-speed countershaft is often used.

Electrically-controlled Drive for Planers. — The planer illustrated in Fig. 62 is a variable-speed type driven by a reversing motor. The speed changes are obtained by an electrical controller and a pilot switch. There are twelve cutting speeds ranging from 25 to 50 feet per minute and twelve return speeds ranging from 50 to 100 feet per minute. These speed changes are varied by turning two handwheels on the front of the controller case. These handwheels have dials graduated to show the various speeds.

In the operation of the planer, the point of reversal is controlled by dogs similar to those on a belt-driven planer. At the instant of reversal, a pilot switch is thrown by one of the dogs and the controller short circuits the armature through suitable resistance, causing the motor to act as a generator and consequently as a powerful electric brake on the planer table. When the speed of the motor has been reduced to a predetermined amount, the armature current is reversed and the table starts on the next succeeding stroke. This sequence of operations takes place at the end of each table stroke, whether on the cutting or return movement and is entirely automatic, being regulated by the controller.

The pilot switch, which may be operated from either side of the planer, takes the place of the belt-shifting device on belt-driven planers. By manipulating the pilot switch, two speeds

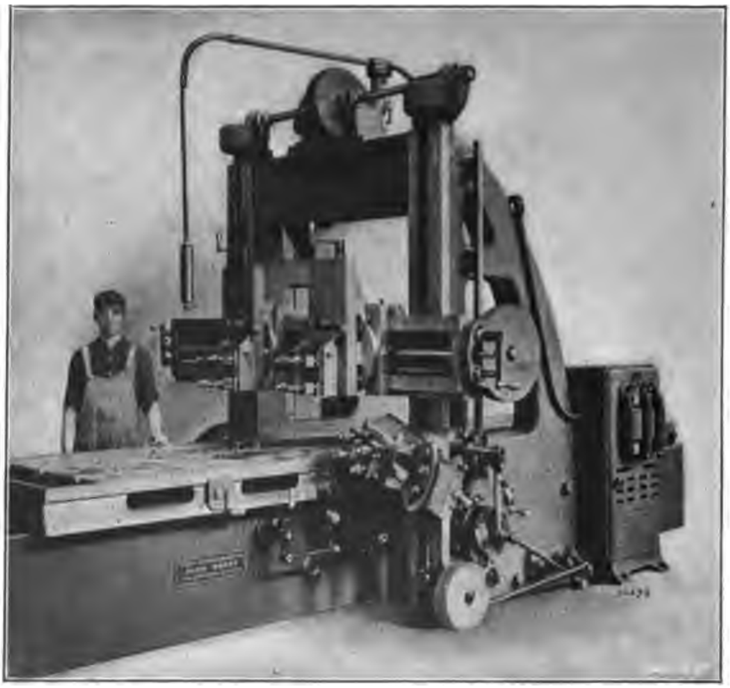


Fig. 62. Niles-Bement-Pond Planer with Reversing Motor Drive

in either direction are obtained. One of these speeds corresponds to that for which the controller is set, and the other is a slow speed which is useful when setting work or for slowing down when cutting hard material. The planer shown in the illustration is equipped with a pendant switch which is suspended from an overhead bracket and hangs above the table. This switch can be moved to any convenient position and may be used to control the movement of the table from either side of the machine.

Double-cutting Planers. — Many attempts have been made to design a planer that would cut with equal efficiency on both the forward and return strokes. One objection has been that two tools could not be used on some classes of work, owing to the lack of clearance at the end of the stroke; consequently, when using a planer having an equal speed of the table in both directions, the absence of a quick return on the idle stroke greatly discounted, if not entirely off-set, the advantages gained on work where double cutting could be employed. In order to overcome this objection, a double-cutting planer has been developed by an English concern, that is equipped with a variable-speed motor drive and a small auxiliary motor for such operations as feeding and traversing the tools. With this arrangement, the forward and return strokes can be made either at a uniform speed or the return stroke can be increased when required. Another design of planer has also been introduced having a belt drive, by means of which the same flexibility as regards the rate of speed of the return stroke can be obtained. The method of holding the double-cutting tools is to fasten them back to back and exactly in line.

Evidently, if planers are to be made double cutting, the successful design must be quite different from that of ordinary planers in order to secure equal support for the tool when cutting in both directions. The single-stroke planer is designed to take a maximum cut in one direction only, and a radical change must be made in its design before it will be possible to plane efficiently in both directions. When the tool-head is clamped to the face of a cross-rail, which, in turn, is clamped to the face of the housing, obviously, the stresses produced in these parts when a cut is taken in one direction are quite different from those produced when the cut is in the other direction. In one case there is a tendency to compress all of the parts solidly together, thus giving a firm support to the cutting tool, whereas in the other, the tendency is to pull all the joints apart, thus depriving the tool of the firmness of its support and increasing the tendency to chatter.

CHAPTER II

THE SHAPER AND SLOTTER

THE shaper, like the planer, is used principally for producing flat or plane 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 the tool moves back and forth across the work, which remains stationary, except for a slight feeding movement for each stroke.

General Description of a Shaper. — A shaper of typical design is shown in Fig. 1. 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*.

Shaper Driving Mechanism. — The driving mechanism for the ram is shown in the sectional views, Fig. 2. 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, an oscillating 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. 1).

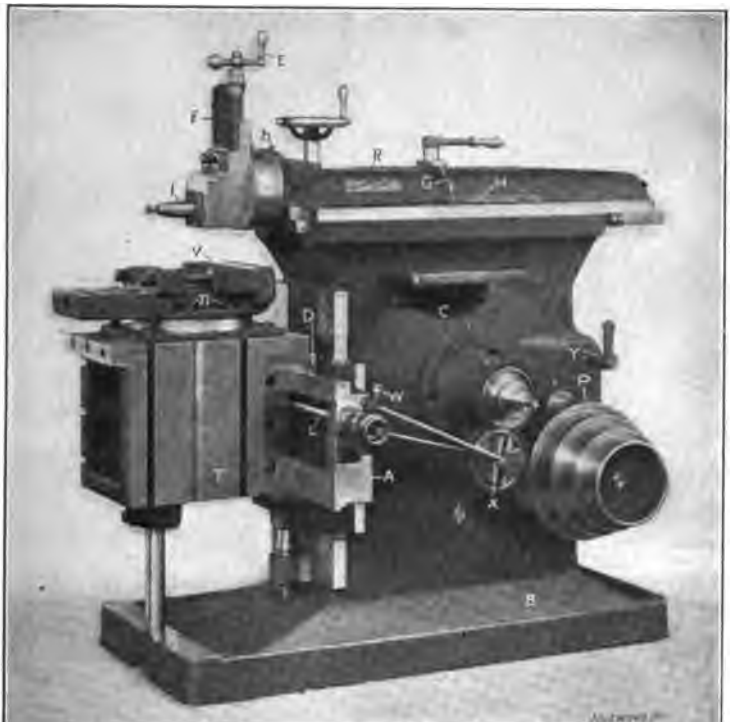


Fig. 1. Cincinnati Back-geared Crank-shaper

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

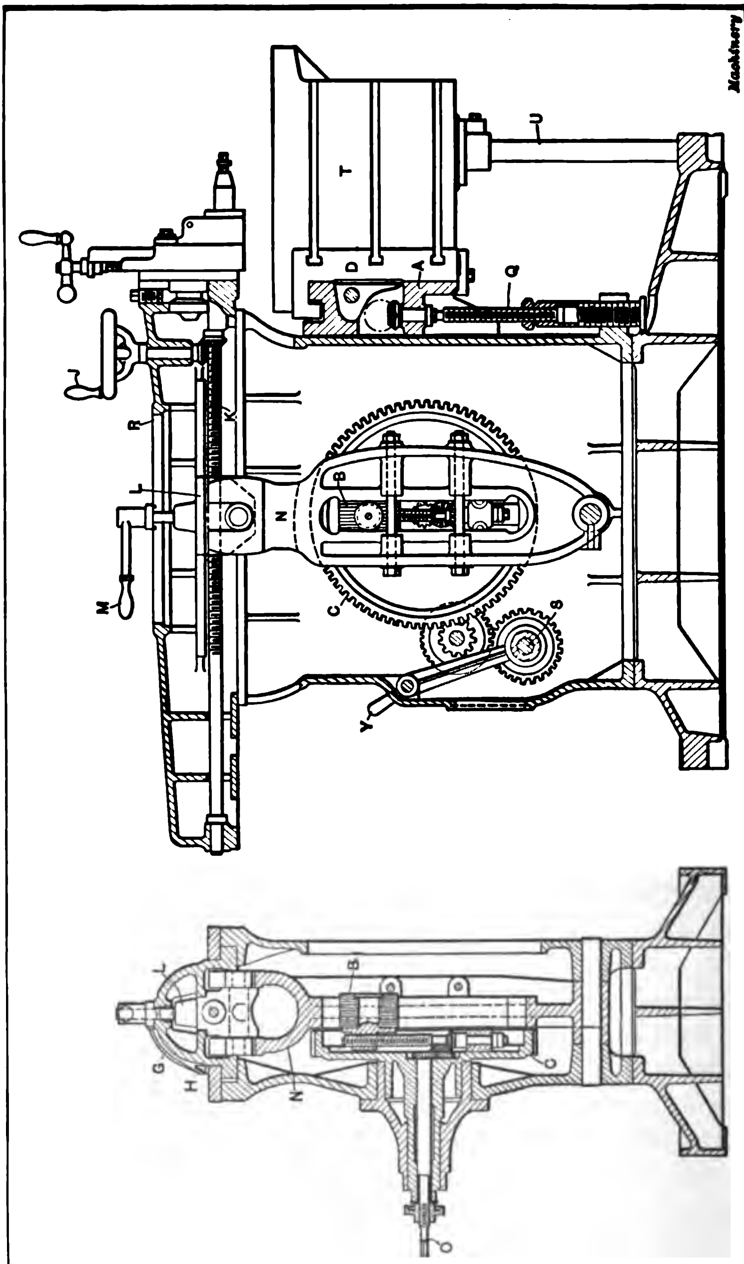


Fig. 2. Longitudinal and Cross-sections of Back-geared Crank-shaper

change the travel of the tool according to the length of the work.

Cross-rail and Table Adjustment. — 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.

Automatic Feeding Mechanism. — The feeding movement of the work-table for each stroke of the ram is derived from a slotted crank *X*, Fig. 1, 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, the pawl is disengaged from 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.

Shaper Speed Variations. — On the particular shaper shown in Fig. 1 there are eight speed changes for the ram. Four of these are obtained by shifting the driving belt on different steps of the cone-pulley *P*, 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.

Examples of Shaper Work. — Most of the work done in the shaper is either held in the vise *V* (Fig. 1) or is clamped to the table *T*, which is provided with slots for receiving the clamping

Fig. 3. A Simple Example of Shaper Work

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. 3 shows an example of the kind of work which is held in the vise. The operation is that of planing a number of steel strips which are clamped together between the vise jaws. After these strips are firmly "bedded" on parallels which have been placed beneath them, the shaper is started and the stroke adjusted both for length and position, to give the tool a movement somewhat greater than the total width of the work. 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 auto-

Fig. 4. Casting of Irregular Shape Bolted to Side of Table

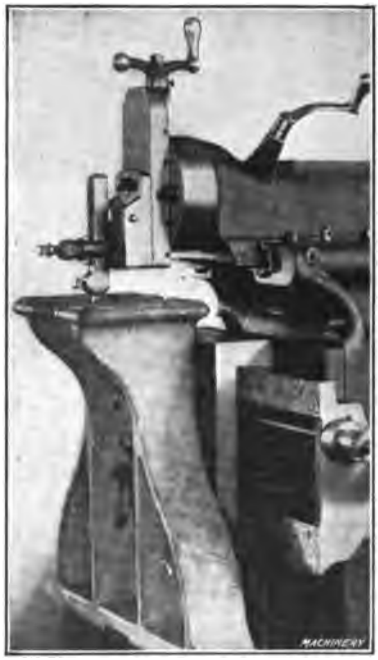


Fig. 5. Table Removed and Casting Clamped to Cross-slide

matic 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. 4 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 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. 5 the table is shown removed and a casting is clamped directly to the face of the cross-slide for planing the top bearing

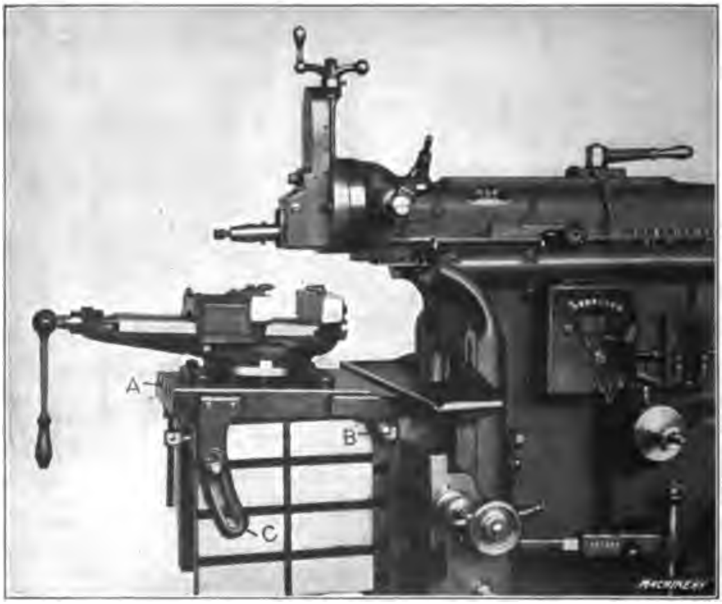


Fig. 6. Shaper Equipped with Tilting Table and Automatic Vertical Feed

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. 1), and its position is shown by degree graduations. Some shapers have an automatic vertical feed for the tool as well as an automatic horizontal feed for the work, but most shapers are not so equipped, the tool being fed vertically by hand. Both the horizontal and vertical feed-screws of the machine, shown in Fig. 1, 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.

Tilting Table for Shaper. — The detail view, Fig. 6, shows a shaper equipped with a tilting table *A* which is very convenient for planing tapering parts. The table swings about the bolts or pivots *B* on each side, and it is held at whatever angle may be required by the slotted arms *C* which are bolted to the sides of the main table. The work may be held either in a vise or be bolted directly to the table. When planing tapering parts that are held between index centers, the tilting table enables the centers to be kept in line with each other, which is especially desirable when indexing is necessary. The cause of the inaccuracy resulting from indexing with the centers out of line is explained in the paragraph headed "Milling Taper Flutes," Chapter IV.

The shaper illustrated in Fig. 6 also has an automatic vertical feed for the tool-slide. The ratchet feed lever *D* which transmits motion to the feed-screw is operated by an adjustable tappet *E*, as the ram moves back and forth. The automatic vertical feed is very convenient, especially for machining wide surfaces.

Swiveling Shaper Table. — The shaper shown in Fig. 7 has a table which swivels through an arc of 90 degrees about a horizontal axis. The angular position of the table is shown by a graduated dial *D*. This swiveling feature is useful especially in connection with tool and die making for planing surfaces at an angle.

Circular Planing Attachment. — The machine illustrated in Fig. 7 is also provided with an attachment for circular, concave planing. A curved surface is produced as the tool-head and tool are turned about a horizontal axis by the automatic feeding mechanism shown. A rotary movement is derived from worm gearing *A*, located just back of tool-slide, the worm being turned intermittently by a ratchet lever *B* which is connected to it through gearing. This ratchet lever is operated by engagement with the adjustable tappet *C*.

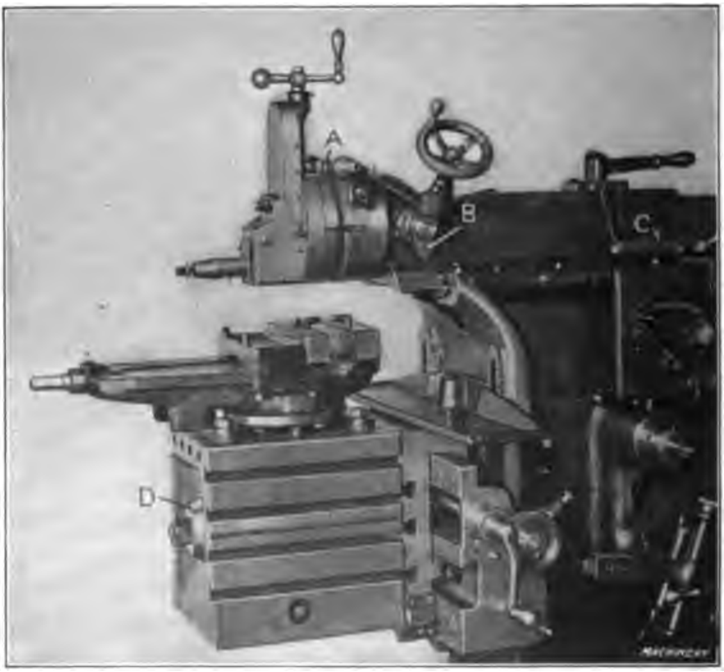


Fig. 7. Shaper having Swiveling Table and Concave Attachment

There are also shaper attachments for convex cylindrical planing, commonly known as circular or cone mandrels. The attachment consists of a base-plate which is bolted to the table and has two uprights. Between these uprights there is an arbor which carries two conical bushings for holding parts having drilled or bored holes. The arbor and work is given a rotary movement by means of worm gearing at the end, which, in turn, is operated by a feed mechanism. Other attachments are sometimes used on the shaper in order to adapt it to a wider range of work, although the ones referred to are the most common types.

Motor-driven Shaper. — Many modern shapers, as well as other machine tools, are driven by a direct-connected electric motor instead of transmitting the power from an overhead countershaft to a cone pulley on the machine. By having a

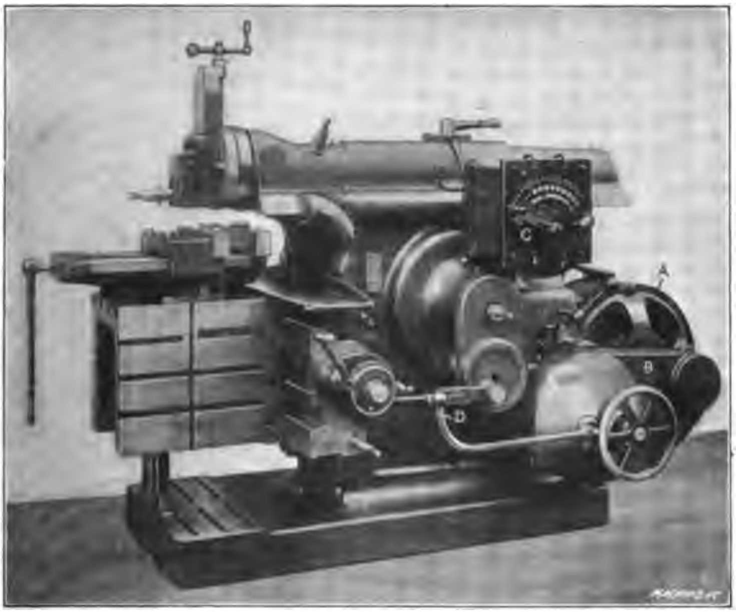


Fig. 8. Gould & Eberhardt Shaper having Variable-speed Electric Motor Drive

motor drive, the machine can be operated independently, and overhead belting is eliminated, thus leaving a clear space for traveling cranes. An electrically driven shaper is shown in Fig. 8. The motor *A* is a variable-speed type and is connected to the driving shaft of the shaper by a silent chain enclosed in guard *B*. Variations in speed are obtained electrically by means of the combination starting box and field rheostat *C*.

On some shapers, a constant-speed motor is used and the speed changes are obtained mechanically by shifting gears in a gear box, through which motion is transmitted. The gear box construction is also found on some belt-driven shapers, in which case a single belt pulley is used instead of a cone pulley.

The long curved lever *D* controls a clutch and brake mechanism for starting and stopping the machine independently of the motor. Shifting the lever in one direction starts the shaper, and moving it in the opposite direction stops the ram at any part of the stroke.

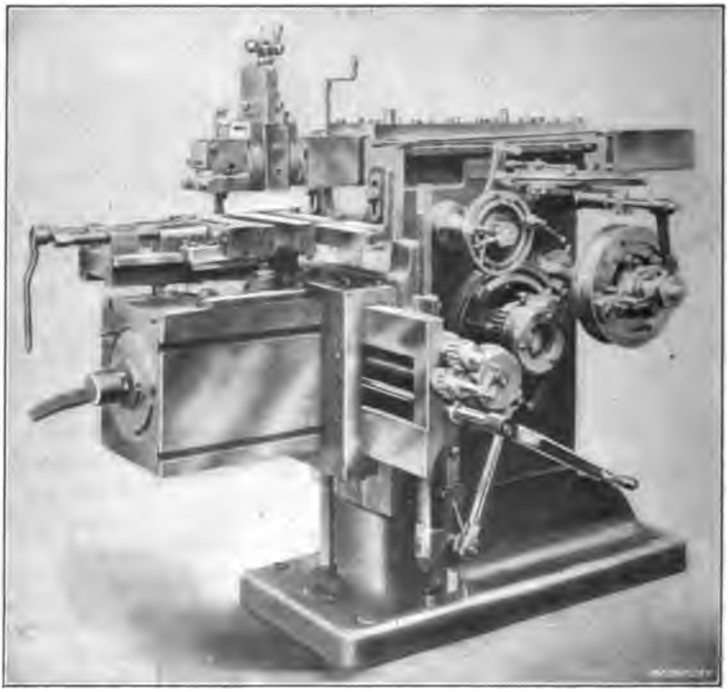


Fig. 9. Morton Draw-cut Shaper

Morton Draw-cut Shaper. — The shaper illustrated in Fig. 9 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 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

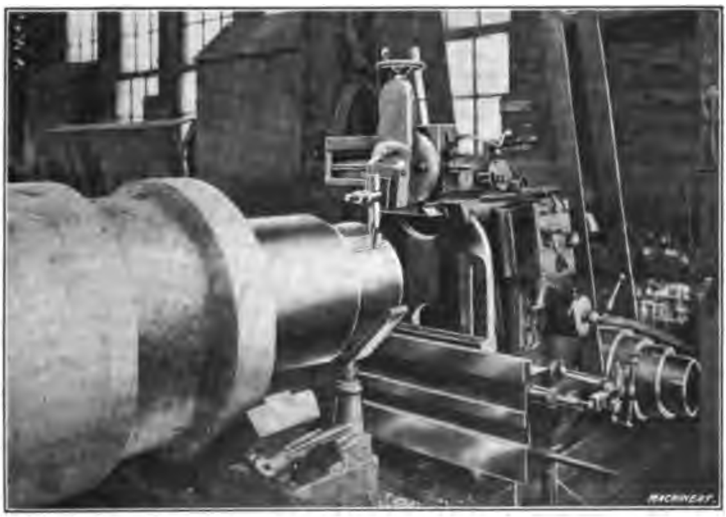


Fig. 10. Planing End of 20-ton Steel Roll, with Shaper having Side-traversing Tool-head

relieve the cross-rail and other bearings from excessive strains, especially when taking deep cuts. As the ram is subjected to a tensile stress, it is claimed that vibrations are practically eliminated and that the tendency to vibrate diminishes as the depth of cut increases. Another advantage of the draw cut is that lines on the outside of the work, showing the location of finished surfaces, are not broken until cut out by the tool.

The Rack Shaper. — A shaper of the type illustrated in Fig. 1, 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.

Special Types of Shapers. — 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. 10, 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.

Pratt & Whitney Vertical Shaper. — The machine shown in Fig. 11 resembles a slotter in many respects, but it is known as a vertical shaper and is adapted for classes of work that are done on horizontal shapers and regular slotting machines. The work table of this shaper can be given a transverse, longitudinal, or rotary movement. The ram which carries the planing or slotting tool moves vertically while the table is fed either by hand or automatically, in whatever direction is required. The transverse feed is effected by shaft *A*, the longitudinal feed by screw *B*, and the rotary feed by shaft *C*. Power is transmitted to the feed mechanism from the cam *D* which operates oscillating arm *E*.

The desired rate of feed is obtained by adjusting shaft *F*, the power being transmitted through a crank at *G* and shaft *H* to the feed pawl and ratchet shown in the illustration. The various power feeds are engaged by sliding pinions *I*, *J* and *K* into mesh. When these pinions are in the outward position, the power feed is disengaged and when they are pushed inward, the power feed is operative. The direction of the feed is controlled by pushing in or pulling out the knob *L*. The feeding action

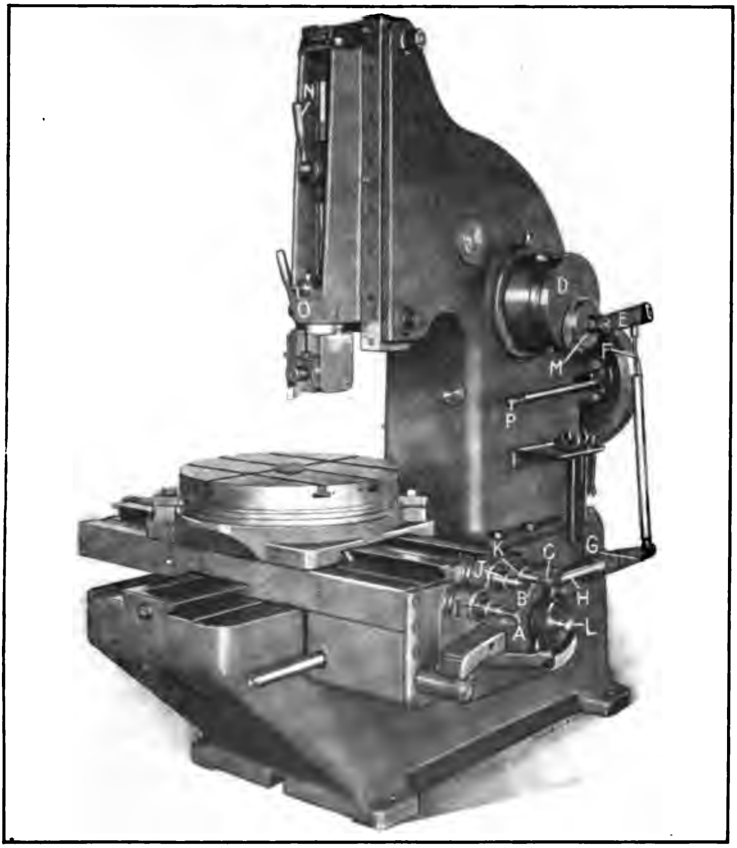


Fig. 11. Pratt & Whitney Vertical Shaper

takes place when the ram is at the upper end of its travel and the tool is clear of the work. Micrometer dials are provided for making accurate adjustments, and the periphery of the rotary table is graduated in degrees.

The mechanism for operating the ram is driven by worm gearing and with this exception it is similar to the driving mechanism used on the Pratt & Whitney horizontal shaper. The ram can be set perpendicular to the table, or at an angle, as shown in Fig. 12, for slotting dies, etc. The ram is mounted in an independent bearing, the upper part of which is pivoted on a trunnion that enables the bearing and the ram to be set in an angular position, which is indicated by degree graduations. The stroke of the ram is indicated by the graduated dial *M*, and the ram may be stopped and started independently of the countershaft by a friction clutch controlled through lever *P*.

Fig. 12. Angular Adjustment of Ram on Vertical Shaper

Fig. 13. Ram Head Swiveled through 90 Degrees

The tool is held in a slotted toolpost carried in a clapper which permits the tool to clear the work on the return stroke, the same as on a horizontal shaper. When exceptionally long tools must be used on internal work, the clapper can be clamped rigidly to the head. The tool-head can be swiveled to four different positions, one of which is shown in Fig. 13, so that the tool can be set for planing different sides without changing the position of the rotary table and by simply using the transverse or longitudinal feeding movement, thus insuring accuracy between the surfaces. Work can often be completed at one setting on a shaper of this type and it may be used for machining concave, convex or irregular surfaces.

Cochrane-Bly Universal Shaper. — Diemakers and toolmakers are often obliged to use a number of machines for making a die or jig, especially if the shape is at all complicated or irregular. This means that the work must be reset in each machine, which not only requires extra time but often makes it difficult to secure accuracy between the different surfaces, thereby increasing, in

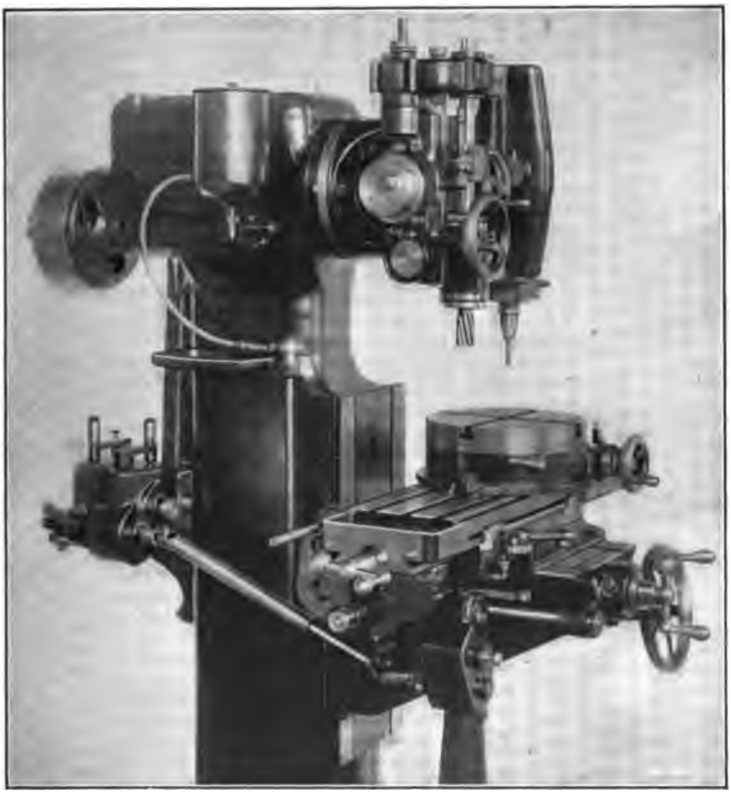


Fig. 14. Cochrane-Bly Universal Shaper and Milling Machine

many instances, the amount of handwork necessary for fitting and finishing. The machine illustrated in Fig. 14 has been designed to perform quite a variety of operations at one setting of the work; therefore it is especially adapted to the making of dies, jigs, or to general tool-room work. This machine is known as a universal shaper, but, in reality, it is a shaper, slotter, milling and drilling machine combined. It is equipped with a shaper ram, a milling and drilling spindle, and suitable speed and feed-changing mechanisms. The milling spindle and shaper ram have universal adjustments so that tools can be presented to the work at any desired angle. Fig. 15 shows the shaper ram set in a horizontal position.

The machine is driven from a constant-speed clutch pulley at the rear, which transmits the power through a double cone of spur gears to the main head. The latter carries bevel gears

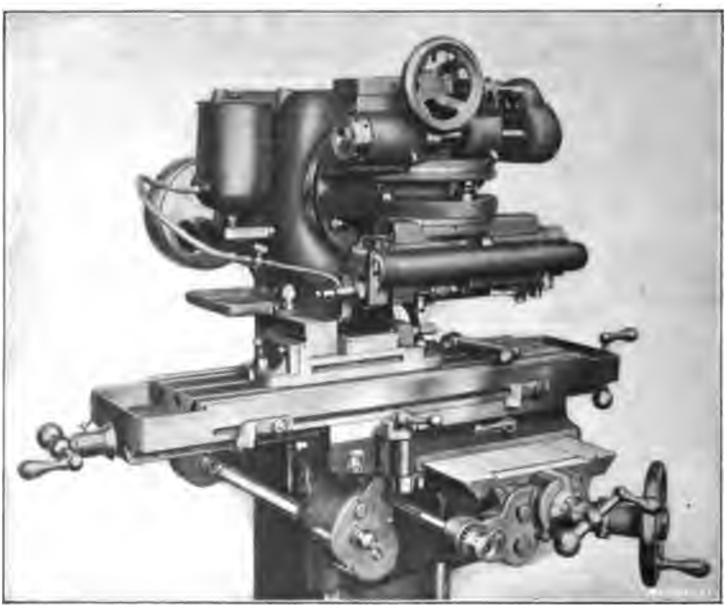


Fig. 15. Shaper Ram of Cochrane-Bly Universal Shaper Set in a Horizontal Position

for driving both the shaper ram and milling spindles. The cones of spur gears provide means for varying the speeds, and the speed changes are effected by means of a lever on the right-hand side of the column. The end of this lever swings around a graduated quadrant which shows the number of ram strokes per minute for any one of the five positions. The shaper ram has a quick return and the strokes can be adjusted from 0 to 6 inches. The ram is equipped with a mechanism which provides a positive relief for the tool on the upward or return stroke.

The milling spindle revolves either to the right or left. It has a sliding movement of 3½ inches for drilling and boring, which is controlled by a handwheel operating through worm gearing. A micrometer screw-stop, reading to thousandths of an inch, is provided to facilitate accurate adjustments. The main head, including the shaper ram and milling spindle, can be revolved about a horizontal axis (after loosening the clamping bolts) by turning a small crank which is located at the upper end of the graduated quadrant previously referred to. The shaper and milling heads each have an independent adjustment about an axis at right angles to the main head, which makes it possible to locate them at any angle.

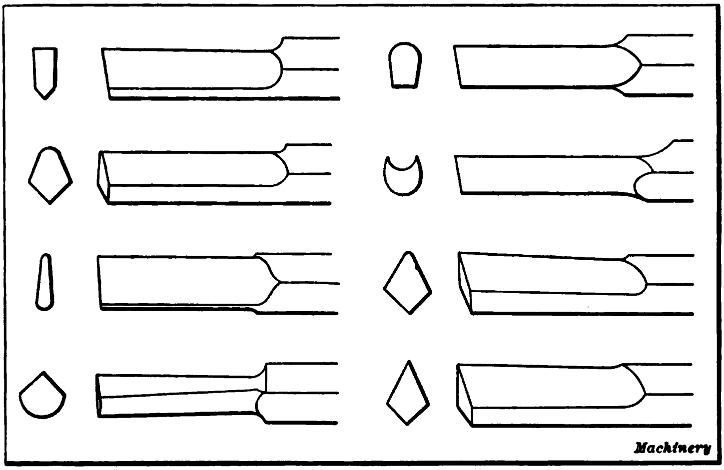


Fig. 16. Set of Slotting Tools for Universal Shaper Illustrated in Fig. 14

Power feed is provided for the longitudinal and transverse movements of the table. Either a continuous or intermittent feed is obtained from a feed-box at the rear. When the milling spindle is being used, the feed is continuous, whereas an intermittent feed, which takes place on the return stroke, is required for the shaper ram. For a continuous feed, the drive is through spur gears, and for an intermittent feed, a crank-and-ratchet mechanism is brought into action. The circular milling and slotting attachment, seen on the main table in Fig. 14, is equipped with power feed and a dividing mechanism.

Tool-holders of various styles for holding slotting or shaping tools can be attached to the tool-head. Fig. 16 shows a set of standard slotting tools such as are used when shaping out small dies, for cutting internal keyways, etc. The shaper toolpost is used when the machine is working either as a horizontal shaper (as shown in Fig. 15) or as a vertical shaper.

The universal features of this machine, in conjunction with the various tools which can be used, make it possible to machine

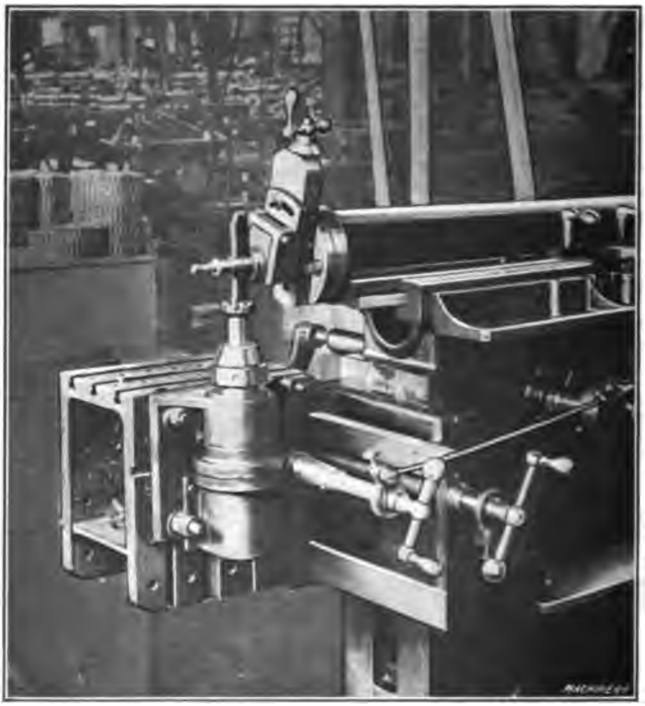


Fig. 17. Shaper Equipped with Fixture for Generating Helical Clutch Teeth

a large variety of such work as blanking and forging dies, punches, forming tools, such as are used in turret lathes, automatic machines, etc., jigs, especially when shaping, milling and boring operations are required, and similar classes of work.

Shaper Attachment for Machining Clutches. — The shaper attachments previously referred to can be used for different classes of work, but occasionally a special attachment is designed for machining only one class of work. An attachment of this kind used for planing four-tooth clutches for automobile starting handles is shown in Fig. 17 applied to a shaper. It consists of a bracket bolted to the table of the shaper, which has at its lower end a hardened four-tooth half-clutch B_1 (Fig. 18) similar in form to the clutch to be made. The other half B of the clutch is also made of hardened steel and is fixed to the end of a spindle which revolves and moves vertically. On the upper end of the spindle the clutch blank is held by means of a split collet. The spindle receives its rotary motion from a revolving sleeve driven by worm and worm-wheel A. The worm is rotated either by the handle seen at the end of the worm shaft in Fig. 17, or automatically by means of a ratchet and pawl which is similar to the device used for feeding the table. This automatic feed derives its motion from the regular feeding mechanism of the machine. A spiral spring keeps the rotating half of clutch B in contact with the lower clutch B_1 which is attached to the bracket.

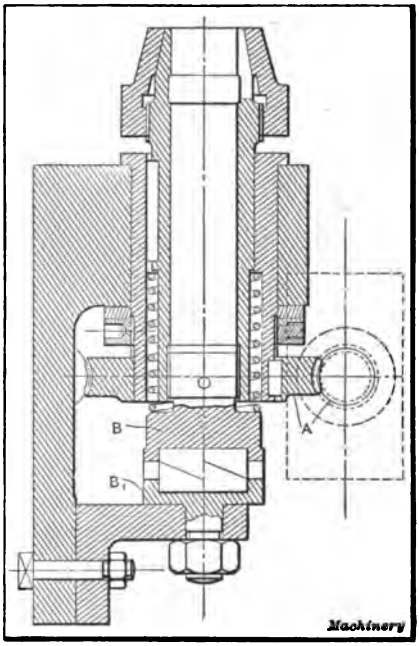


Fig. 18. Vertical Section of Fixture shown in Fig. 17

The fixture operates as follows: When the worm-wheel is revolved by the handle referred to, the work spindle rotates and, owing to the hardened four-tooth clutch fixed to its lower end, receives, besides the rotary motion, an upward movement during a quarter turn; it then drops to its lower position and, as the rotary movement continues, it again rises, and so on for each succeeding quarter turn. Prior to forming the clutch teeth, the tool-slide is inclined to a suitable angle and four slots are cut at points corresponding to the faces of the teeth and to a depth represented by the lowest position of the arbor carrying the clutch. The slotting tool is then replaced by a narrow planing tool which generates helical or spiral teeth as the spindle rotates. Good results both as to output and accuracy are obtained with this simple fixture. The clutches are well machined and can be used without further finishing.

The Slotting Machine. — The slotting machine or "slotter," as it is commonly called, is a vertical machine used 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. 19), 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 narrow slots are held in a vertical position, whereas larger slots or 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

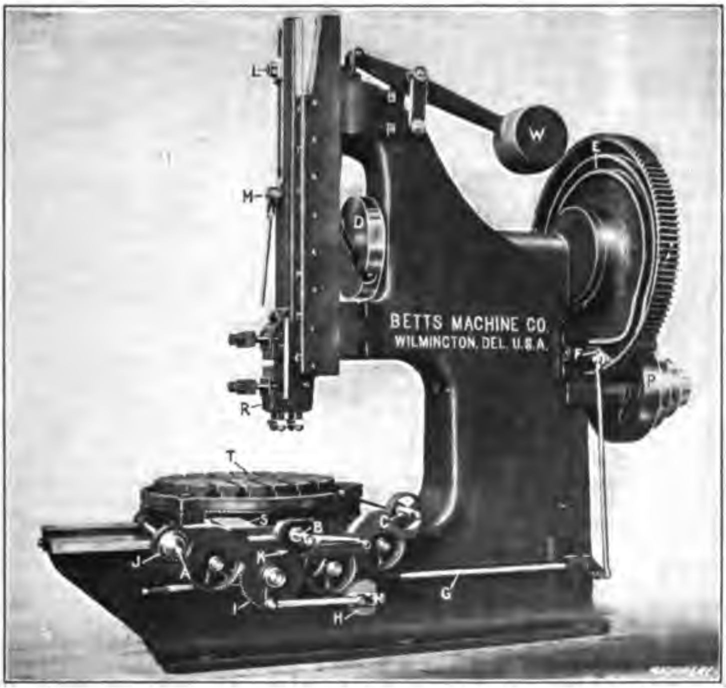


Fig. 19. Betts Slotting Machine

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 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.

Example of Straight and Circular Slotting. — A typical example of the kind of work done on the slotter is shown in Fig. 20

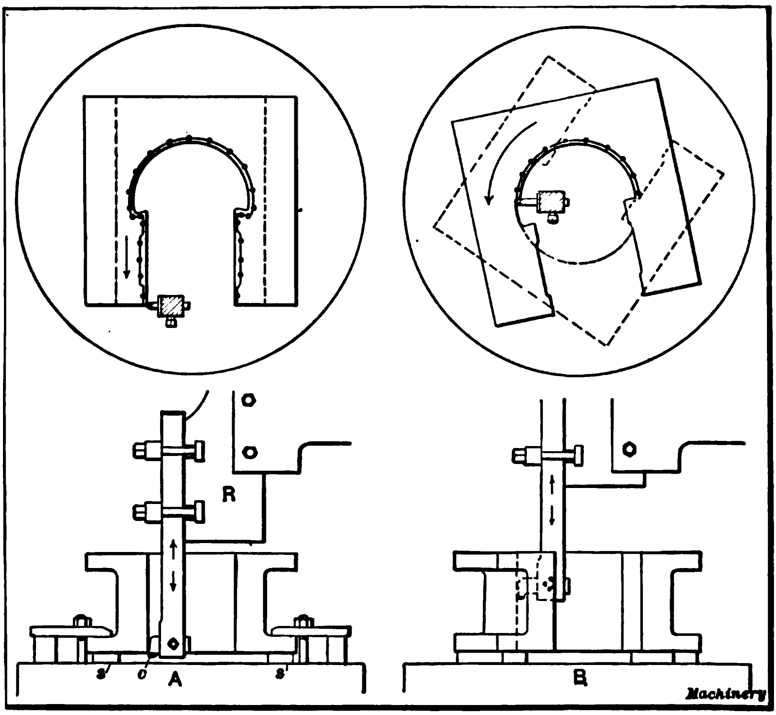


Fig. 20. Example of Straight and Circular Slotting

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 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 halfway around.

The sketch at *B* indicates how the curved seat for the brass bearing 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 as the tool moves up and down, thus machining a circular seat into which the bearing brass is afterwards inserted. 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.

Slotting an Engine Connecting-rod. — Fig. 21 shows how a slotter is used for machining the rectangular opening in the end of a connecting-rod, into which the bearing brasses are afterwards fitted. Prior to the slotting operation, the sides of the rod are finished by planing or milling. A row of holes is then drilled in the solid end of the rod just inside the lines laid out for

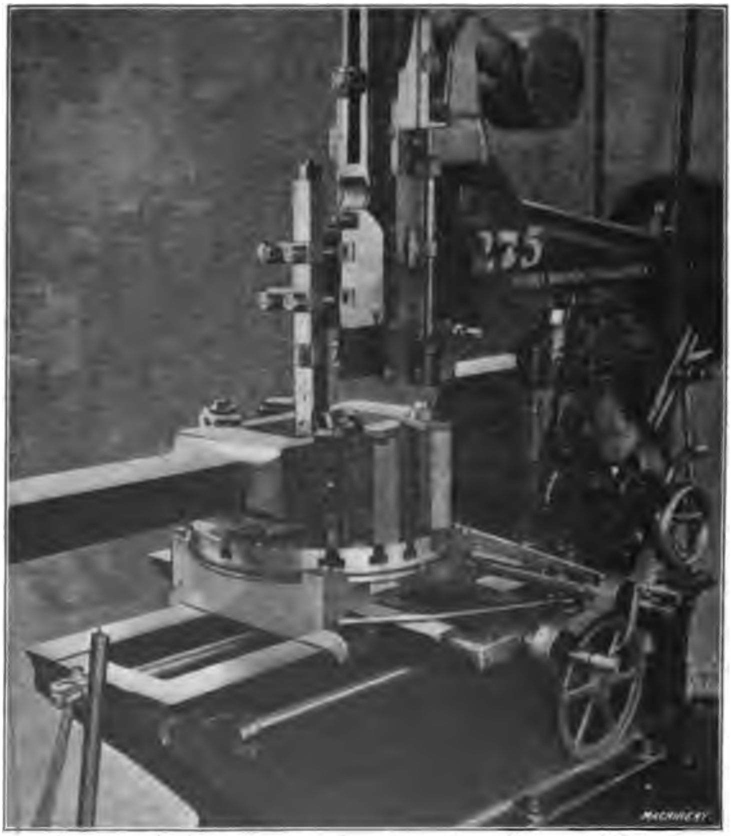


Fig. 21. Slotting End of Engine Connecting-rod on a Dill Slotter

the rectangular opening, and the interior part is removed in the form of a solid block. The rod is then clamped to the slotter table upon two parallels which provide a clearance space for the tool at the lower end of the stroke. The long sides are slotted by using the longitudinal feed and the short sides by means of the cross-feed. The tool, of course, is turned in the toolpost to face the different surfaces as they are slotted. When using a tool-holder of the type shown, on work of this kind, it is necessary to replace it with another form of tool for finishing the corners. The style of tool shown at *B*, Fig. 22, could be used, because the cutting edge is at an angle of 45 degrees to the shank.

Ordinarily, when using the slotter to machine surfaces which are at right angles to each other, the table is fed first laterally and then longitudinally or *vice versa*, but in this case, owing to the size and weight of the rod, the lengthwise cuts are taken by feeding the tool-head of the slotter, the work remaining stationary except when machining the end surfaces. This feeding of the tool is possible with the particular make of slotter shown as it has a traveling head, so that the tool can be given a feeding movement when slotting a part which is large and cumbersome.

When slotting heavy, overhanging castings or forgings, such as the one illustrated, the outer end should be supported, and usually it is advisable to mount the supports on two pairs of rollers arranged one above the other and at right angles, so that the work can easily be fed in a lateral or lengthwise direction. The support may consist simply of blocks with the rollers interposed between them, although special supporting stands equipped with rollers are often used. By means of roller supports, very large castings can be machined on the slotter. The support should be just high enough to hold the part level, thus relieving the table of the excessive load to which it would be subjected if no support were used.

The Dill Slotter. — The slotter shown in Fig. 21 differs in several respects from the one illustrated in Fig. 19. As previously mentioned, it has a traveling head which permits cuts to be taken by feeding the tool instead of the work. The ram and tool can also be set close to the column or some distance away from it, depending upon the nature of the work. When both table feeds are used, the traveling head is clamped in the desired position. The machine has a quick traverse for moving the head or table rapidly in any direction, when considerable adjustment is required. This quick traverse is operated by a lever located at the side of the machine. The automatic feeding movement may be either intermittent or continuous, the intermittent feed taking place at the top of the stroke and the continuous feed throughout the cutting stroke. The intermittent feed is the proper one to use for most work, but the continuous feed is useful, especially for finishing the ends of narrow slots, which require a long slender tool. The intermittent feed is used until the tool reaches the end of the slot; the continuous feed is then engaged, thus causing the feed to take place gradually throughout the length of the stroke in order to overcome the spring of the tool and square the end of the slot.

On the crank disk of this slotter there is a stroke indicator which shows the length of stroke for which the machine is set. This is simply a pointer having a curved end which is held in contact with the crankpin bushing by a spring. As the pin is adjusted to or from the center, the pointer is moved a proportional amount by the curved end and the stroke is indicated by a suitable scale on the edge of the crank disk. The cutter bar or ram is fitted in an adjustable guide which can be raised or lowered by a crank handle to the position where it will give the ram the best support. The tool is held in a relief apron to prevent the cutting edge from dragging over the slotted surface on the upward stroke.

Slotter Tools. — Some of the tools used in the slotter are illustrated in Fig. 22. Those shown at *A*, *B* and *C* are forged from the solid bar and have 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. Many tools of this type have square shanks so that special clamps are not required. The cutter *t* is held by set-screw *e* 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. Tools having broad flat cutting edges are used in the slotter for taking light finishing cuts, but the feeds are usually less than when planing because there is less rigidity. Some slotter tools are designed so as to machine two surfaces at the same time. Tools of this

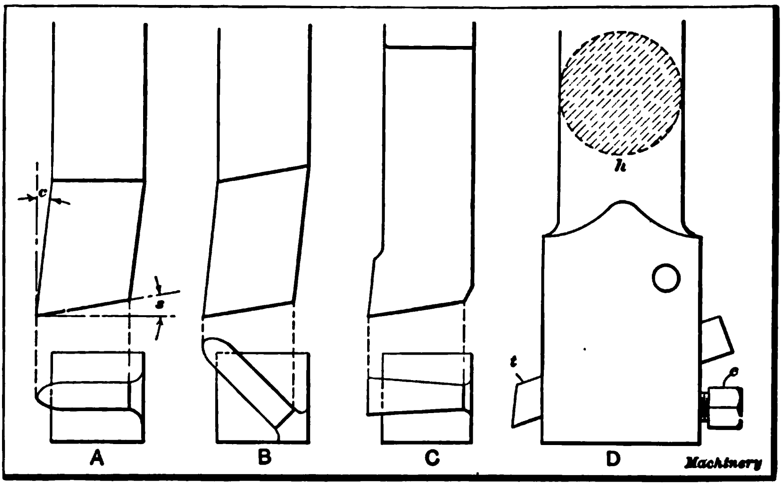


Fig. 22. Typical Slotter Tools

type are often used when slotting connecting-rod straps. Two or more straps are clamped in a pile and the double-ended tool enters at the open end, and operates in both sides. Ordinarily, there is a roughing cutter which is followed by a finishing cutter.

When grinding slotter tools the cutting edge is given slope *s* at the end (see sketch *A*) and the front side is ground to a clearance angle *c*. For ordinary work the slope angle should be 10 or 12 degrees, and the clearance angle 4 or 5 degrees. 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.

CHAPTER III

CONSTRUCTION AND USE OF PLAIN 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.

Surfaces are milled 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 held on the table of the milling machine and 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

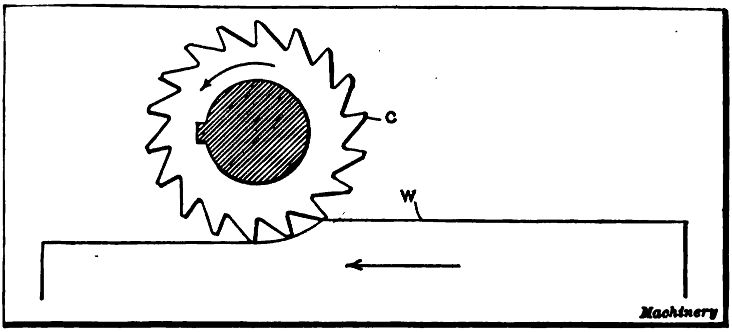


Fig. 1. End View of Cylindrical Cutter Milling Flat Surface

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. — 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 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-

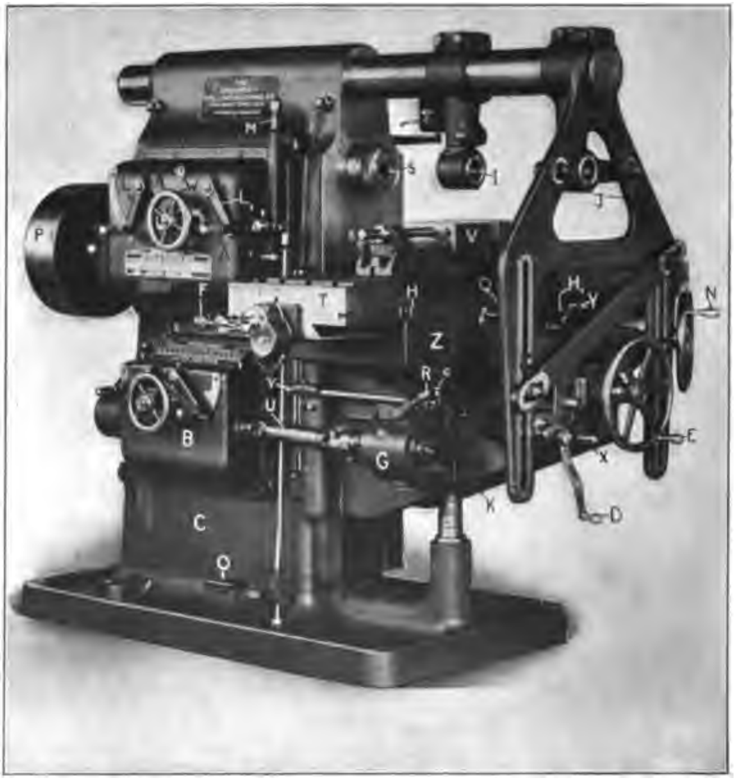


Fig. 2. Cincinnati Plain Milling Machine

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-changing Mechanism. — 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, 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 Feed-changing Mechanism. — 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, 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.

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 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

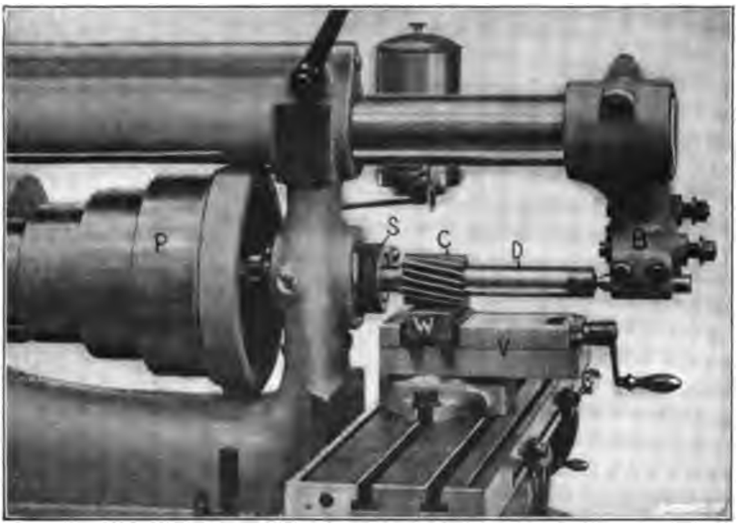


Fig. 3. Milling a Small Rectangular Block

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

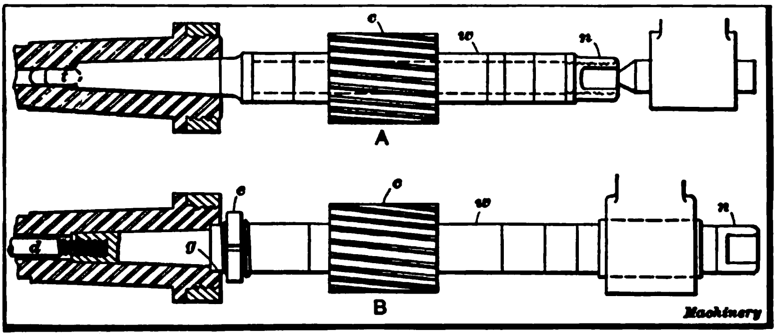


Fig. 4. Cutter Arbors for Milling Machine

cutter *C* would be used (in a machine of this type), having a width somewhat greater than the surface to be milled. This cutter 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 be placed as near the spindle as circumstances will permit (as illustrated in Fig. 3), 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* (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.

Milling Machine Vises. — Three types of milling machine vises which are commonly used are shown in Fig. 5. The one

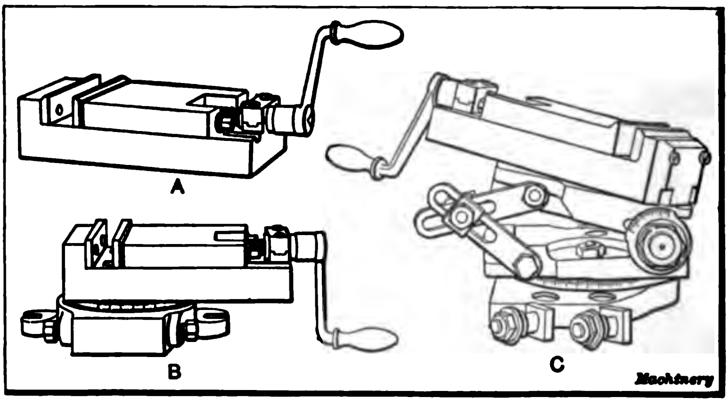


Fig. 5. Milling Machine Vises

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 position 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, 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 are shown in connection with examples of milling referred to later.

Direction of Feed 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.

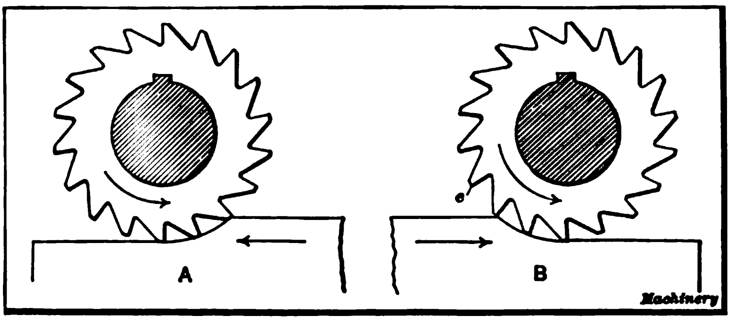


Fig. 6. (*A*) Work feeding against Rotation of Cutter. (*B*) Work feeding with Rotation of Cutter

Right- and Left-hand Cutters. — 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 or rear side, is said to be right-hand, and, inversely, a left-hand cutter is one that turns to the left (counter-clockwise) when milling.

Milling with Nicked Roughing Cutter. — 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 cast-

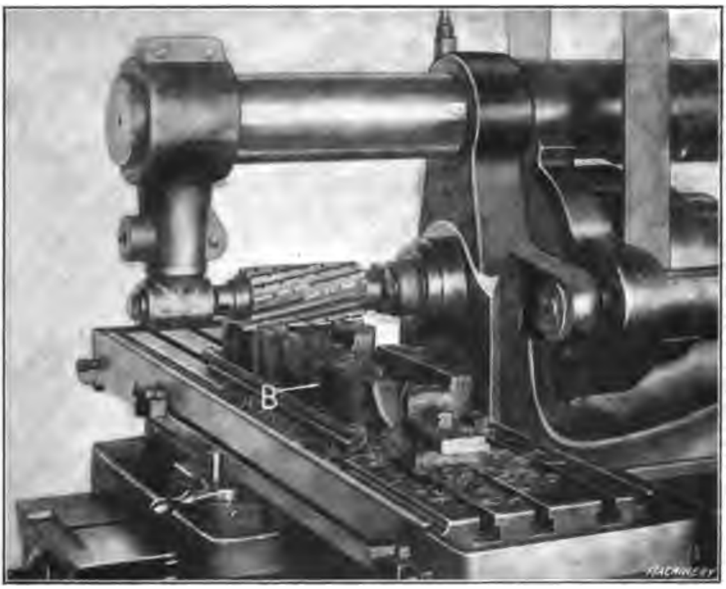


Fig. 7. Milling Cast-iron Bearing Caps

ings 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 $\frac{1}{8}$ 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.

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 the nature of the work varies widely, the stock of cutters must be comparatively large, and, inversely, when a machine is

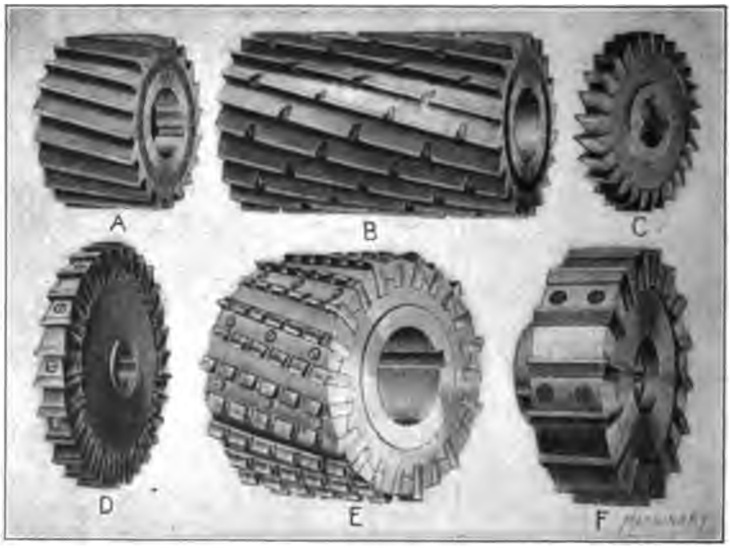


Fig. 8. Cylindrical, Side, and Face Milling Cutters

used for milling only a few parts, a large cutter equipment is not necessary.

Cylindrical Cutters. — 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

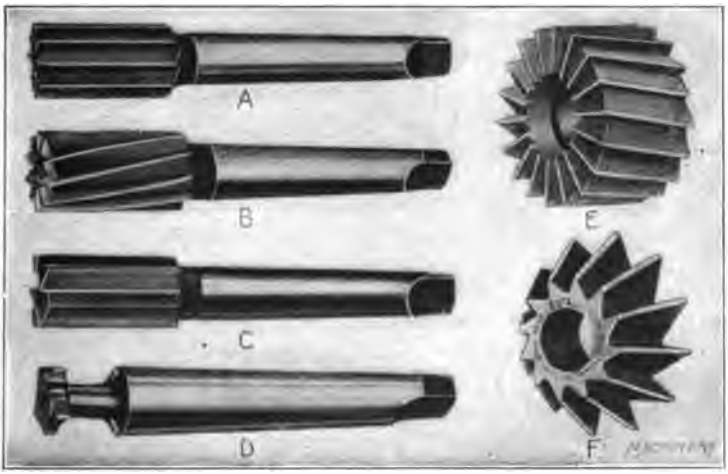


Fig. 9. End Mills, T-slot Cutter, Shell End Mill, and Angular Cutter

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.

Side Milling Cutter. — 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 or slots and for other operations, examples of which will be shown later. 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.

Cutters of Inserted-tooth Type. — 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

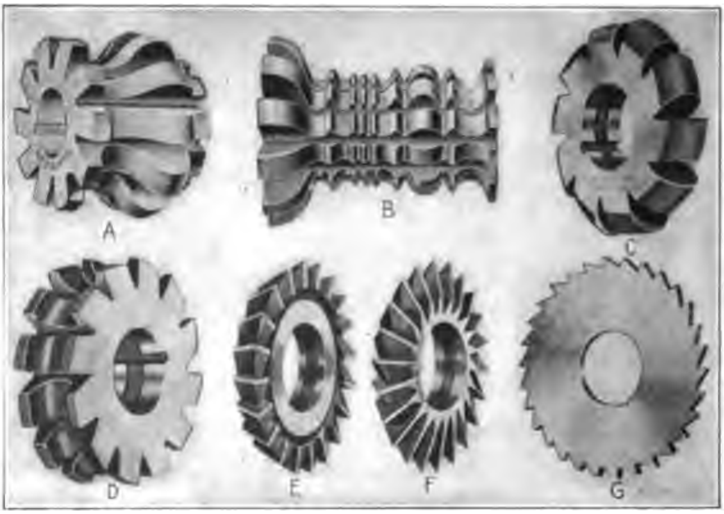


Fig. 10. Formed Cutters, Angular Cutters, and Slitting Saw

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.

End Mills. — 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 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.

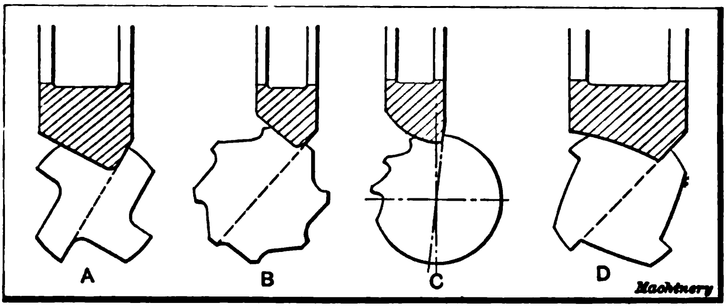


Fig. 11. Diagrams Illustrating Use of Formed Cutters for Fluting Taps Reamers, etc.

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. 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.

Formed Cutters. — 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.

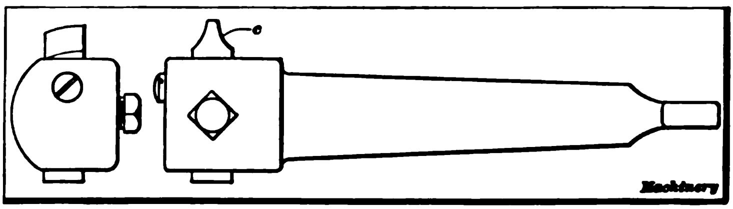


Fig. 12. Fly-cutter and Arbor

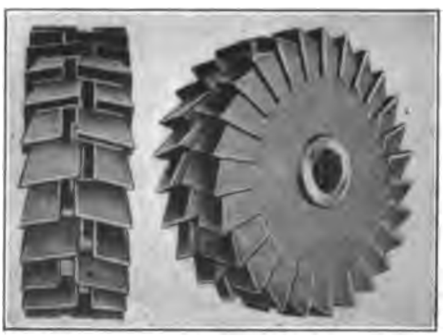


Fig. 13. Interlocking Side Milling Cutter

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.

Angular Cutters. — 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. An angular cutter is also shown at *F*, Fig 9. The teeth are at an angle of 60 degrees with the axis. This form of cutter is used for milling dovetail slots and for similar work. The particular style shown has a threaded hole and is screwed onto the arbor.

Slitting Saw. — The thin cutter illustrated at *G* (Fig. 10) is known as a slitting saw, and it is used for milling narrow slots, cutting off stock, and for similar purposes.

Fly-cutter. — 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 a taper shank the same as an end

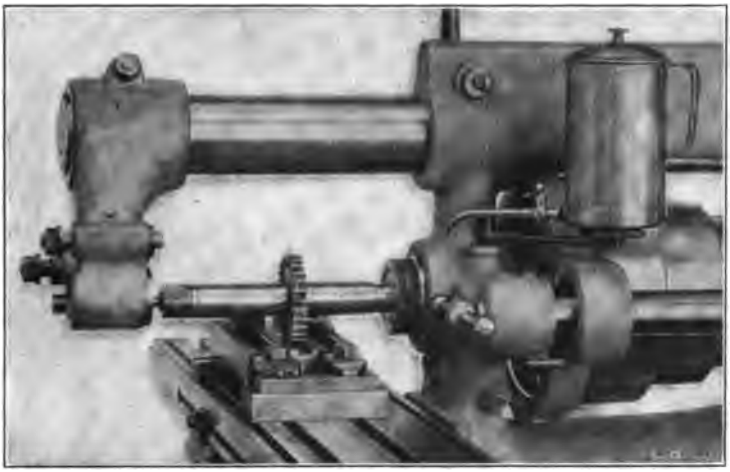


Fig. 14. Milling Groove with Interlocking Cutter

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

Interlocking Side Mill. — 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.

Form 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.

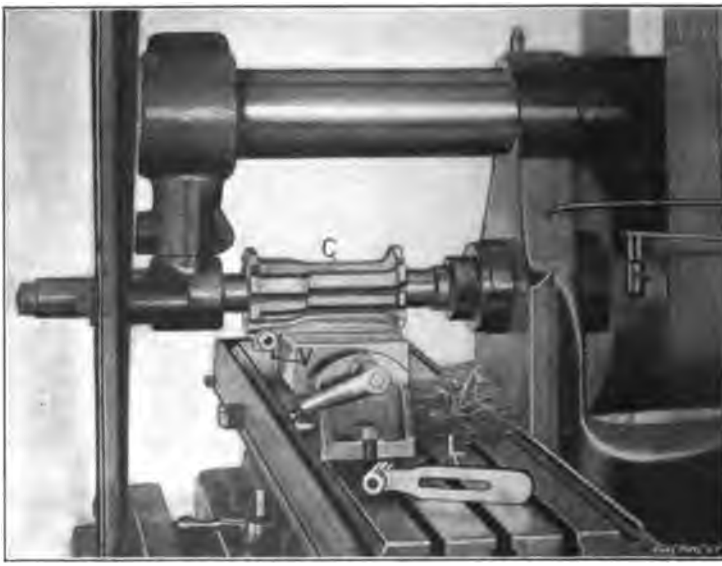


Fig. 15. Example of Form Milling

Because of this fact, milling machines are widely used for manufacturing a great variety of small machine parts having an irregular outline. The high-speed steel cutters and powerful machines now used also make it possible to finish 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. 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.

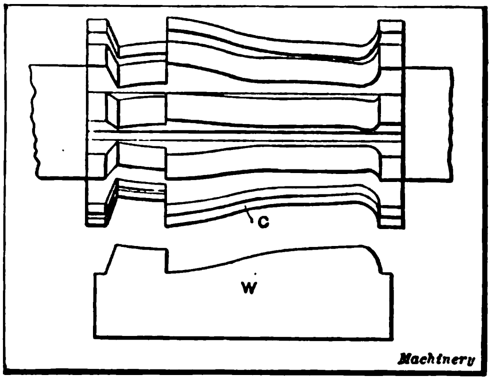


Fig. 16. Formed Cutter for Milling Part W

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 same 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

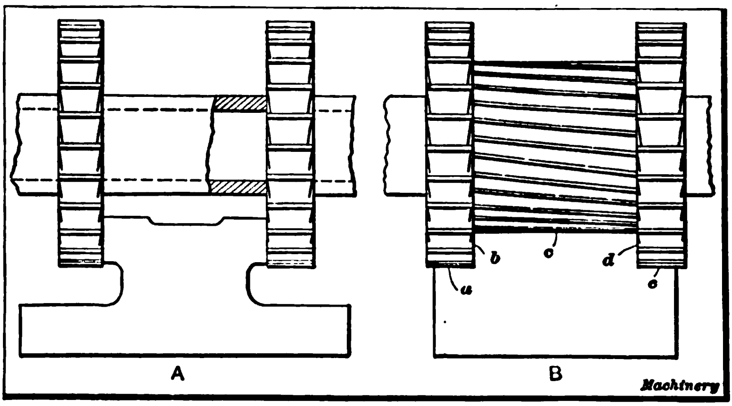


Fig. 17. (A) Straddle Milling. (B) Gang Milling

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. 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 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 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

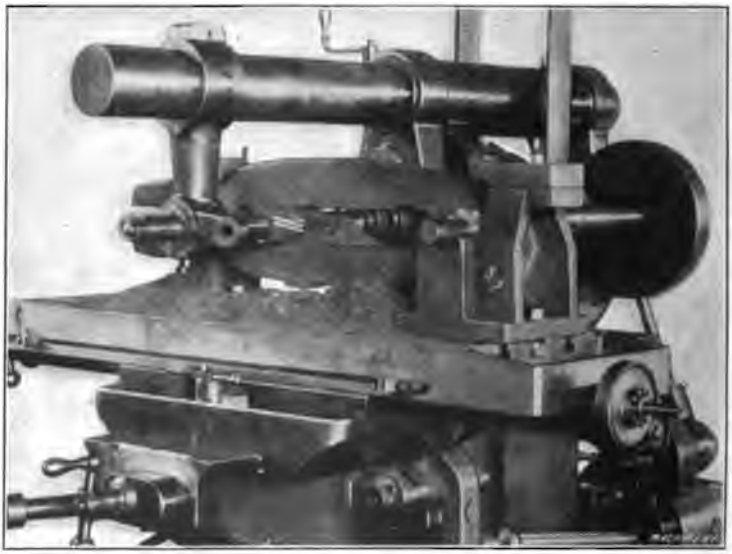


Fig. 18. Milling Slot of Crank-shaper Rocker-arm

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 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.

Example of Straddle Milling. — 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

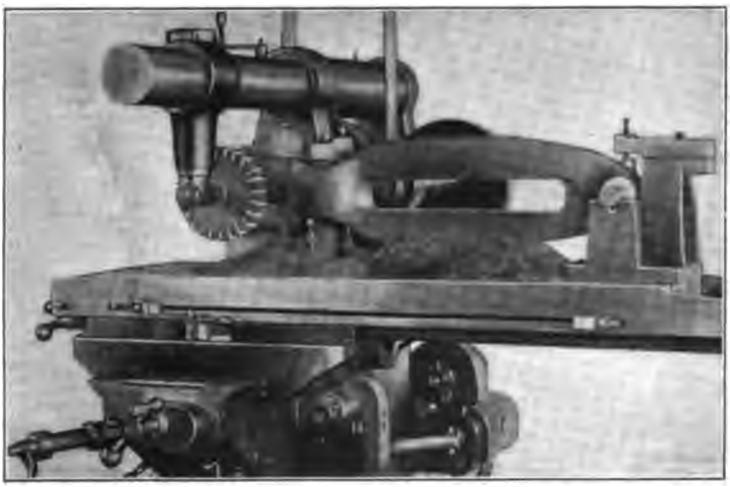


Fig. 19. Finishing End of Rocker-arm with Straddle Mill

left end of the rocker-arm is also milled by this same cutter, as well as the raised pads on the top and bottom of the arm. This cutter is $2\frac{3}{4}$ inches in diameter, and when milling the long central slot, a $\frac{1}{16}$ 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 $8\frac{1}{2}$-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 $2\frac{1}{4}$ 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 set-screws 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.

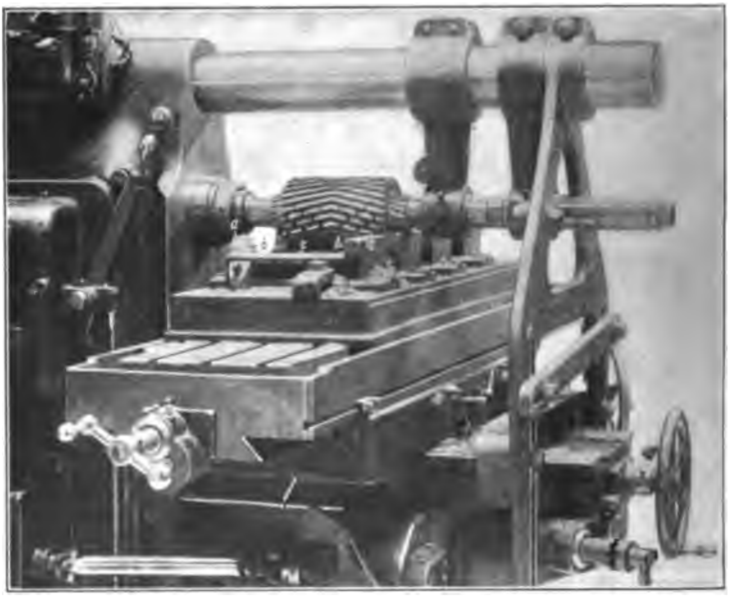


Fig. 20. Example of Gang Milling

Gang Milling. — 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.

Examples of Gang Milling. — 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-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 $9\frac{3}{8}$ inches and they are 6 inches in diameter. The speed

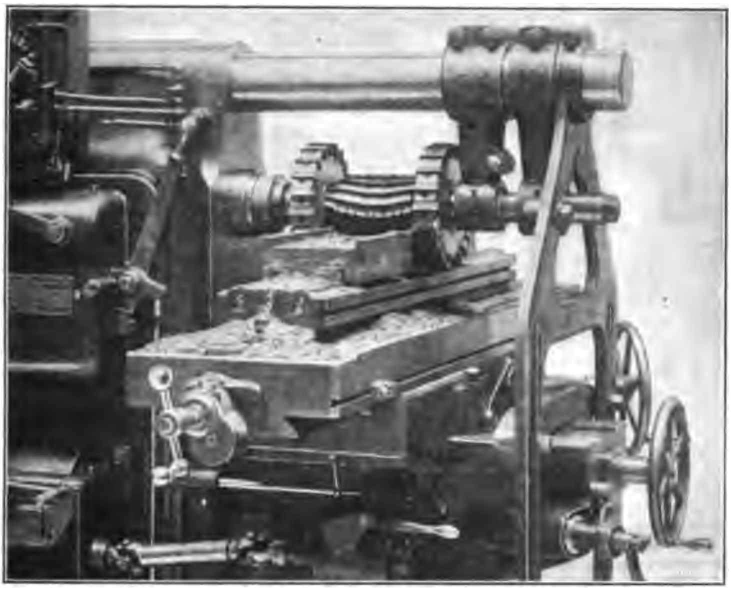


Fig. 21. Milling Top and Sides or Casting with Gang Mill

of the cutter is 32 revolutions per minute and the greatest depth of cut about $\frac{3}{16}$ 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 $10\frac{1}{2}$ 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 depend 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.

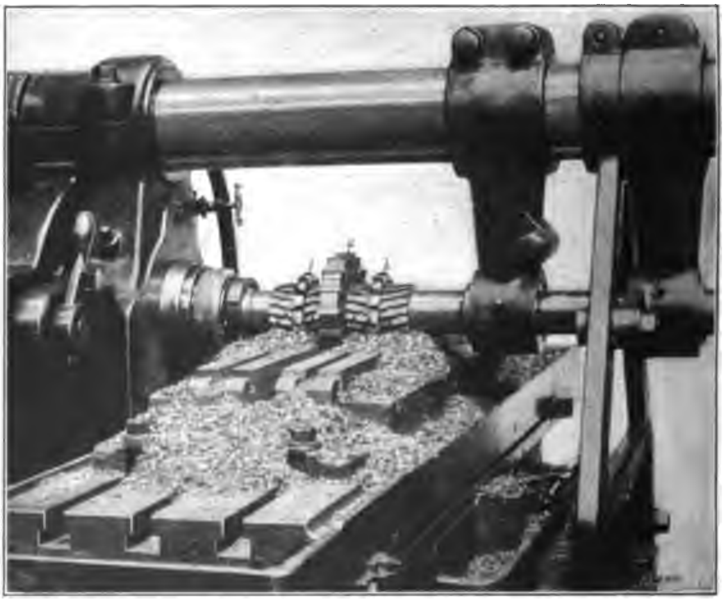


Fig. 22. Milling Two Parts Simultaneously

Fig. 22 shows an example of gang milling in which two castings are placed side by side and rough-milled simultaneously. The gang-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 should 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

Fig. 23. Another Gang Milling Operation

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 of the casting, as the illustration indicates. The speed of rotation is 33 revolutions per minute, and the table travel, $6\frac{1}{8}$ 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 outboard bearing. For some classes of work, the cutter, instead of being placed on an arbor, is attached directly to the machine

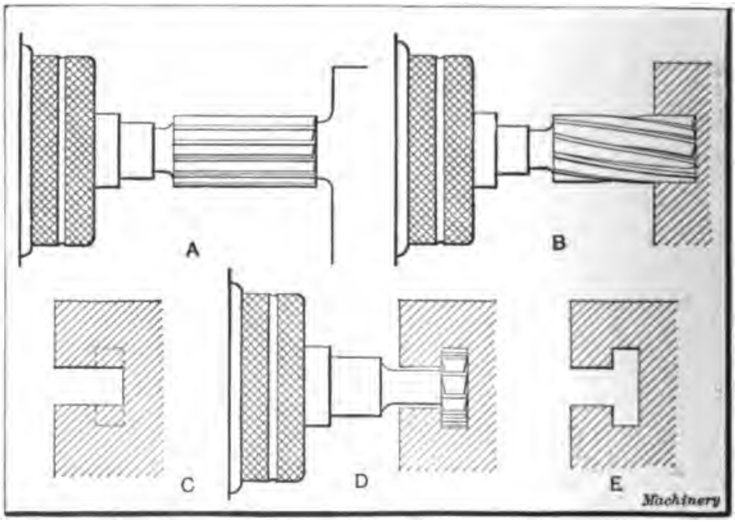


Fig. 24. End Milling — Diagrams Illustrating Use of T-slot Cutter

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.

Cutting Grooves with an End Mill. — 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 cutter. As previously mentioned, if it is necessary to start a groove by

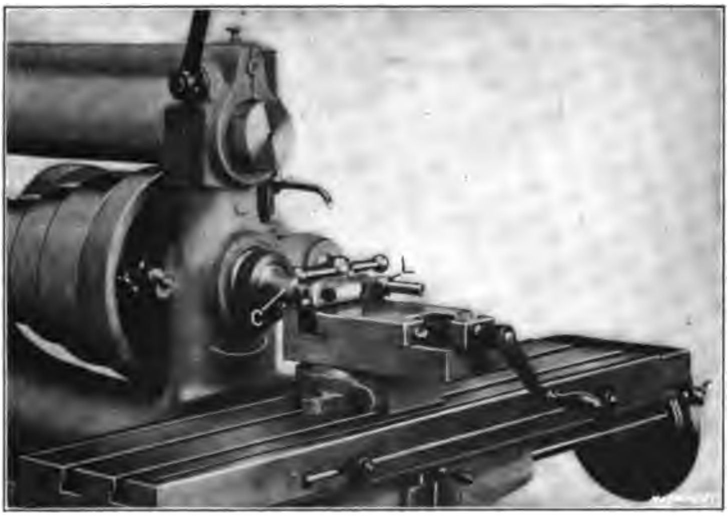


Fig. 25. Milling Slot with End Mill

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.

Milling T-slots. — 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.

Milling Plain Slots. — 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

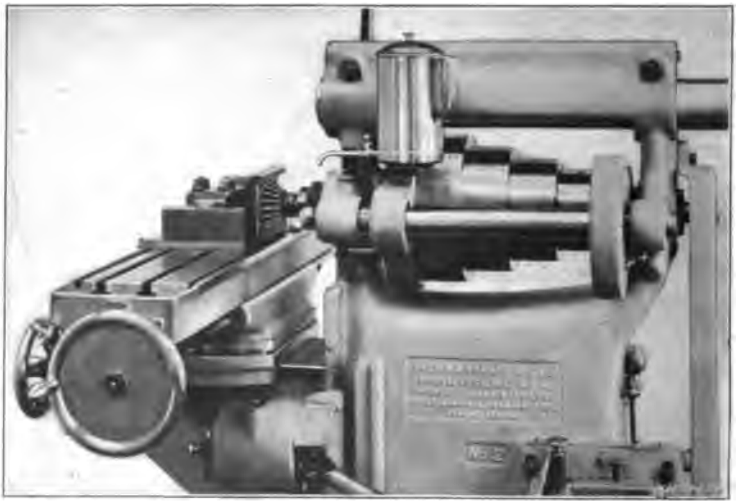


Fig. 26. Milling a Dovetail Groove

place for the milling cutter. The link is held in a vise and the metal between the two holes is 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.

Milling a Dovetail Groove. — 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.

Milling with a Face Cutter. — An end milling operation is shown in Fig. 27, which differs from those previously referred to,

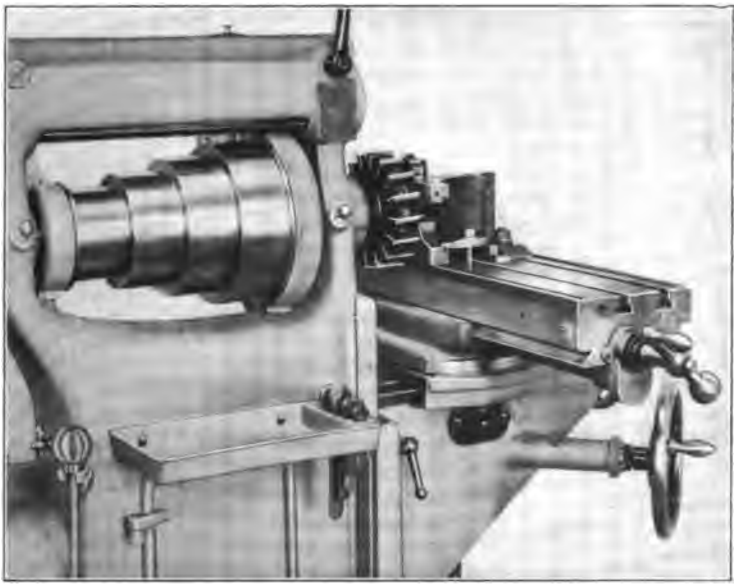


Fig. 27. Finishing Vertical Surfaces with Face Mill

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.

Milling a Keyway in a Shaft. — A simple method of holding a shaft for milling a keyway is illustrated by sketches *A* and *B*, Fig. 28. The blocks *b* are aligned with the machine table by tongue-pieces *t* which fit a T-slot in the table, and the work is held both against the blocks and downward by the oblique

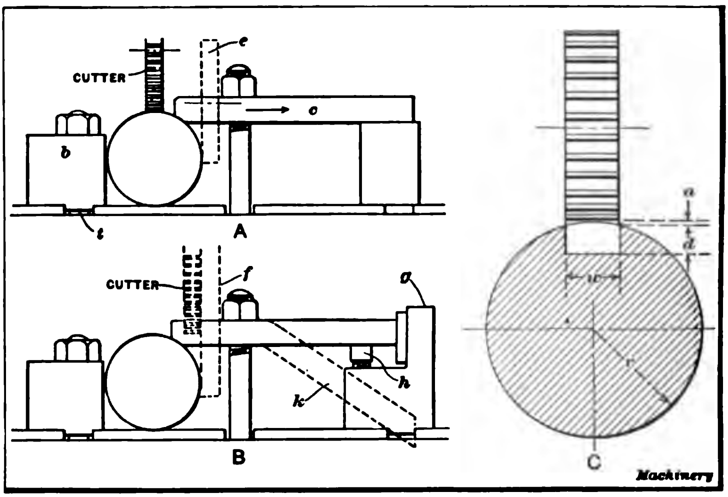


Fig. 28. Views Illustrating Simple Methods of Holding Cylindrical Work and Setting Cutter for Keyseating

pressure from the clamps. As the clamps are tightened, they tend to shift backward as shown by the arrow (see view *A*). For this reason clamps having rather close-fitting bolt holes should be used. A special packing block, similar to the one shown at *B*, is sometimes used to keep the clamps in place. This block has an extension *g* against which the clamps abut, and also an adjustable screw *h* for varying the height. A tongue-piece which fits a slot in the table holds the block in position. By the use of a clamp bent as indicated by the dotted lines *k*, any backward movement when tightening can also be avoided, as the end of this clamp rests against the side of the T-slot. The clamps should be placed opposite the liner blocks, as otherwise the shaft might be sprung out of true.

This method of holding a cylindrical piece, while suitable under ordinary conditions, would not be economical if a large quantity of shafts were to be keyseated, as a special fixture in which two or more could be held and machined at one time would make a greater production possible.

Centering the Keyway Cutter. — The cutter should be set central with a vertical center-line passing through the center of the shaft. One method of doing this is as follows: Set the outer side of the cutter in the same vertical plane as the side of the shaft by holding a scale *f* (sketch *B*) against the outer faces of the milling teeth, and adjust the work until the scale just touches it, as shown; then move the work out a distance equal to the diameter of the shaft minus one-half the width of the cutter. If the cutter runs true and care is taken to hold the scale against the outer ends of the teeth, fairly accurate results can be obtained by this method.

When the size of the shaft will permit, the cutter can be used directly for centering, by raising the work and adjusting it until the side of the cutter barely comes into contact with it, as indicated by the dotted lines at *e* in the upper view. The work is then lowered and moved out a distance equal to the diameter of the shaft plus one-half the cutter width.

Another method of centering the cutter with a cylindrical piece is as follows: Feed the shaft back and forth beneath the revolving cutter until a spot, having a width slightly greater than the width of the keyway, is milled; then with the cutter still revolving, set it central with the milled spot. The object of having the cutter in motion while adjusting it is to obtain an accurate or average setting, even though the sides of the cutter run somewhat out of true.

Still another method of centering a cutter, especially of the formed type, was described in connection with Fig. 3, Chapter V.

Gaging Depth of Keyseat. — When a keyseat is to be milled to a certain depth *d* (see view *C*), the cutter can be set as follows: Start the machine and adjust the cutter until it grazes the top of the shaft; then set the dial of the elevating screw to zero. Next sink the cutter to the total depth of the keyway, which equals the depth d at the side, plus the height a of the arc. This height a can be determined by the following formula:

$$a = r - \sqrt{r^2 - (\tfrac{1}{2}w)^2}$$

in which r = radius of shaft, and w = width of keyway.

Example. — If the shaft radius is $1\frac{1}{4}$ inch, the width of the key-seat $\frac{1}{2}$ inch, and the depth at the side $\frac{3}{8}$ inch, what is the total depth as measured from the top of the arc?

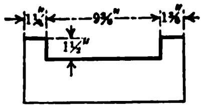
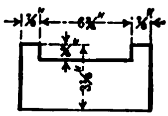
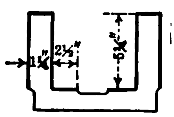
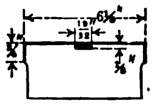
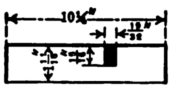
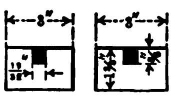
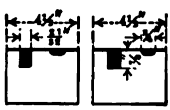
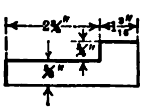
$$a = 1.25 - \sqrt{1.25^2 - (\tfrac{1}{2} \times \tfrac{1}{2})^2} =$$
$$1.25 - \sqrt{1.5} = 0.025 \text{ inch.}$$

The total depth then equals $\frac{3}{8}$ or $0.375 + 0.025 = 0.4$ inch. Therefore the cutter, after being set to graze the top of the shaft, would be sunk to a depth of 0.4 inch, the depth being measured by the graduated dial of the elevating screw.

Speeds for Milling. — The proper speed for the cutter, and the feeding movement of the work for each revolution of the cutter, are governed by many different factors. The speed of the cutter depends largely upon the kind of material being milled. Obviously, tool steel cannot be cut as fast as soft machine steel or cast iron, whereas brass can be cut at a 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.

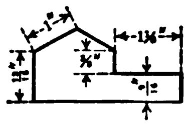
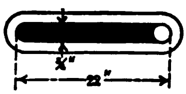
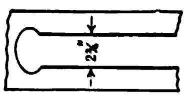
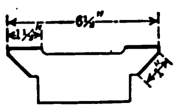
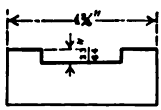
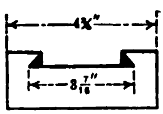
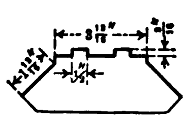
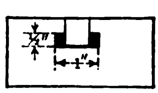
A general idea of the speeds that are feasible when using carbon-steel cutters may be obtained from the following figures which represent the velocity (in feet per minute) at the circumference of the cutter. For taking roughing cuts in cast iron, 40 feet per minute; in machine steel, 60 feet per minute; in tool steel, 25 feet per minute; and in brass, 75 feet per minute. Finishing cuts are 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 success-

Speeds and Feeds for Milling. — 1*

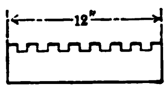
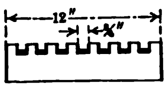
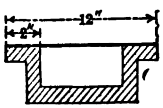
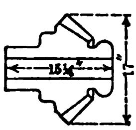
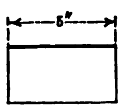
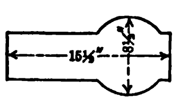
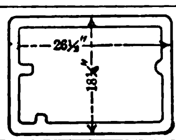
Milled Surface Indicated by Heavy Line	Material Milled, Width and Depth of Cut, Feed of Table and Speed of Cutters
	Material, cast iron. Total width of cut, 15 inches. Maximum depth $\frac{5}{16}$ inch. Feed, $4\frac{3}{4}$ inches per minute. Largest cutter of gang, 6 inches diameter, $9\frac{5}{8}$-inch face. Speed, 32 revolutions per minute.
	Material, cast iron. Total width of milled surface, $16\frac{5}{8}$ inches. Depth of cut, $\frac{5}{16}$ inch. Feed, 6.3 inches per minute. Diameter of side mills for finishing sides of casting, $10\frac{1}{2}$ inches. Speed of cutter, 21 revolutions per minute.
	Material, cast iron. Total width of milled surface, 23 inches. Depth of cut, $\frac{1}{8}$ inch. Feed of table, $4\frac{3}{4}$ inches per minute. Diameter of side mills, $13\frac{1}{2}$ inches. Diameter of intermediate cutters for top surfaces, 3 inches. Speed, 14 revolutions per minute.
	Material, cast iron. Total width of cut, $7\frac{5}{8}$ inches. Size of milled groove, $\frac{19}{32}$ inch wide, $\frac{1}{8}$ inch deep. Feed of table, 9.9 inches per minute. Depth of cut, $\frac{1}{8}$ inch.
	Material, cast iron. Total width of cut, $13\frac{5}{8}$ inches. Size of slot milled from solid, $\frac{15}{16}$ by $\frac{19}{32}$ inch. Depth of cut on top and sides, $\frac{5}{16}$ inch. Feed, 4 inches per minute. Cutter diameters, 8, $3\frac{1}{2}$ and $5\frac{3}{4}$ inches. Speed, 36 revolutions per minute.
	Material, close-grained cast iron. Operation, roughing two castings simultaneously, removing $\frac{3}{16}$-inch stock and milling from solid two $\frac{5}{8}$-inch slots. Feed, 4 inches per minute. Speed of gang-cutter, 36 revolutions per minute.
	Material, 50-point carbon steel bars. Operation, milling two bars simultaneously. Travel of table, $1\frac{1}{16}$ inch per minute. Depth of cut, $\frac{1}{4}$ inch. High-speed steel cutters, 4 inches and $5\frac{3}{4}$ inches in diameter. Peripheral speed of large cutter, 30 feet per minute.
	Material, cast iron. Total width of finished surface, $4\frac{3}{4}$ inches. Depth of cut, $\frac{1}{8}$ inch. Feed per minute, $1\frac{7}{8}$ inch. Cutter diameters, $4\frac{1}{2}$ and 3 inches, respectively. Limit of accuracy, 0.001 inch.

* From MACHINERY'S Handbook — Data represents actual practice.

Speeds and Feeds for Milling — 2

Milled Surface Indicated by Heavy Line	Material Milled, Width and Depth of Cut, Feed of Table and Speed of Cutters
	Material, cast iron. Total width of surface finished, 5 inches. Depth of cut, 3/32 inch. Feed of table, 2.9 inches per minute. Largest cutters in gang, 5½ inches; smallest, 2 inches. Speed, 53 revolutions per minute.
	Operation, milling slots in cast-iron bars 1 inch thick, with a single cut, using a ¾-inch, 3-fluted, high-speed steel end mill. Feed of table, 3⅝ inches per minute. Speed of cutter, 365 revolutions per minute, giving a surface speed of 72 feet.
	Material, close-grained cast iron. Operation, milling both sides of a slot. Diameter of cutter, 2¾ inches. Width of cut, 2¾ inches. Depth of cut at top and bottom, 1/16 inch. Feed, 3 inches per minute.
	Material, close-grained cast iron. Operation, roughing dovetail bearings. Depth of cut, 3/16 inch. Feed, 7¾ inches per minute. Width of surface milled by side mill, 1⅛ inch; by angular cutter, 1¼ inch. Speed, 36 revolutions per minute. Machine, vertical type.
	Material, steel castings. First operation, roughing out channel and top surface. Depth of cut, ⅛ inch; ¼ inch on the sides of channel. Feed, 7¾ inches per minute. Cutters, high-speed steel. (Succeeding operation follows.)
	Second operation, in vertical machine. Cutters, 6-inch side mill, 3-inch angular mill, mounted as a gang, but used independently. First cut, truing top surface. Feed. 2¼ inches per minute. Dovetailed sides finished in two cuts. Feed, 1 1/16 inch per minute, feed being slow to insure accuracy.
	Material, gray iron. Total width of cut, 9.4 inches. Average depth, 3/16 inch. Feed, 6⅛ inches per minute. Diameter of angular cutters for sloping sides, 7½ inches. Diameter of cutters for top surfaces, 3½ and 3⅛ inches. Speed, 33 revolutions per minute.
	Operation, undercutting T-slots in cast iron. Cutter, high-speed steel, 1 inch in diameter, ½ inch wide. Speed, 286 revolutions per minute. Feed of table, 15¾ inches per minute.

Speeds and Feeds for Milling — 3

Milled Surface Indicated by Heavy Line	Material Milled, Width and Depth of Cut, Feed of Table and Speed of Cutters
	Material, cast-iron plates. First operation, milling full width of plate. Depth of cut, ⅛ inch. Feed of table, 4.9 inches per minute. Cutter, 4 inches in diameter. Speed, 66 revolutions per minute. (Succeeding operation follows.)
	Second operation, finishing slots and sides. Width of slots, ¾ inch. Feed of table, 1¾ inch per minute. Cutter diameters, 4 and 8 inches, respectively. Speed, 66 revolutions per minute. Limit of accuracy, 0.001 inch.
	Material, steel. Operation, finishing simultaneously the four sides of two connecting-rod straps. Width of each milled surface, 2¼ inches. Depth of cut, ⅛ to 3/16 inch. Feed of table, 1 inch per minute. Cutters, high-speed steel, 8½ inches in diameter. Cutting speed, 50 feet per minute.
	Material, gray iron. Diameter of face mill, 12⅝ inches. Surface is rough milled by one passage of cutter, then feed is reversed and a finishing cut 0.010 inch deep is taken. Rate of feed, 20 inches per minute. Machine, vertical type.
	Material, steel castings. Operation, facing flat surface with a 9½-inch face mill. Depth of roughing cut, 3/16 inch. Feed, 3 11/16 inches per minute. Speed, 21 revolutions per minute. Depth of finishing cut, 0.010 inch. Machine, vertical type.
	Material, machine steel bars. Operation, milling flat surface 5 inches wide, with 12-inch inserted-tooth cutter. Depth of cut, ⅛ inch. Feed, 16 inches per minute. Speed, 17 revolutions per minute. Machine, vertical type.
	Material, cast iron. Maximum width of cut, 8¼ inches. First operation, roughing cut 3/16 inch deep; feed, 7¾ inches per minute. Second operation, finishing cut; feed, 20 inches per minute. Machine, vertical type.
	Material, cast iron. Roughing cut, 3/16 inch deep; feed, 20 inches per minute. Cutter, 10-inch face mill. Rectangular surface is covered by using longitudinal and cross-feeds. Machine, vertical type.

fully, 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.

Feeds for Milling. — The distance that the work feeds per revolution of the cutter must 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 width and depth of the cut, the kind of material being milled, the quality of the finish required, the rigidity of the work and the power of the machine. 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. The tables "Speeds and Feeds for Milling" also contain considerable data taken from actual practice.

Lubricants for Milling. — A lubricant that has been extensively used for milling is made in the following proportions: 1 pound of sal soda (carbonate of soda), 1 quart of lard oil, 1 quart of soft soap, and enough water to make 10 or 12 gallons. This mixture is boiled for one-half hour, preferably by passing a steam coil through it. The soap and soda in this solution improve the lubricating quality and also prevent the surfaces from rusting. Lard oil and animal or fish oils are also used as a lubricant, and some manufacturers mix mineral oil with lard or fish oil. The soda solution or some of the commercial lubricants on the market are much cheaper than oil and more generally used. 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.

CHAPTER IV

APPLICATION OF UNIVERSAL MILLING MACHINE AND SPIRAL HEAD

THE milling machine illustrated in Fig. 1 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 III, the table of a plain machine is carried by a saddle 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* 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

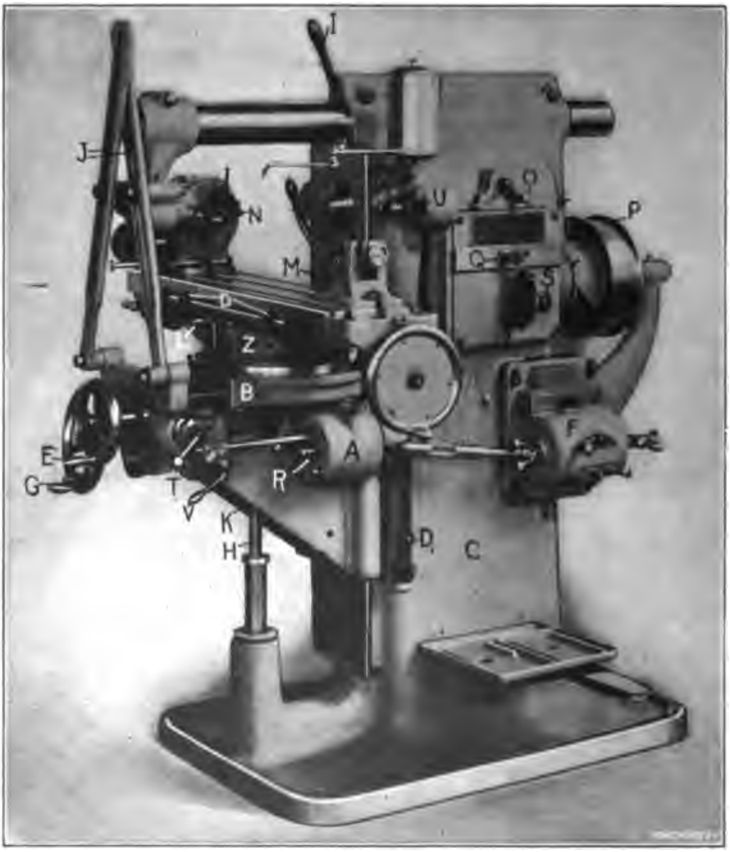


Fig. 1. Brown & Sharpe Universal Milling Machine

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, transverse 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 bronze-bushed bearing and also an adjustable 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 footstock *M*, when milling work that must be supported between the centers. The spiral head is also used independently, that is, without the footstock, 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.

Construction of the Spiral Head. — 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. 2. 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

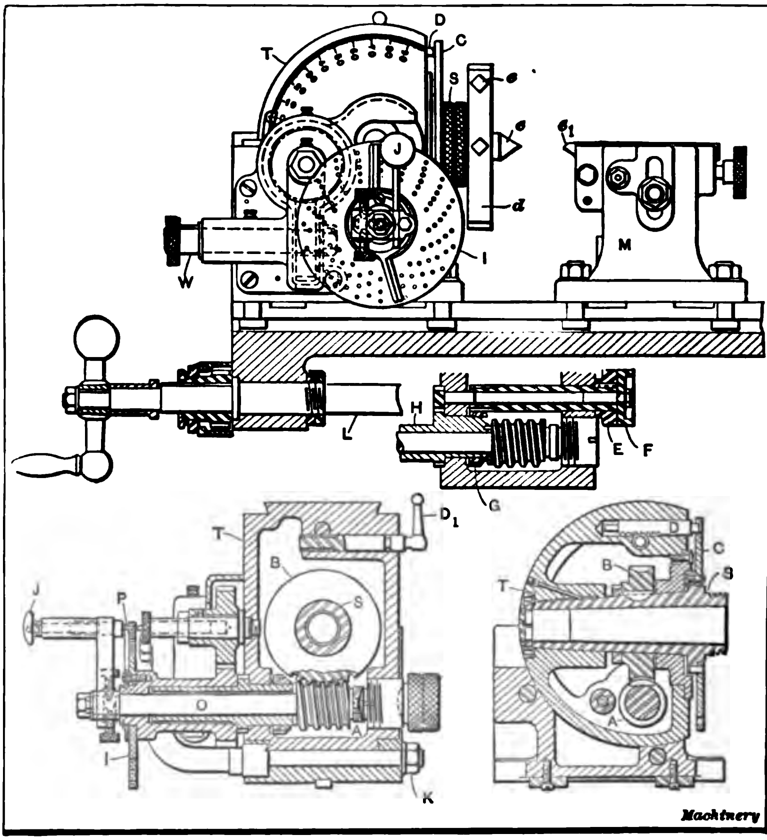


Fig. 2. Spiral Head Used for Spiral Milling and Indexing

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 used when milling flutes in reamers, taps, etc., but, as only a limited number of divisions can be obtained, it is necessary to use crank *J* and index plate *I* for most indexing operations.

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 the work feeds past the cutter. These change gears (which are not shown in this illustration) 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*. For the method of determining what size gears to use for milling a helix of given lead see "Helical Milling."

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 $\frac{1}{2}$ a degree. The spindle of this particular head can be set to any angle between 10 degrees below the horizontal 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 footstock 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 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 more important to have a clear understanding of its application to various kinds of work.

Use of the Spiral Head. — 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

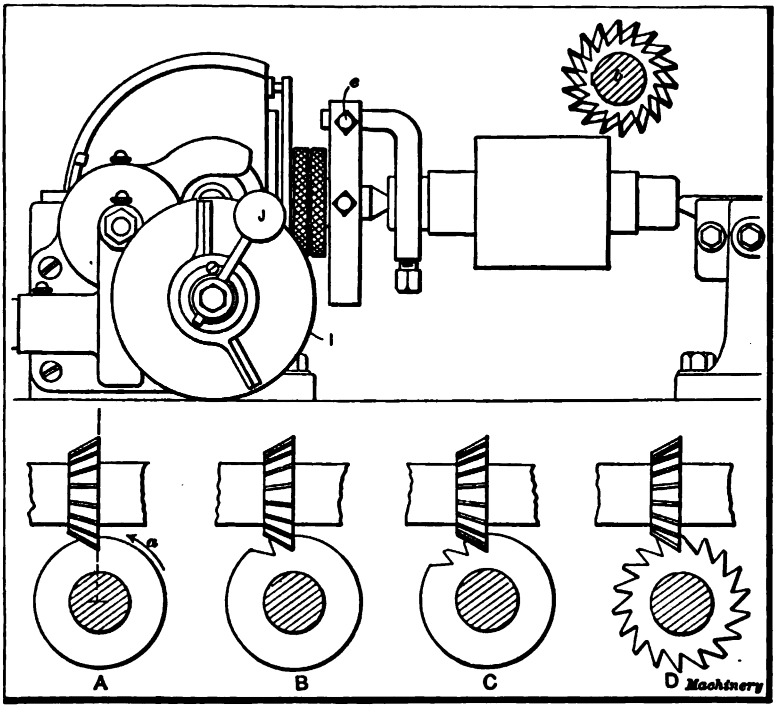


Fig. 3. Views Illustrating Use of Spiral Head for Indexing

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. 3. 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 a corresponding amount to the axis. A cutter of this type which is largely used for milling straight teeth is shown at *E* in Fig. 10, Chapter III. 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. 3, 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 $\frac{1}{18}$ 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 $\frac{1}{18}$ 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 whatever part of a revolution is required, by turning crank J, Fig. 2. 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 $40 \div 2$, or 20, and for $\frac{1}{12}$ of a revolution, the turns would equal $40 \div 12$, or $3\frac{1}{3}$, 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 40, with rare exceptions 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. 3, we find that the crank J must be turned $2\frac{2}{9}$ times to index the cutter from one tooth to the next, because there are 18 teeth, or divisions, and $40 \div 18 = 2\frac{2}{9}$. The next question that naturally arises is, how is the crank to be rotated exactly $\frac{2}{9}$ 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. 4. The number of holes in the different circles of this particular plate are 33, 31, 29, 27, 23 and 21.

In order to turn crank J $\frac{2}{9}$ 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 $\frac{2}{9}$ of a turn equals $27 \times \frac{2}{9}$, or 6 holes. After the latch-pin is adjusted to the 27-hole circle, the indexing of the cutter $\frac{1}{18}$ of a revolution is accomplished by pulling out the latch-pin and turning the crank 2 complete turns, and then $\frac{2}{9}$ of a turn, or 6 holes in a 27-hole circle. After each tooth groove is milled in the cutter, this indexing opera-

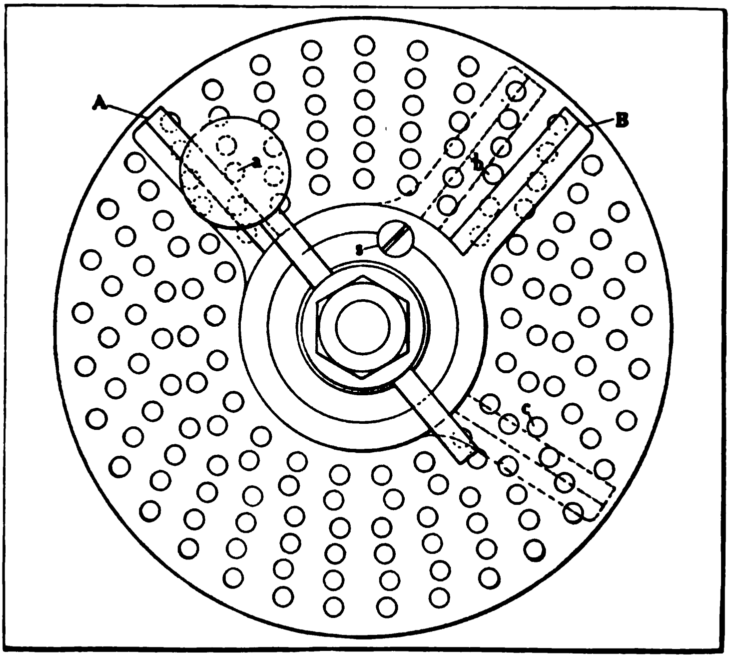


Fig. 4. Diagram showing how Sector is Used when Indexing

tion is repeated, the latch-pin being moved each time $2\frac{2}{9}$ 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. 4), 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 $\frac{2}{9}$ 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 $\frac{2}{9}$ 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 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."

Indexing Tables. — In actual practice the number of turns of the index crank for obtaining different divisions is determined by referring to indexing 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 $1\frac{26}{39}$ of a turn, instead of $1\frac{2}{3}$, 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 $\frac{2}{3}$ of a revolution, after making one complete turn.

Compound 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 previously explained, 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.

The Principle of Compound Indexing. — 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

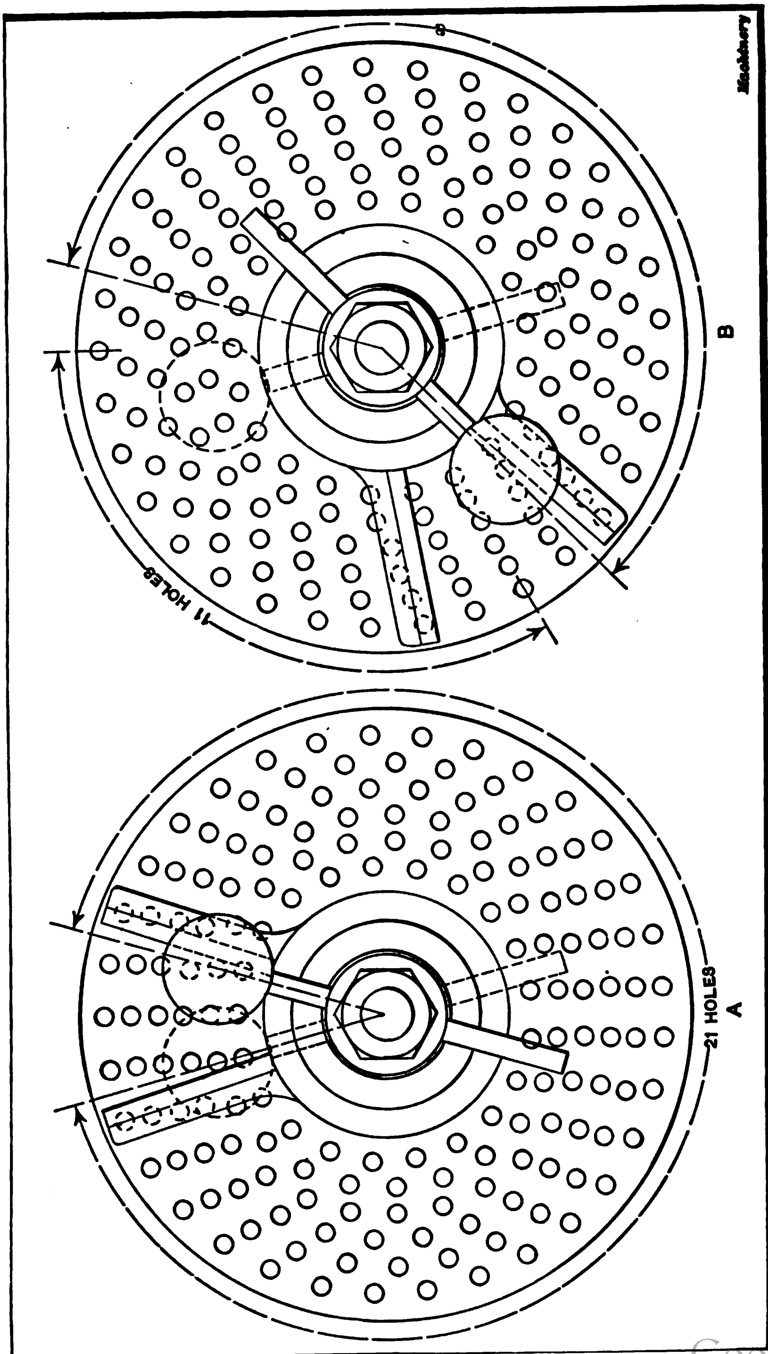


Fig. 5. Diagrams Illustrating the Principle of Compound Indexing

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.

Example of Compound Indexing. — 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 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. 5 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.

Indexing by Using Simple and Compound Systems. — 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.

Rule for Compound Indexing. — 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:

$$\begin{array}{rl} 69 = & \cancel{3} \times \cancel{23} \\ 33 - 23 = 10 = & \underline{\cancel{2} \times \cancel{5} \qquad\qquad} \\ 40 = & \cancel{2} \times 2 \times 2 \times \cancel{5} \\ 33 = & \cancel{3} \times 11 \\ 23 = & \cancel{23} \times 1 \end{array}$$

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:

$$\begin{array}{r} +\frac{44}{23}-\frac{44}{33} \\ \underline{-\frac{23}{23}+\frac{33}{33}} \\ +\frac{21}{23}-\frac{11}{33} \end{array}$$

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.

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. 6 and 7. 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.

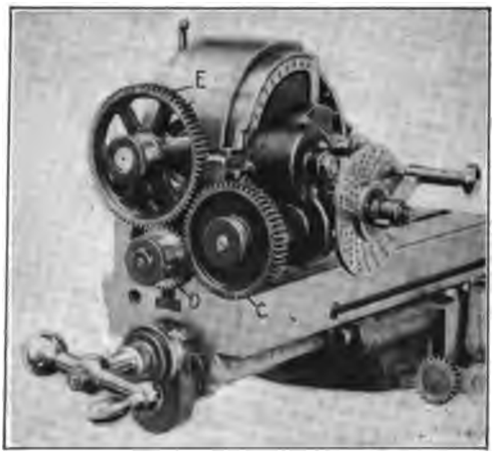


Fig. 6. Index Head Geared for Differential Indexing

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. 8) 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 rotate the plate, and crank in opposite directions, and then two idler gears are interposed between the spindle and worm-shaft gears.

Principle of the Differential Indexing System. — Fig. 6 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 movement of the plate.

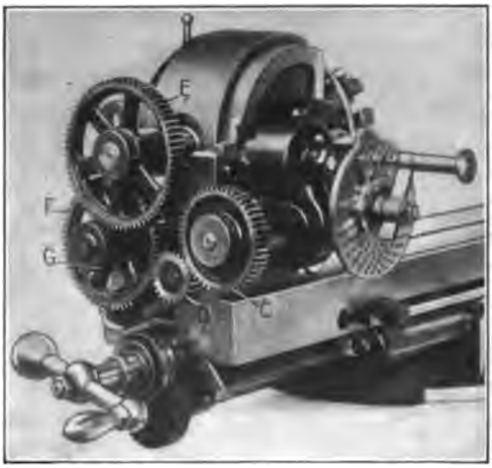


Fig. 7. Index Head Equipped with Compound Gearing for Differential Indexing

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. 7 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.

Change-gears for Differential Indexing. — The following example is given to illustrate the method of determining the change-gears to use for differential indexing: Suppose 59 divisions were required, what circle of holes and gears should be

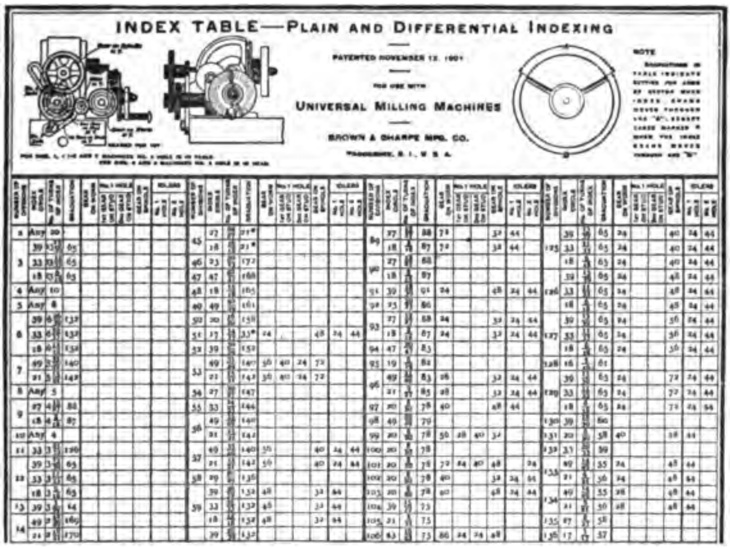


Fig. 8. Part of Index Table for Plain and Differential Indexing

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 $39\frac{1}{3}$ 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 of indexing cannot be used for helical or spiral milling, because the spiral head is then geared to the lead-screw of the machine. (See "Helical Milling.")

High-number, Reversible Index Plates. — The dividing heads furnished with Cincinnati milling machines are equipped with

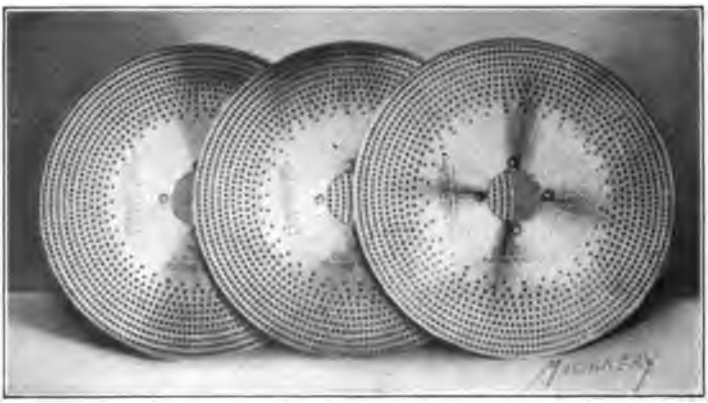


Fig. 9. Index Plates for Obtaining a Large Number of Divisions by Simple Indexing

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. 9) 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.

Angular Indexing. — 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 $\frac{1}{9}$ of a turn. If we want to index 35 degrees, the number of turns the crank must make equals $35 \div 9 = 3\frac{8}{9}$, 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 $11\frac{1}{2}$ 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 $\frac{1}{34}$ 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.

Rule for Angular Indexing. — 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

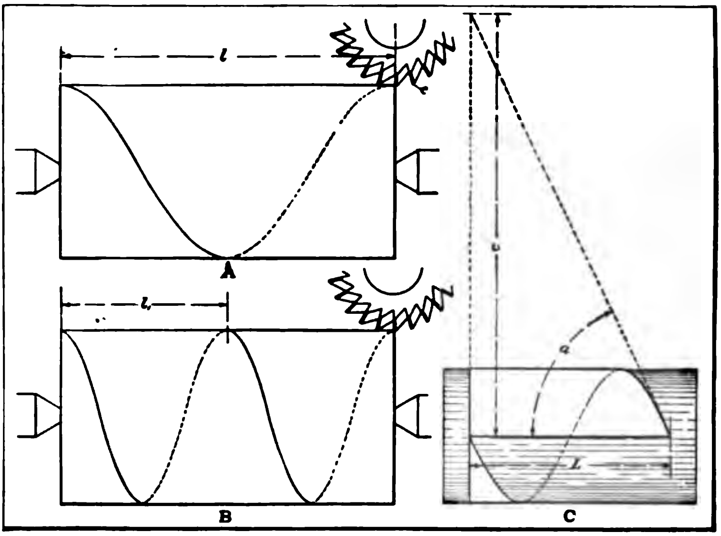


Fig. 10. Diagrams Illustrating the Principle of Helical or Spiral Milling

possible to obtain the movement by the ordinary method of simple indexing.

Helical or Spiral Milling. — The spiral head is not only used for indexing or dividing, but also in connection with the milling of helical or "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 footstock, 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 a spiral of given lead are ordinarily determined be referring to a table which accompanies the machine, although the gear sizes can easily be calculated, as will be explained later.

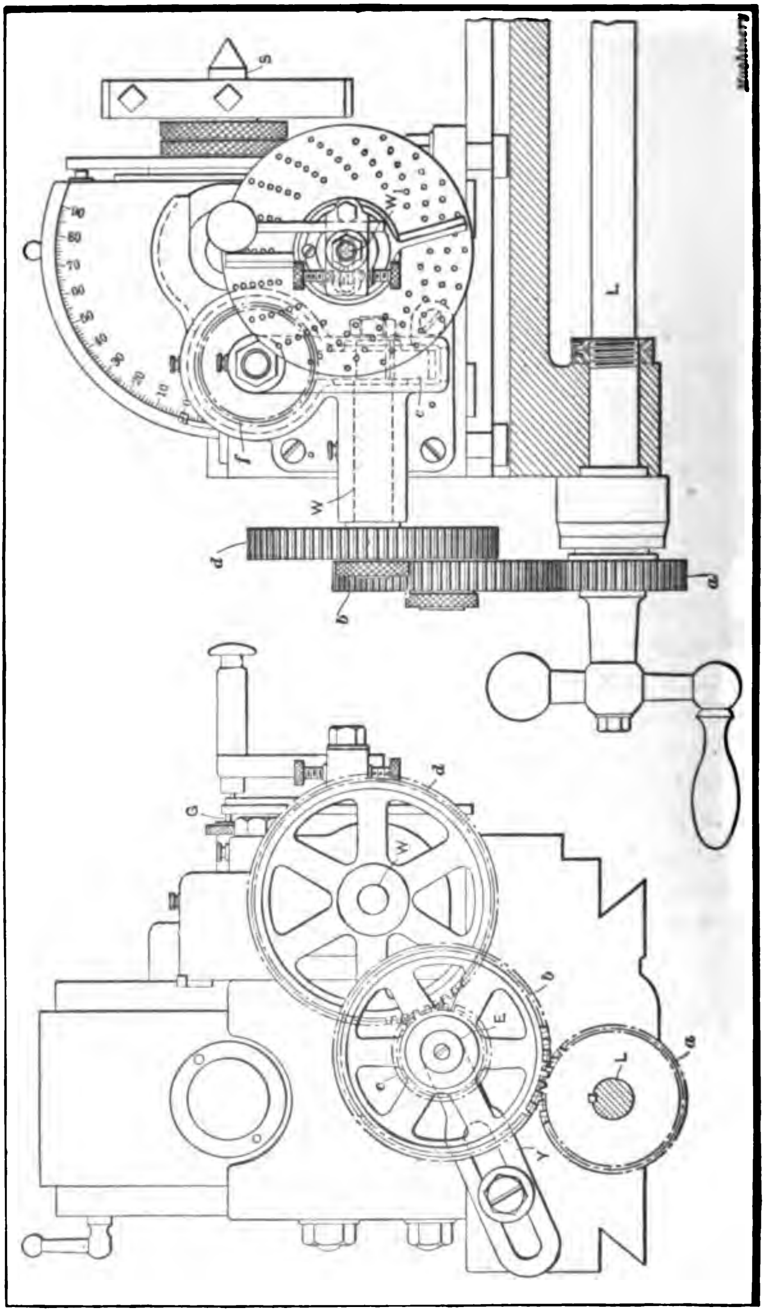


Fig. 11. The Indexing or Spiral Head of a Universal Milling Machine Geared for Spiral Milling

Example of Spiral Milling. — As an example of spiral milling, suppose we have a cylindrical cutter blank $3\frac{1}{4}$ 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

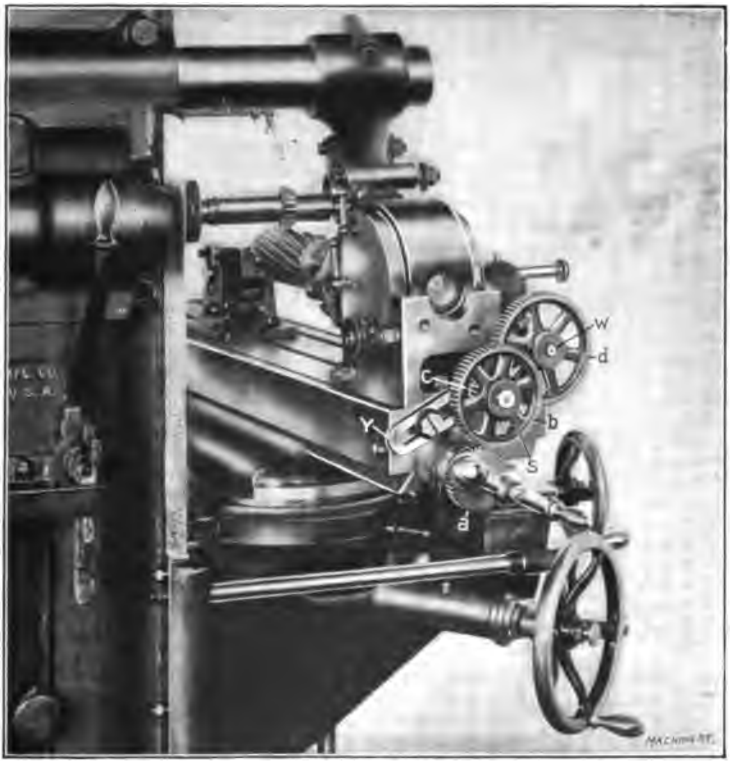


Fig. 12. Universal Machine arranged for Spiral Milling

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 are needed, provided the lead of the spiral is known. A small section of one of these tables is reproduced in 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

	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	54	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. 13. Part of Table showing Gear Combinations to use for obtaining Spirals of Different Lead

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 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 i, Fig. 12, Chapter V), 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.

Cutter for Milling Spiral Flutes. — If we assume that the grooves or flutes of the cutter shown in Fig. 12 are to be milled to an angle of 60 degrees, evidently the cutter must have teeth

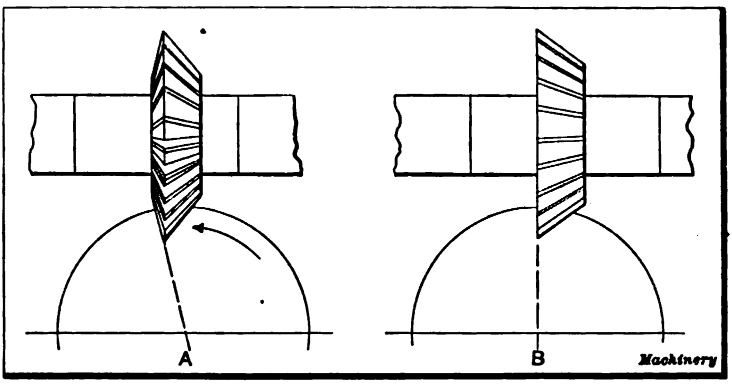


Fig. 14. Double- and Single-angle Cutters

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 for Milling Spiral Flutes. — A method of setting a double-angle cutter, for milling the teeth in spiral mills, which is simple and does not require any calculation, 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

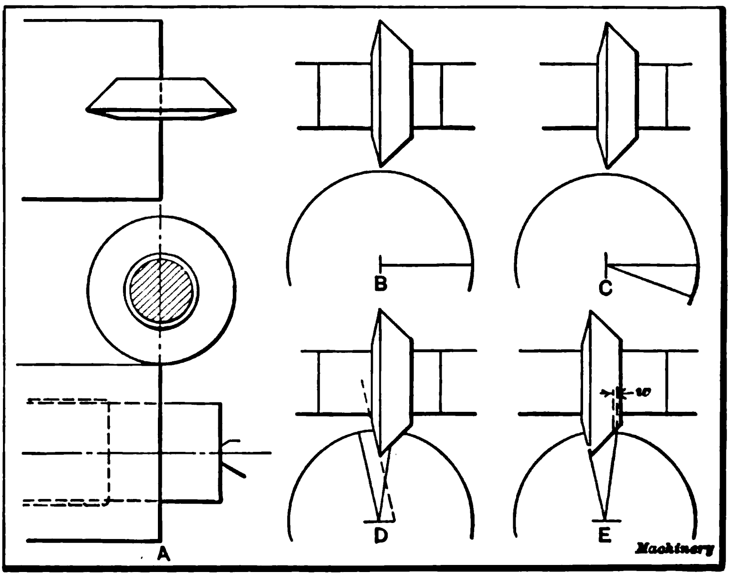


Fig. 15. Setting a Double-angle Cutter for Milling Teeth of a Spiral Milling Cutter

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 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. — 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 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 of the cutter illustrated in Fig. 12 is

$3\frac{1}{4}$ 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.

Milling Spiral Flutes. — 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 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 order to find what size gears to use, this ratio is resolved into two factors as follows:

$$\frac{12}{10} = \frac{3}{2} \times \frac{4}{5}$$

Each factor is then multiplied by some trial 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 $\frac{32}{40}$, represents 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 Helix or Spiral Angle. — 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 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 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.

Use of Chuck on the Spiral Head. — It is often necessary to use a spiral-head in connection with milling of parts which can-

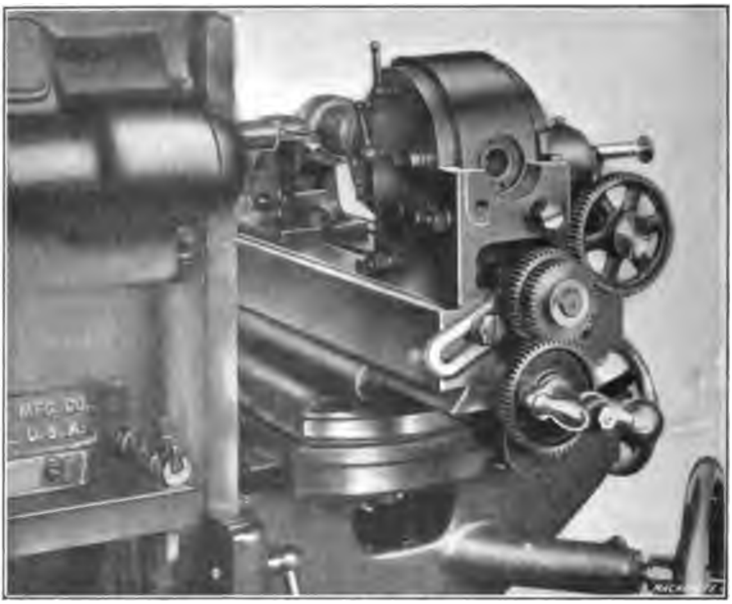


Fig. 16. Milling a Spiral Groove with an End Mill

not 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. 17. 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. These bolts should afterwards be tightened.

The bolt is held in a three-jaw 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ of a revolution, after which the latch-pin is again moved

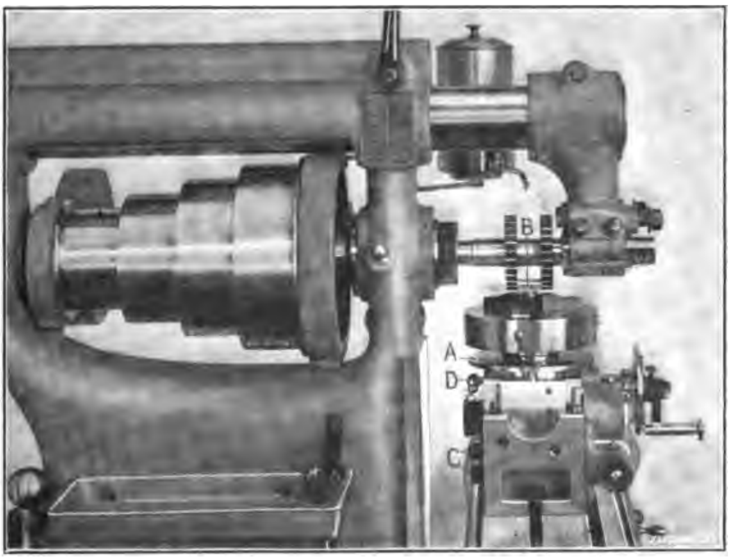


Fig. 17. Straddle Milling a Square Bolt-head

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 footstock 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.

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 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. 18. 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 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. The spindle of many vertical attachments can only be adjusted in a plane parallel with the front face of the column or at right angles to the axis of the spindle. A vertical attachment of this type,

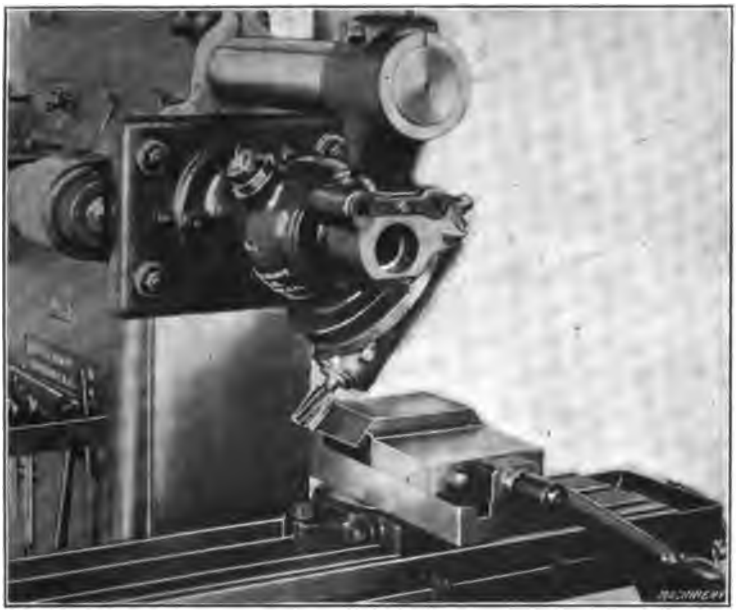


Fig. 18. Vertical Attachment Applied to a Horizontal Milling Machine

which is designed for comparatively heavy vertical milling operations, is illustrated in Fig. 21.

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. 19. 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. 19 shows the attachment slotting a rectangular opening in a screw machine tool which is held in the vise. As this opening

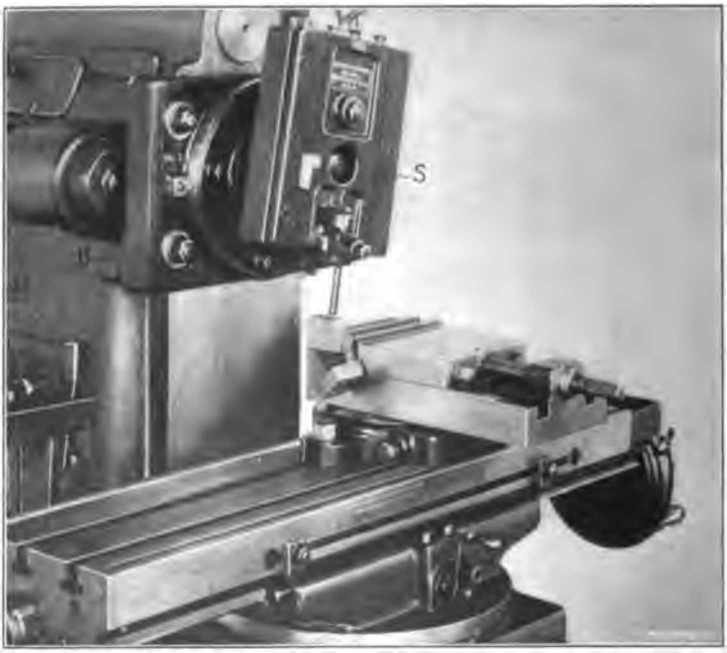


Fig. 19. Slotting Attachment Applied to a Milling Machine

must be at an angle, the tool slide is inclined from the vertical, as shown. A previously drilled hole forms a starting place for the slotting tool.

Fig. 20 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 $\frac{1}{4}$ 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. 21. It is bolted to the machine and has a round table *A* which can be rotated for milling circular surfaces or slots. This attachment is generally used in connection with

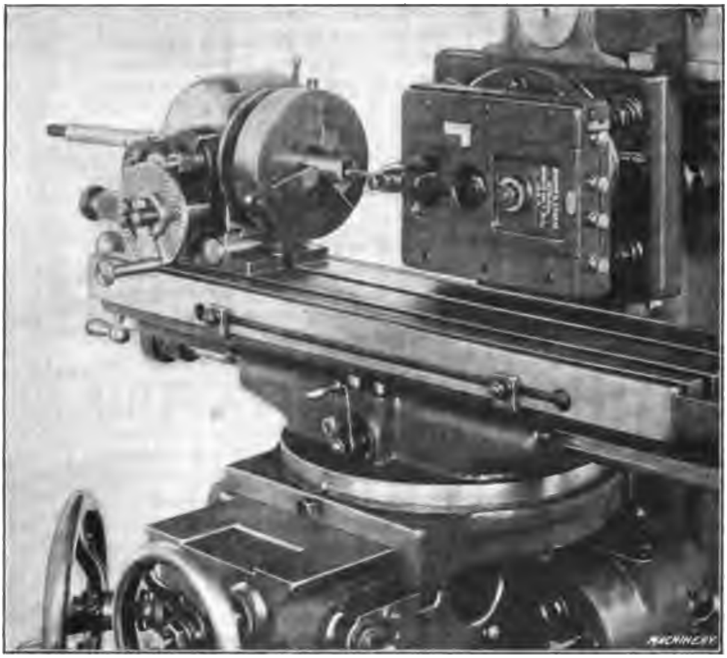


Fig. 20. Slotting Attachment finishing Square Hole in Long Rod held in Spiral Head

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* which transmits motion to the table through worm gearing. The base of the table is graduated in degrees and a dial just back of handwheel *H* is graduated to read to $\frac{1}{12}$ degree or 5 minutes. These angular graduations are often needed for dividing a circular surface or when milling to angles. Some circular attachments have a power feed for the table, which can be disengaged automatically at any point by means of adjustable stops which are bolted to the periphery of the table.

Spiral Milling with Universal Attachment. — When milling a spiral, it is not always possible to align the cutter with the helix

Fig. 21. Combined use of Vertical and Circular Milling Attachments

or "spiral" angle by swinging the table around, as illustrated in Fig. 12. With most universal milling machines it is inconvenient, if not impossible, to swivel the table to a greater angle than 45 degrees; hence, for greater angles, it is the general practice to leave the table in its normal position at right angles to the spindle of the machine, and use a special swiveling attachment for holding the cutter at the proper angle. Fig. 22 illustrates this method of spiral milling.

The operation is that of milling sextuple threads on a worm.

The pitch diameter of the worm is 3.68 inches and the lead of the thread, 6 inches. Therefore the tangent of the helix angle equals $(3.68 \times 3.1416) \div 6 = 1.92$, which is the tangent of $62\frac{1}{2}$ degrees. With this particular milling machine the table can be swiveled to an angle of about 50 degrees. Therefore, it is necessary to use a universal attachment.

The table is set at zero and the attachment is swung around $27\frac{1}{2}$ degrees from its position at right angles to the machine spindle $(90 - 62\frac{1}{2} = 27\frac{1}{2})$, thus setting the cutter in line with

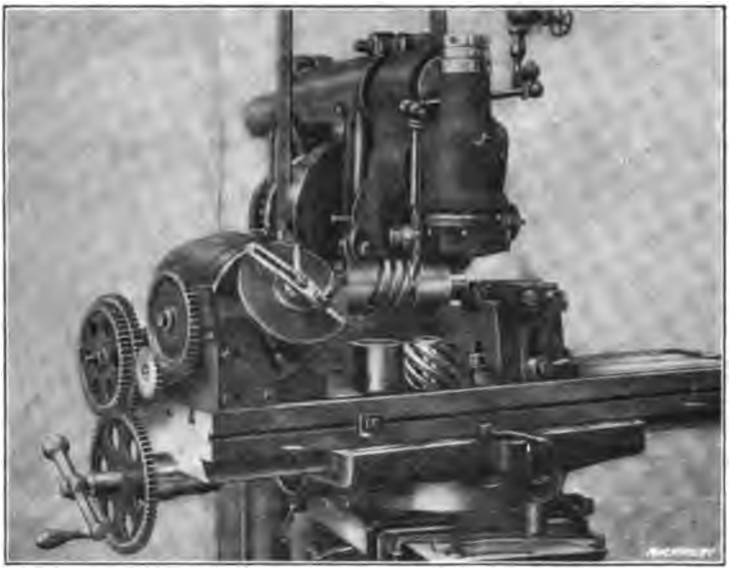


Fig. 22. Milling Sextuple Threaded Worms in Kempsmith Machine by use of Universal Attachment

the helix angle. After one thread groove is milled, the cutter is indexed one-sixth revolution for milling the next groove, and so on until the six thread grooves are completed. Three worm blanks are held on the arbor at one time and roughing and finishing cuts are taken. A plain blank and a finished worm may be seen on the machine table. The cutter is 4 inches in diameter and runs 64 revolutions per minute for this particular operation. The included angle between the sides of the worm thread is 29 degrees and the depth of the thread groove equals $0.6866 \times$ pitch.

The spindle of the attachment illustrated can be set at any angle throughout the entire circle. It can be used for milling spiral gears or other work, the helix angle of which is beyond the range of the swiveling table. When cutting threads in the milling machine the only limitation is similar to that imposed when cutting threads of large lead in the lathe, although in a reverse order. When milling worm threads or spiral gear teeth of small lead as compared with the diameter, the rotary movement of the blank may be so great as compared with the slow-moving feed-screw, that there will be difficulty in transmitting

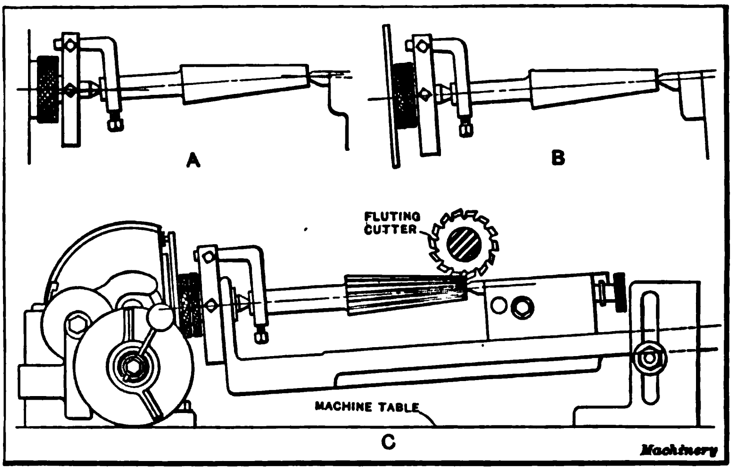


Fig. 23. (*A*) Incorrect Method of Holding Taper Blank for Fluting. (*B*) Correct Way. (*C*) Taper Milling Attachment

sufficient power to feed the work against the cutter, through the gearing that is necessary to give the required speed of rotation.

Milling Taper Flutes. — When milling flutes in taper reamers, milling cutters, etc., which are held between centers, the axis of the dividing-head spindle and the axis of the work should coincide or be in line with each other. Sketch *A*, Fig. 23, shows an incorrect method of holding a taper reamer mounted between centers for fluting. When a "plain" indexing head is used that does not have angular adjustment like a "universal" head, taper work is sometimes held in this way; that is, the tailstock is blocked up on parallels to hold the reamer or cutter blank at the required angle. The axis of the work, however, is at an angle with the dividing-head spindle and, consequently, the indexing is inaccurate.

The cause of this inaccuracy is illustrated in Fig. 24. If the work is indexed exactly one-half revolution from the position shown, point *A* will move to position A_1, but owing to the angularity of the driving dog and work, the dividing head will move through an angle *x* or *y* (depending upon the direction of the indexing movement) which is either greater or less than 180 degrees or one-half revolution. The result is that all the flutes will not be milled to the same width, because a given angular

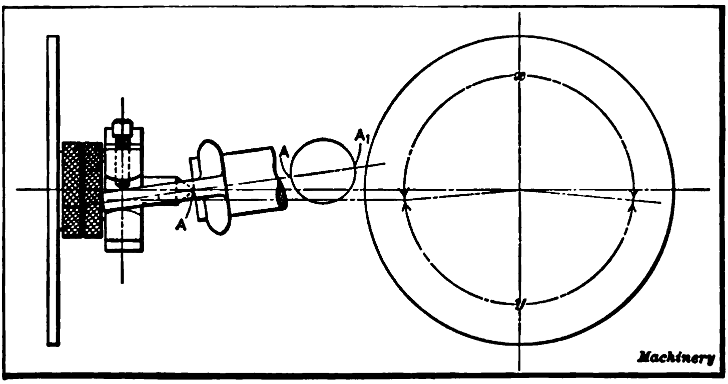


Fig. 24. Diagram Illustrating Error in Indexing when Axes of Work and Dividing Head Spindle do not Coincide

movement of the dividing-head spindle rotates the work farther when the driving dog is passing through the lower half *y* of the circle than when passing through the upper half *x*. Another objection to setting taper parts, as shown by sketch *A* in Fig. 23, is that the dog moves in and out through the slot of the driver plate; hence, the dog must be clamped rather loosely to permit this movement and prevent any binding action.

Sketch *B* illustrates the proper method of holding a taper blank for fluting. The dividing-head spindle is set at whatever angle is required to hold the blank in the proper position, and the center of the tailstock (which is adjustable on modern designs) is also aligned with the axis of the work. As the axis of the dividing-head spindle and blank coincide, they rotate the same amount for each indexing and equal flutes are milled; moreover, there is no movement of the dog relative to the driver plate.

A simple method of aligning the reamer or cutter blank with the dividing-head spindle is as follows: Place the dog in a vertical position and adjust it until the end of the "tail" or driving arm just touches the driver plate at the top; then index the driver plate one-half revolution and again make a test. If there is space between the dog and driver plate, the tailstock center is too high; inversely, if the dog bears heavily at the bottom, the tailstock center is too low and should be adjusted accordingly to secure an even contact at both top and bottom.

Taper Milling Attachment. — Sketch *C*, Fig. 23, shows a special attachment for taper milling. With this attachment, alignment between the dividing-head spindle, work, and tailstock center is assured and the desired angular setting can be obtained easily. One end of the attachment is secured to the spindle of the dividing head and the opposite end is bolted to a slotted knee clamped to the table of the machine. This knee is graduated to correspond with the graduations on the spiral head. The footstock of the attachment can be adjusted along a T-slot to suit the length of the work. An attachment of this kind is especially desirable when there is considerable taper milling to be done.

In determining the angular position of the work and dividing head for milling taper reamers, etc., the number of angles involved usually makes the calculation difficult and, ordinarily, the setting can be obtained by the "cut-and-try" method in less time than is required to compute the angle. When using a single-angle cutter for fluting reamers, the angle of inclination can be determined by using the rule given in the paragraph headed "Milling Angular Cutters."

Multiple Index Centers. — Multiple index centers are often used in preference to the single-spindle type, for such operations as fluting taps and reamers, milling nuts, cutting small gears, or for similar work. A design of multiple index center that is common has three parallel spindles which are geared together and are indexed in unison. There are also three footstock centers in alignment with the dividing-head spindles. Obviously, with centers of this type three reamers or other parts can be milled at the same time by using a gang of three cutters. For taper milling, multiple index centers are made with an independent base or table which can be elevated to the required angle, the same as the taper attachment illustrated at *C* in Fig. 23.

Compensating Dog or Driver. — When a taper part is held between centers as illustrated at *A*, Fig. 23, it is well to use what is known as a compensating dog or driver, instead of the ordinary type, in order to secure more accurate indexing. The

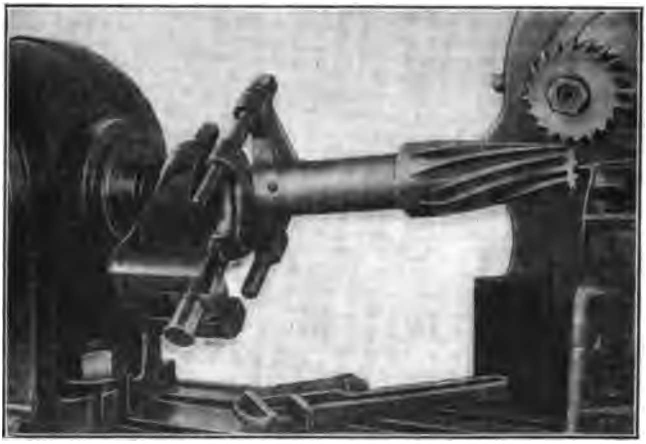


Fig. 25. Compensating Driver which Practically Eliminates Error when Indexing Taper Work

compensating dog, which is illustrated in Fig. 25, has a forked arm which is secured to the dividing-head spindle. This arm is engaged by a ball-shaped part mounted on the cylindrical end of the driver. The latter is clamped in such a position that the center of the cylindrical driving end is approximately in line with the end of the work. The ball fits closely between the curved surfaces of the forked arm and adjusts itself as the relation between the driver and arm change owing to the angularity between the axes of the work and the index spindle. The forked arm can be adjusted to take up all play between the ball and the curved surfaces of the slot which it engages. As the driving is done at a point opposite the end of the work, the irregularity of the indexing movement is very slight and negligible for ordinary milling or fluting operations. Moreover, there is no binding action between the dog and driver plate such as may occur with the ordinary dog.

Milling Clutch Teeth. — A common method of milling a straight-tooth clutch is indicated by the diagrams *A*, *B* and *C*,

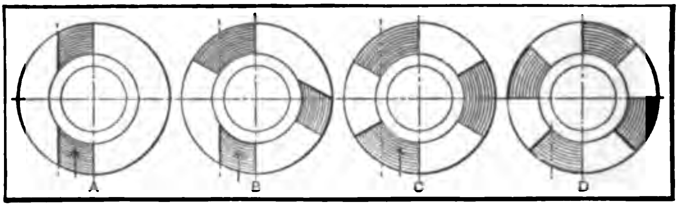


Fig. 26. Diagrammatical Views showing Simple Method of Cutting Clutch Teeth

Fig. 26, which show the first, second, and third cuts required for forming the three teeth. The work is held either in the chuck of a dividing head (the latter being set at right angles to the table), or in a plain vertical indexing attachment especially designed for this class of work. A plain milling cutter may be used (unless the corners of the teeth are rounded), the side of the cutter being set to coincide with the center-line of the clutch. When the number of teeth in the clutch is odd, the cut can be taken clear across the blank as shown, thus finishing the sides of two teeth with one passage of the cutter. When the number of teeth is even, as at *D*, it is necessary to mill all the teeth on one side and then set the cutter for finishing the opposite side; therefore, clutches of this type commonly have an odd number of teeth. The maximum width of the cutter depends upon the width of the space at the narrow ends of the teeth. If the cutter must be quite narrow in order to pass the narrow ends, some stock may be left in the tooth spaces, which must be removed by a separate cut.

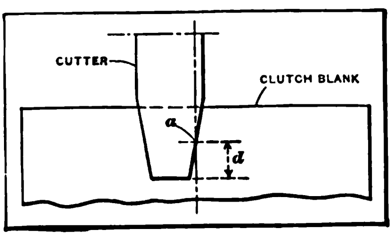


Fig. 27. Diagram showing Position of Cutter for Milling Angular Clutch Teeth

When milling clutches have angular teeth, the cutter should be set as indicated in Fig. 27; that is, so that a point *a* on the cutter at a radial distance *d* equal to one-half the depth of the clutch teeth lies in a radial plane. When it is important to eliminate all backlash, point *a* is sometimes located at a radial distance *d* equal to six-tenths of the depth of the tooth, in order to leave clearance spaces at the bottoms of the teeth so that the two clutch members will fit together tightly. In other words, the tooth spaces are made slightly narrower and the teeth wider. Clutches having angular teeth are sometimes used when a clutch

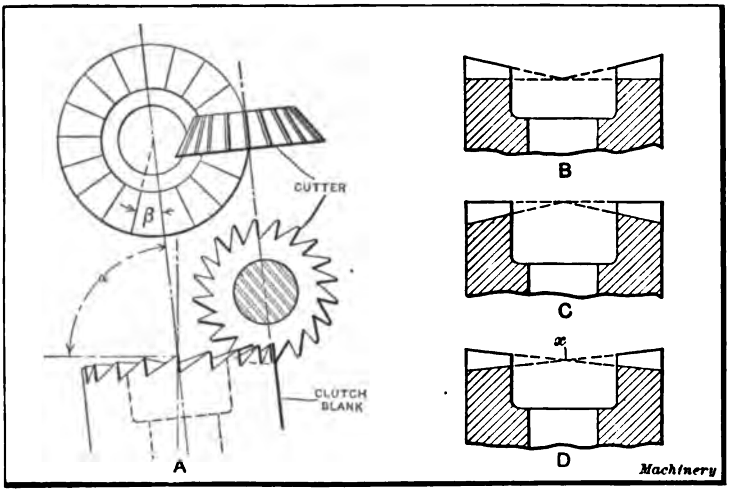


Fig. 28. Milling Saw-tooth Clutches

is required to run in either direction without backlash. The inclination of the sides of the teeth is varied to suit requirements and should not exceed 8 or 9 degrees.

Milling Saw-tooth Clutches.—When milling saw-tooth clutches the axis of the clutch blank should be inclined a certain angle α from the vertical, as shown at *A* in Fig. 28. If the teeth were milled with the blank vertical, the tops of the teeth would incline towards the center as at *B*, whereas, if the blank were set to such an angle that the tops of the teeth were square with the axis, the bottoms would incline upwards as at *C*. In either case, the two clutch members would not mesh completely, because the outer points of teeth cut as at B would bear at the bottom of the grooves in the opposite member, and the inner ends of teeth cut as at C would strike first, thus leaving spaces between the teeth around the outside of the clutch. In order to secure better contact between the clutch teeth, they should be cut as indicated at D, or so that the bottoms and tops of the teeth have the same inclination, converging at a central point x. The teeth of both members will then engage across the entire width. The angle α required for cutting a clutch as at B can be determined by the following formula in which α equals the required angle, and N, the number of teeth:

$$\cos\alpha = \frac{\sin\left(\frac{360 \text{ deg.}}{N}\right) \times \cot \text{ cutter angle}}{1 + \cos\left(\frac{360 \text{ deg.}}{N}\right)}$$

Expressing this formula as a rule, the cosine of the angle to which the milling machine index head is set equals the sine of angle β (see sketch A) multiplied by the cotangent of the cutter angle divided by the cosine of angle β plus 1.

Example. — A saw-tooth clutch is to have 8 teeth milled with a 60-degree cutter. To what angle α must the dividing head be set?

$$\cos\alpha = \frac{\sin 45^\circ \times \cot 60^\circ}{1 + \cos 45^\circ} = \frac{0.7071 \times 0.5773}{1 + 0.7071} = 0.2391$$

By referring to a table of sines and cosines we find that 0.2391 is the cosine of 76 degrees 10 minutes which is the required angle.

Cam Milling in a Universal Milling Machine. — Plate cams having a constant rise, such as are used on automatic screw machines, can be cut in a universal milling machine, with the spiral head either in a vertical position or set at an angle α, as shown in Fig. 29. When a cam is milled with the spiral head set in a vertical position, the "lead" of the cam (or its rise for one complete revolution) will be the same as the lead for which the machine is geared; but when the spiral head and cutter are inclined, any lead or rise of the cam can be obtained, provided it is less than the lead for which the machine is geared, that is, less than the forward feed of the table for one turn of the spiral-head spindle. The cam lead, then, can be varied within certain limits by simply changing the inclination α of the spiral head and cutter. In the following formulas for determining this angle of inclination, for a given rise of cam and with the machine geared for a certain lead, let

α = angle to which index head and milling attachment are set;

r = rise of cam in given part of circumference;

R = "lead" of cam, or rise, if latter were continued at given rate for one complete revolution;

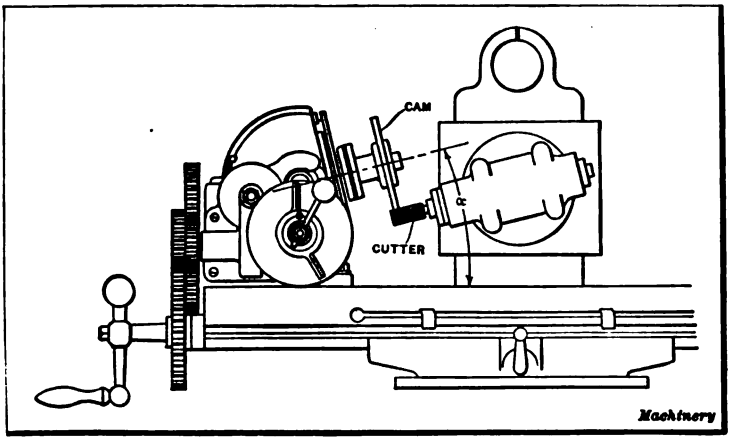


Fig. 29. Milling a Plate Cam by use of Spiral Head and Vertical Milling Attachment

L = spiral lead for which milling machine is geared;

N = part of circumference in which rise is required, expressed as a decimal in hundredths of cam circumference.

$$\sin \alpha = \frac{R}{L}, \text{ and } R = \frac{r}{N}; \text{ hence, } \sin \alpha = \frac{r}{N \times L}$$

For example, suppose a cam is to be milled having a rise of 0.125 inch in 300 degrees or in 0.83 of the circumference, and that the machine is geared for the smallest possible lead, or 0.67 inch, then

$$\sin \alpha = \frac{r}{N \times L} = \frac{0.125}{0.83 \times 0.67} = 0.2247,$$

which is approximately the sine of 13 degrees. Therefore, to secure a rise of 0.125 inch with the machine geared for 0.67 inch lead, the spiral head is elevated to an angle of 13 degrees and the vertical milling attachment is also swiveled around to locate the cutter in line with the spiral-head spindle, so that the edge of the finished cam will be parallel to its axis of rotation.

When there are several lobes on a cam having different leads, the machine can be geared for a lead somewhat in excess of the greatest lead on the cam, and then all the lobes can be milled without changing the spiral head gearing by simply varying the angle of the spiral head and cutter to suit the different cam leads. Whenever possible, it is advisable to mill on the under side of the cam, as there is less interference from chips; moreover, it is easier to see any lines that may be laid out on the cam face. To set the cam for a new cut, it is first turned back by operating the handle of the table feed-screw, after which the index crank is disengaged from the plate and turned the required amount.

Cam milling is generally done on machines designed for this purpose, such as are illustrated and described in Chapter VI.

Cutting Teeth in End and Side Mills. — When milling the end teeth in end mills or the side teeth in side mills, the dividing head should be set at such an angle that the "lands" or tops of the teeth will have a uniform width. This angle α (see Fig. 30) at which the dividing-head spindle should be set from its horizontal position can be determined as follows:

Rule. — Multiply the tangent of the angle between adjacent teeth (equals 360 ÷ No. of teeth required) by the cotangent of the cutter angle; the result is the cosine of the angle α at which the dividing head must be set.

Expressing this rule as a formula,

$$\cos \alpha = \tan \theta \cot \beta$$

in which

α = angle of elevation of dividing head;
θ = tooth angle of cutter blank = 360 ÷ No. of teeth;
β = angle of cutter used for grooving.

A practical example, illustrating the application of the foregoing rule and formula, is given in the following paragraph.

Example of Side Cutter Milling. — The side teeth of a 30-tooth side or straddle milling cutter are to be milled with a 70-degree cutter. To what angle α (Fig. 30) must the dividing head be set to secure lands of uniform width?

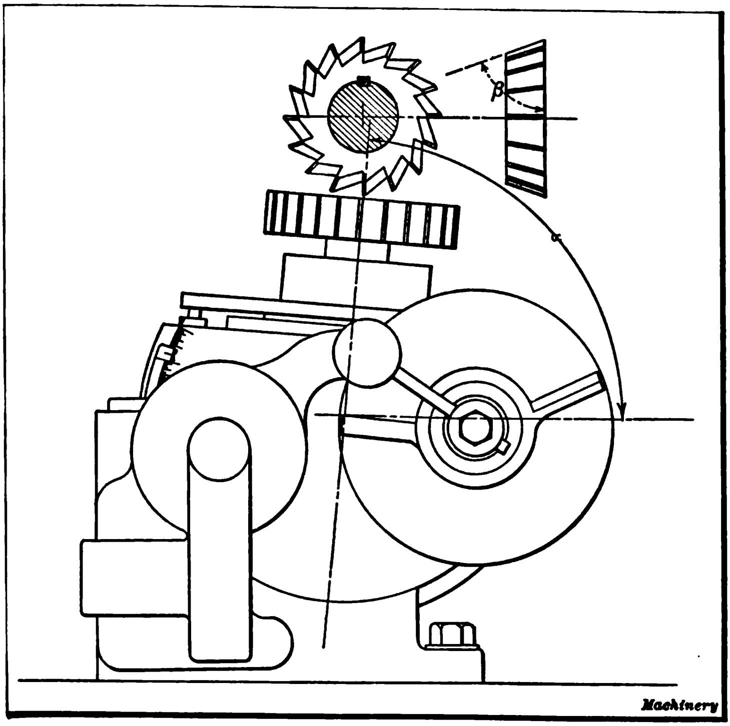


Fig. 30. Dividing or Index Head set for Cutting Side Teeth in Side Milling Cutter

The angle θ between the teeth $= 360 \div 30 = 12$ degrees; the tangent of 12 degrees is 0.2125.

The cotangent of the cutter angle or 70 degrees = 0.3639. Therefore,

$$\cos \alpha = 0.2125 \times 0.3639 = 0.0773.$$

The angle whose cosine is 0.0773 is approximately $85\frac{1}{2}$ degrees, which is the angle of elevation at which to set the dividing head.

When milling the end teeth in an end mill, the angle α would be determined in the same way as indicated by the preceding example for a side milling cutter. The teeth on the cylindrical part of the cutter are usually milled first and then the end or side teeth (as the case may be) are cut to match those on the periphery.

Milling Angular Cutters. — The angle at which the dividing head should be set when milling the teeth of angular cutters, or fluting taper reamers with a "single-angle" cutter, can be determined as follows:

Rule. — Divide the cosine of the angle θ (Fig. 31) between adjacent teeth (equals 360 ÷ No. of teeth required) by the tangent of the blank angle β; the quotient is the tangent of angle γ.

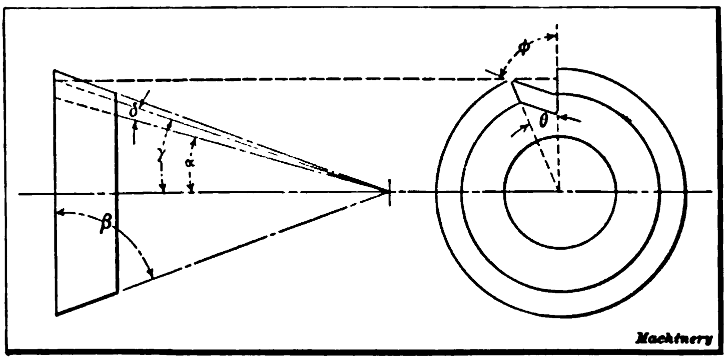


Fig. 31. Diagram showing Angles Involved in Calculation for Determining Position of Index Head when Milling Teeth in Angular Cutter

Next multiply the tangent of the angle θ between the teeth by the cotangent of the grooving cutter angle ϕ, and then multiply the result by the sine of angle γ; the product will be the sine of angle δ. Subtract angle δ from angle γ to obtain the angle α at which the dividing head should be set.

This rule is rather unwieldy and can be more clearly expressed by formulas. Thus,

$$\tan\gamma = \frac{\cos\theta}{\tan\beta}, \qquad \sin\delta = \tan\theta\cot\phi\sin\gamma.$$

Angle of elevation $\alpha = \gamma - \delta$.

The meaning of the letters used in these formulas and the foregoing rule is indicated by the illustration, Fig. 31.

Example of Angular Cutter Milling. — To illustrate the application of the rule and formulas given in the preceding paragraph, suppose that 18 teeth are to be milled in a 70-degree milling cutter blank, with a 60-degree single-angle cutter. To what angle α (see Fig. 32) must the dividing head be set to obtain "lands" of uniform width? In this example, the angle θ (Fig.

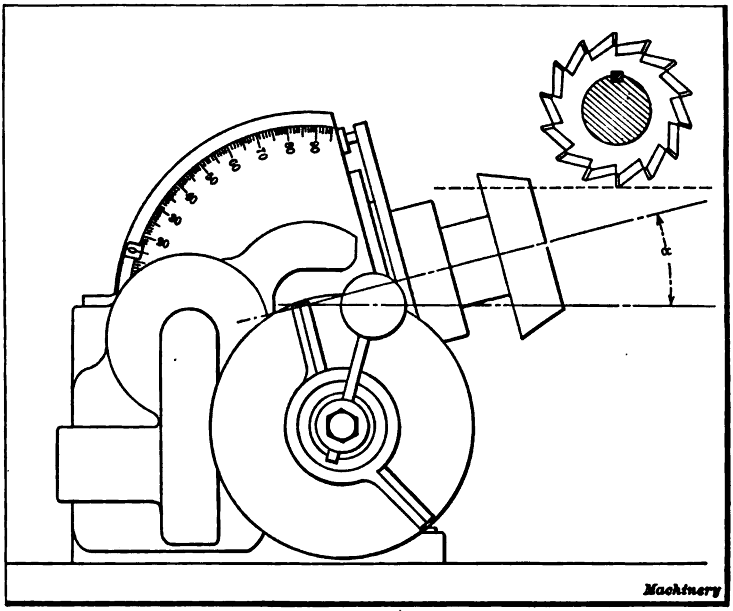


Fig. 32. Index Head set at Angle of 15 Degrees for Cutting Teeth in 70-degree Blank with 60-degree Cutter

31) between adjacent teeth = 360 ÷ 18 = 20 degrees; blank angle β = 70 degrees; cutter angle ϕ = 60 degrees.

$$\tan\gamma = \frac{\cos\theta}{\tan\beta} = \frac{0.9396}{2.7474} = 0.342.$$

The angle whose tangent is 0.342 is 18 degrees 53 minutes.

$$\sin\delta = \tan\theta \cot\phi \sin\gamma = 0.3639 \times 0.5773 \times 0.3236 = 0.0679.$$

The angle whose sine is 0.0679 is 3 degrees 53 minutes, approximately. Therefore angle α at which the dividing head should be set equals the difference between angles γ and δ or $18° 53' - 3° 53' = 15$ degrees.

CHAPTER V

GEAR CUTTING IN THE MILLING MACHINE

SPUR, spiral, and bevel gears are cut ordinarily 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.

Cutting a Spur Gear. — Fig. 1 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 to use for Spur Gears. — The type of cutter that is used for milling the teeth of spur gears is shown in Fig. 2. 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 the shape 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. 1 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.

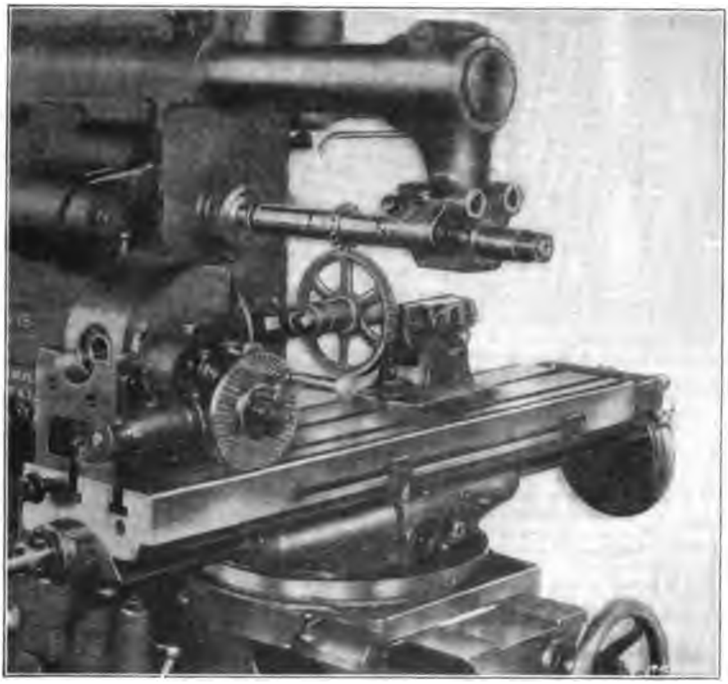


Fig. 1. Cutting the Teeth of a Spur Gear in a Universal Milling Machine

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. 3. A true arbor is placed between the dividing head and footstock 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 which it is moved to position *C*, or until it just touches a tissue paper "feeler" as before. The horizontal dimension

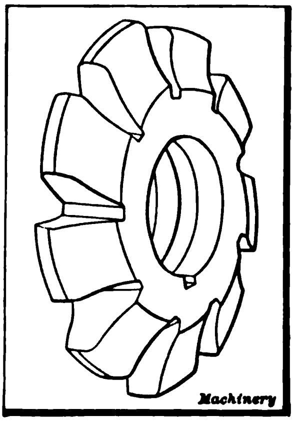


Fig. 2. Cutter for Milling the Teeth of Spur Gears

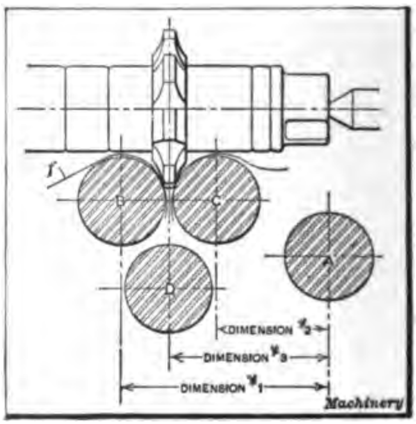


Fig. 3. Method of setting Cutter Central with Arbor

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.

Testing Position of Cutter. — A method of testing the position 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, by adjusting the gear blank. Another trial cut is then taken and the test repeated. When the cutter is set, the saddle should be clamped in position.

Setting the Cutter to Depth. — 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. 1. 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.

Testing Thickness of Tooth at Pitch Line. — The special vernier, gear-tooth caliper, shown in Fig. 4, 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 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

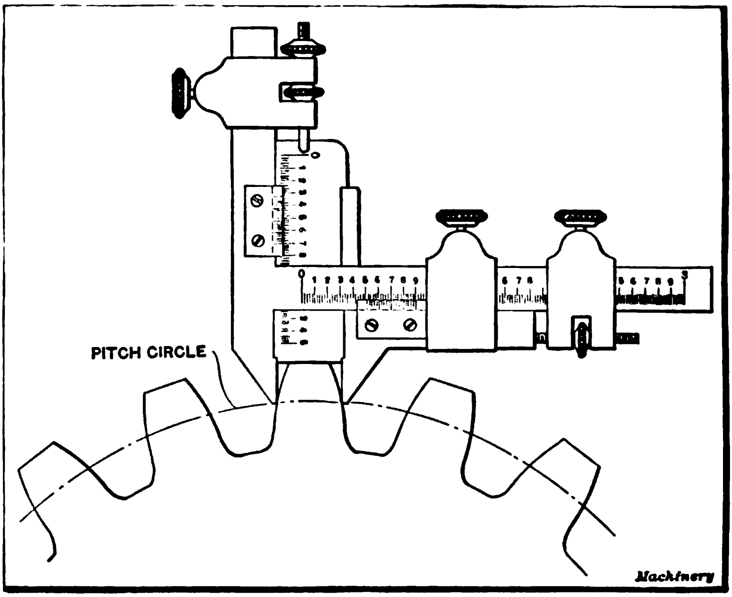


Fig. 4. Vernier Caliper for Measuring the Thickness of Gear Tooth at the Pitch Circle

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.

Chordal Thickness of Tooth at Pitch Line. — When a gear tooth is measured as shown in Fig. 4 it is the chordal thickness T (see Fig. 5) 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.

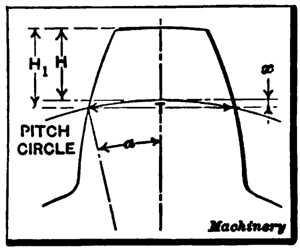


Fig. 5. Detail View of Gear Tooth

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.

Milling the Teeth. — 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

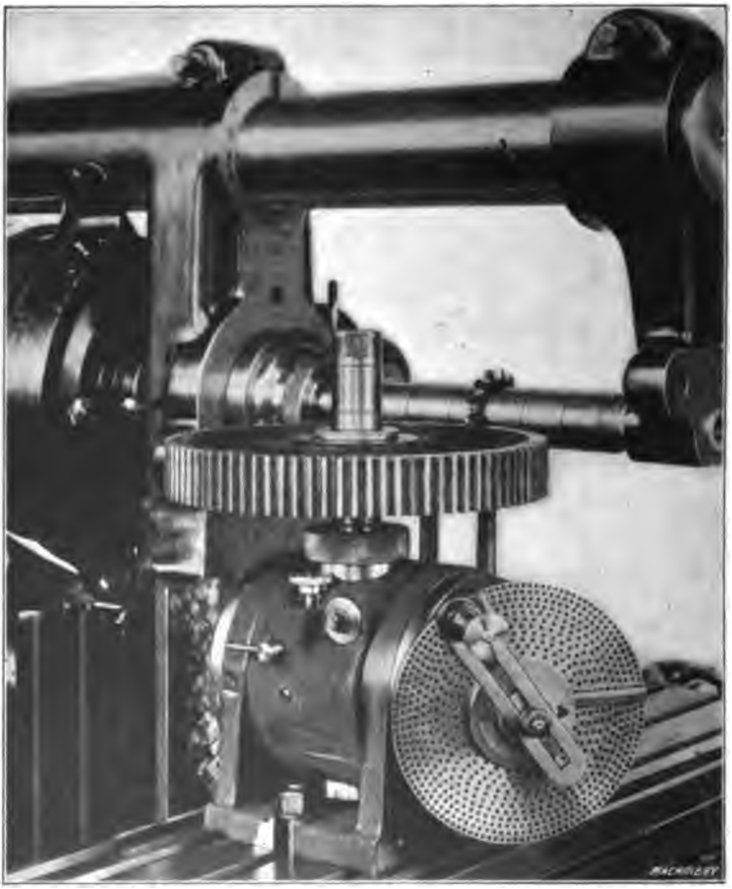


Fig. 6. Dividing Head set in Vertical Position for Cutting Spur Gear 18 inches in Diameter

finishing cuts. Special "stocking" cutters are often used for rough-milling coarse gears preparatory to finishing with 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.

Gear Cutting Attachment. — When it is necessary to cut comparatively large spur gears on a milling machine, a gear cutting attachment is preferable to the regular dividing head. This attachment, in its usual form, is similar to a dividing head, but is larger and heavier in construction. If the gear is too large to clear the machine table when mounted between the centers (as illustrated in Fig. 1), the centers are sometimes raised far enough to provide room for the gear blank by placing parallel blocks beneath the index head and tail-center. If the gear blank is so large that it will not pass under the cutter arbor with the table in its lowest position, it may be possible to cut the gear by using an "under-cutting attachment." The centers are raised far enough to provide room for the cutter beneath the gear, and the arbor is supported by a special out-board bearing.

Fig. 6 illustrates a simple method of cutting a spur gear which is too large to be held between the centers on a horizontal arbor. Instead of increasing the swing of the centers by placing parallel blocks beneath them, the dividing-head spindle is set in a vertical position. The gear blank is held on a short arbor inserted in the spindle and the rim is supported to take the downward thrust of the cut, by two vertical studs or rods placed on the cutting side, as the illustration shows. When milling the teeth, the gear blank is fed up against the cutter by using the power vertical feed. The spur gear shown in this illustration has teeth of 5 diametral pitch and is 18 inches in diameter.

Cutting Spur Gear on Circular Attachment. — Fig. 7 illustrates how a circular milling attachment is sometimes used for holding a comparatively large gear while milling the teeth. The gear is clamped in a horizontal position and it is centered by the finished bore of the hub which fits over a plug inserted in the central hole of the table.

The cutter, which is held on the regular arbor, forms the tooth spaces as the table is fed vertically by power. It will be noted that this particular attachment is equipped with an index plate. By holding a large gear on the circular attachment, the rim is more rigidly supported than when the gear is held on an arbor mounted between the centers of a dividing head.

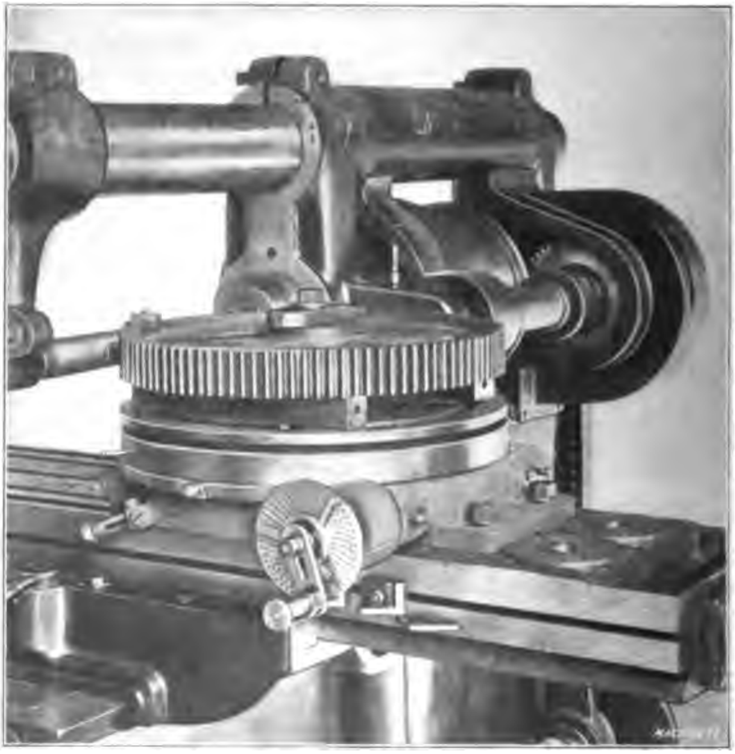


Fig. 7. Cutting Spur Gear by use of Circular Milling Attachment

Rack Cutting in the Milling Machine.—The method of cutting a rack in the milling machine by the use of a rack-cutting attachment is illustrated in Fig. 8. This attachment is securely clamped to the face of the machine column and its cutter spindle is parallel with the table. The spindle is driven from the main spindle of the machine through bevel and spur gearing. The rack teeth are formed by cutting tooth spaces straight across the rack blank (using the automatic transverse feed) and after each space is milled, the machine table and rack is indexed a distance equal to the pitch of the rack teeth. This indexing movement is obtained by the attachment mounted on the left end of the table. This attachment consists of an indexing or locking disk *A* carried by a bracket bolted to the table, and change gearing which connects the locking disk with the table feed-screw.

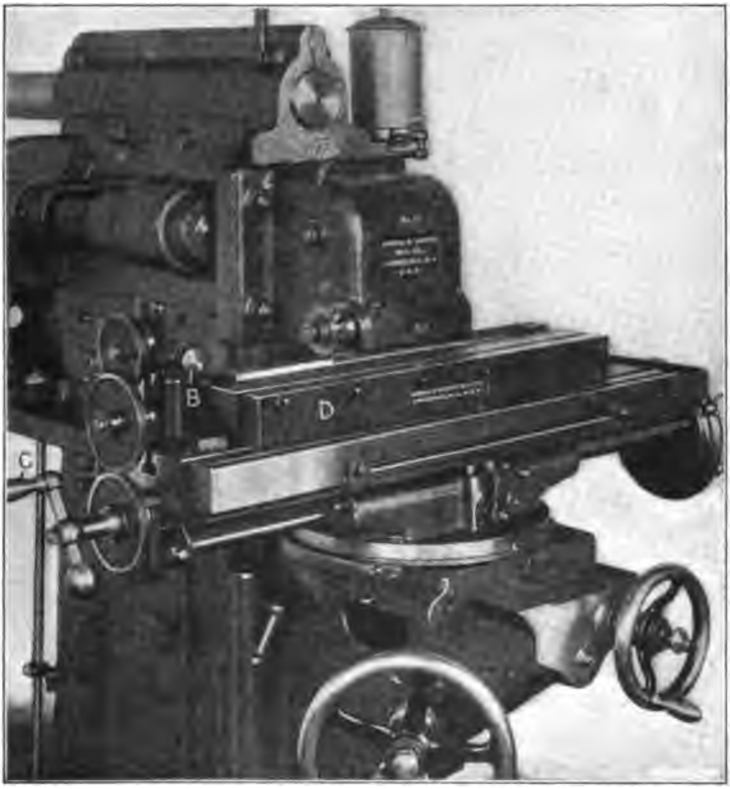


Fig. 8. Milling a Rack with Brown & Sharpe Rack-cutting Attachment

The indexing disk has a notch or slot in its periphery which is engaged by a locking pin *B*.

When cutting a rack, the indexing disk and feed-screw are connected by gears which will cause the table and rack to move a distance equal to the required pitch of the rack teeth, while the disk makes one revolution, or, for some pitches, two revolutions. The attachment is operated as follows: After one tooth

Index Table for Rack-cutting Indexing Attachment (B. & S. Milling Machine)

Diametral Pitch						Circular Pitch				
Pitch	Gear on Index Disk	First Gear on Stud	No. of Turns of Index	Work Moves	Correct Pitch	Pitch	Diametral Pitch	Gear on Index Disk	First Gear on Stud	No. of Turns of Index
3	88	42	2	1.0476	1.0472	1	3.141	112	28	1
3½	88	49	2	0.8979	0.8975	15/16	3.351	105	28	1
4	88	28	1	0.7857	0.7853	7/8	3.590	98	28	1
4½	88	63	2	0.6984	0.6981	13/16	3.866	91	28	1
5	88	35	1	0.6285	0.6283	4/5	3.927	112	35	1
5½	112	49	1	0.5714	0.5711	3/4	4.188	84	28	1
6	88	42	1	0.5238	0.5235	11/16	4.569	77	28	1
7	88	49	1	0.4489	0.4487	2/3	4.712	112	42	1
8	88	56	1	0.3928	0.3926	5/8	5.026	70	28	1
9	88	63	1	0.3492	0.3490	3/5	5.236	84	35	1
10	88	70	1	0.3142	0.3141	4/7	5.497	112	49	1
11	88	77	1	0.2857	0.2855	9/16	5.585	63	28	1
12	88	84	1	0.2619	0.2617	1/2	6.283	56	28	1
13	88	91	1	0.2417	0.2416	4/9	7.068	112	63	1
14	88	98	1	0.2244	0.2243	7/16	7.180	98	56	1
15	88	105	1	0.2095	0.2094	3/7	7.330	84	49	1
16	88	112	1	0.1964	0.1963	2/5	7.854	56	35	1
18	44	63	1	0.1746	0.1745	3/8	8.377	84	56	1
20	44	70	1	0.1571	0.1570	4/11	8.639	112	77	1
22	44	77	1	0.1428	0.1427	1/3	9.424	56	42	1
24	44	84	1	0.1309	0.1308	5/16	10.053	70	56	1
26	44	91	1	0.1208	0.1208	3/10	10.472	84	70	1
28	44	98	1	0.1122	0.1121	2/7	10.995	56	49	1
30	44	105	1	0.1047	0.1047	1/4	12.566	56	56	1
32	44	112	1	0.0982	0.0981	2/9	14.137	56	63	1
						1/5	15.708	56	70	1
						3/16	16.755	42	56	1
						2/11	17.278	56	77	1
						1/6	18.849	56	84	1

Note:—It is not necessary to change gear on screw or second gear on stud when changing for the different pitches.

space is milled, pin *B* is withdrawn and feed-screw handle *C* is turned until pin *B* again engages the notch in the disk, which indexes the rack for cutting the next tooth space, provided the disk and feed-screw are connected by the proper change-gears. A No. 1 involute cutter corresponding to the pitch of the gearing that is to mesh with the rack should be used. The rack teeth are cut to the same depth and width as spur gear teeth of similar pitch. The total depth of a tooth space equals 2.157 divided by the diametral pitch, or 0.6866 times the circular pitch. The rack to be cut is held in a special vise or fixture *D* which is bolted to the machine table. Several narrow racks can be held in this fixture at the same time and the teeth be cut simultaneously.

The accompanying table shows what change-gears should be used for indexing different pitches. The left half of the table is used when the diametral pitch of the rack teeth is given. This pitch, which is listed in the first column, corresponds to the diametral pitch of the gear which is to mesh with the rack. The right half of the table is for circular pitches, the pitch in this case being equal to the center-to-center distance between adjacent rack teeth. This table also gives the number of turns for the indexing disk; with but three exceptions all pitches are indexed by a single turn of the disk. The gear *E* (Fig. 8) next to the indexing disk, and the first gear on the stud (which is the one meshing with gear *E*) are the only gears which require changing for different pitches.

Gashing and Hobbing a Worm-wheel. — 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. 9 and 10. 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. 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-

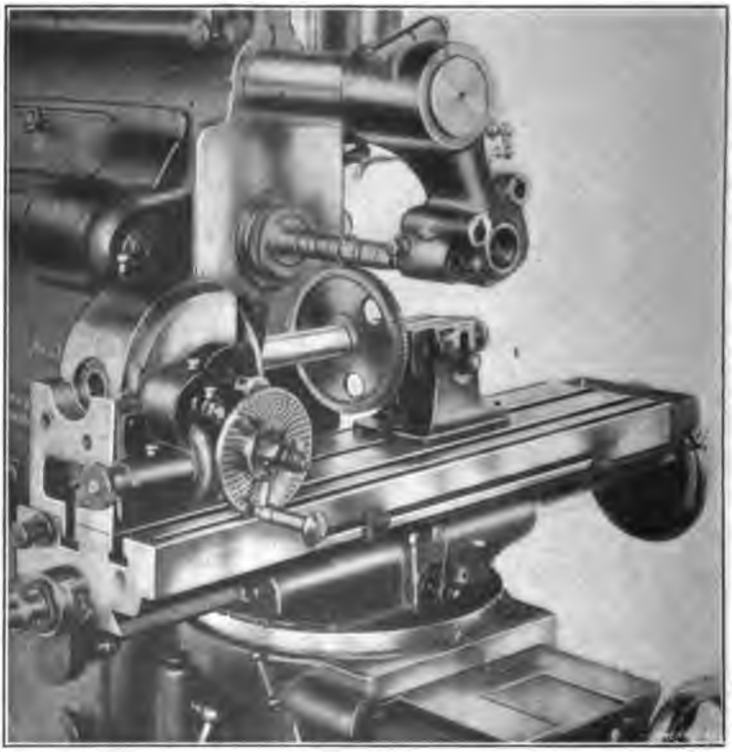


Fig. 9. Gashing a Worm-wheel in a Universal Milling Machine

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 illustrated in Fig. 9, 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

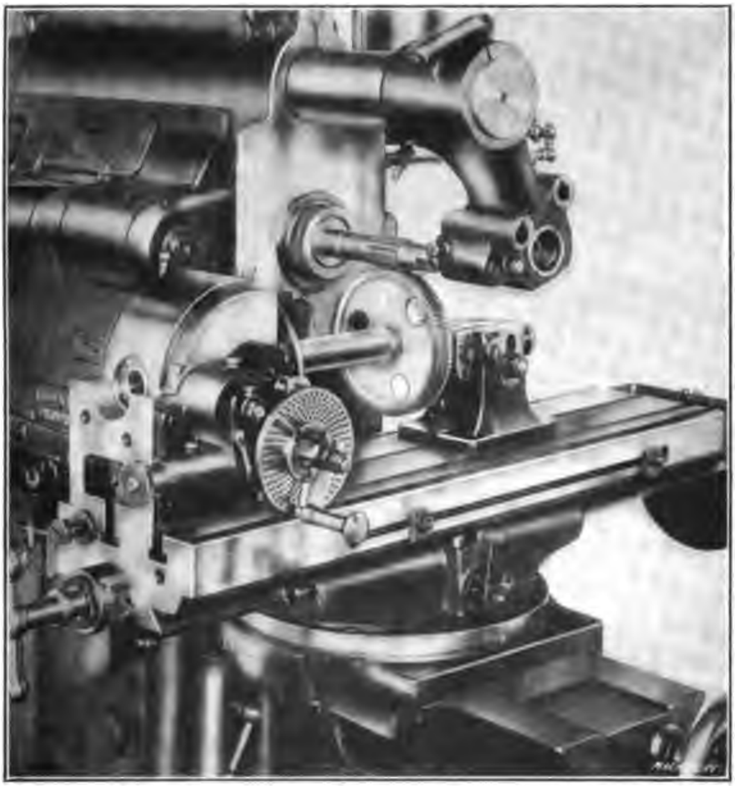


Fig. 10. Hobbing the Teeth of a Worm-wheel

the table longitudinally until the distances between the blade and arbor are the same on both sides.

Angular Position of Table for Gashing Worm-wheel. — 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. 11. 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 found by subtracting twice the addendum of the teeth from the outside diameter of the worm. The addendum equals the linear pitch $\times$ 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

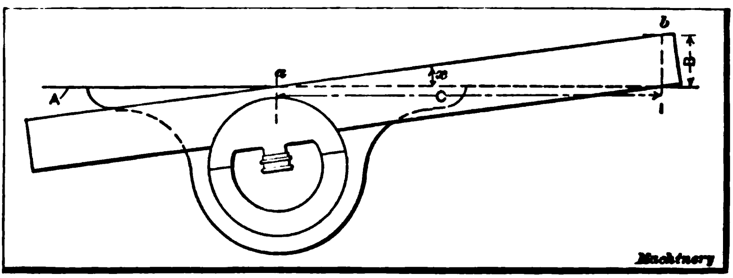


Fig. 11. Simple Method of obtaining Helix Angle of Worm

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 makes 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. 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 into 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. 10. 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.

Testing Center Distance between Worm and Wheel. — 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. When the worm is larger in diameter than the arbor, subtract, and when it is smaller, add the difference between the radii.

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 shown in Figs. 9 and 10) 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 *center*, 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 between 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.

Cutting a Spiral Gear. — The teeth of spiral gears are often cut in universal milling machines, as indicated in Fig. 12, 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.

Pitch of 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

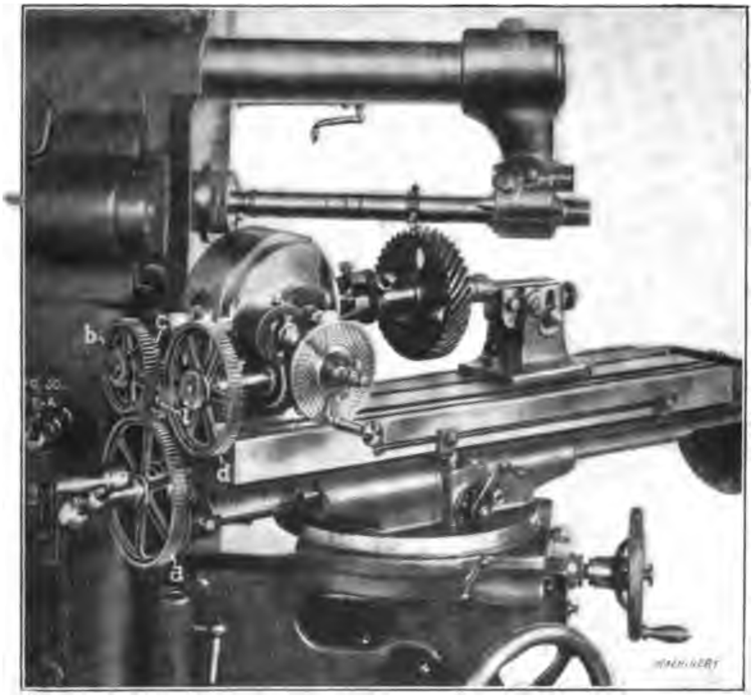


Fig. 12. Cutting the Teeth of a Spiral Gear in a Universal Milling Machine

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. 13.

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. 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 30 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, 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. 12 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, $\frac{3.1416}{0.3927} = 8$, 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., are 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.

Number of Cutter to Use for Spiral Gears.—As previously explained, the proper cutter to use for spur gears depends not

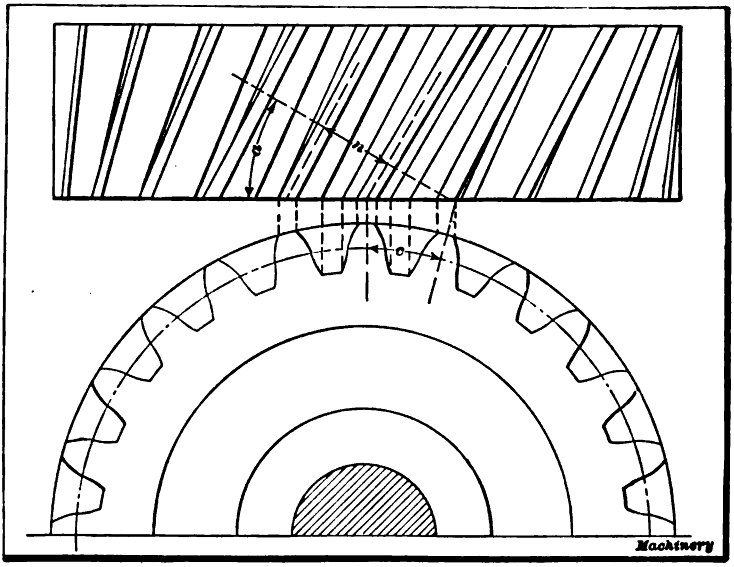


Fig. 13. The Circular Pitch of a Spiral Gear is the Distance *c* and the Normal Pitch, the Distance *n*

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 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 in the paragraph headed "Cutter to use for Spur Gears," 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 (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 the Machine for Spiral Milling. — The change-gears *a*, *b*, *c* and *d*, Fig. 12, 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 spiral gear shown in Fig. 12 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.

Angular Position of Table for Cutting Spiral Gear. — 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, Chapter IV), 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 makes 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, consequently, 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. 3.

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.

Milling Bevel Gears. — Small bevel gears are occasionally cut in the milling machine with a formed cutter, but as the curve of a bevel gear tooth changes throughout its length, obviously a formed cutter having a fixed curve will not produce teeth of the theoretically correct shape. The inaccuracy, however, is not so pronounced when the teeth are small, but the milling process is unsatisfactory for forming teeth of coarse pitch, especially if the gears are to revolve rapidly when in use.

When a bevel gear is cut by milling, the gear blank is mounted on an arbor inserted in the dividing-head spindle, and the latter is set to the cutting angle as shown in Fig. 14. A formed cutter

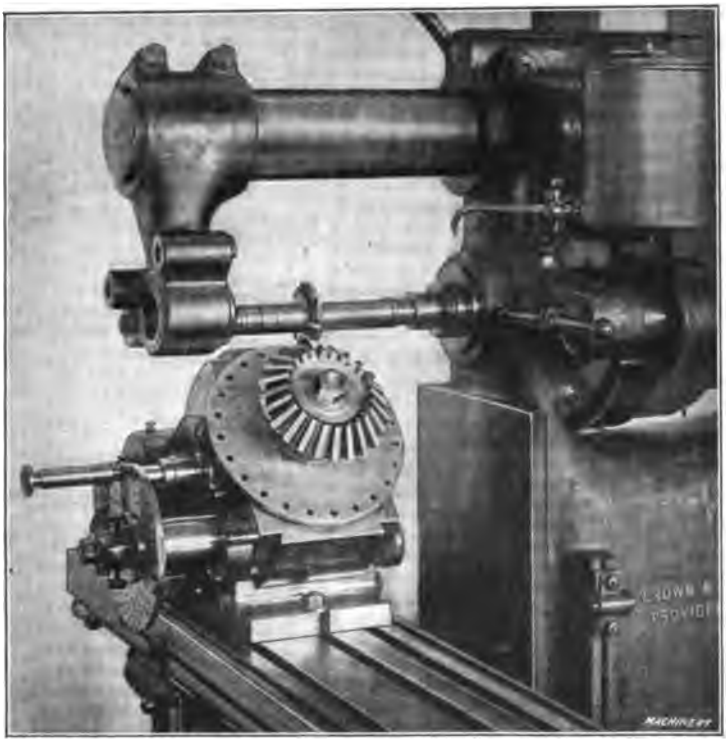


Fig. 14. Milling Machine arranged for Cutting a Bevel Gear

is used, and it is necessary to take two cuts through each tooth space, with the gear blank slightly off center, first on one side and then on the other, to obtain a tooth of approximately the correct form. The gear blank is also rotated proportionately to obtain the proper tooth thickness at the large and small ends. The different steps or operations connected with cutting a bevel gear are as follows: setting the blank to the cutting angle;

selecting the cutter; taking a trial cut; determining the amount of offset; and milling the teeth. These different operations will be referred to in the order given.

Angular Position of Bevel Gear Blank.—The angle α (see Fig. 15) at which the dividing-head spindle should be set for milling the teeth equals the pitch cone angle β, minus the *addendum* angle θ of the tooth. Ordinarily, the cutting angle for bevel gears equals the pitch cone angle minus the *dedendum* angle; when cutting the teeth by milling with a formed cutter, the first rule is preferable as it gives a uniform clearance at the bottom of the tooth spaces and a somewhat closer approximation to the theoretically correct tooth shape.

For bevel gears with shafts at right angles, the tangent of the pitch cone angle of the pinion is found by dividing the number of teeth in the pinion by the number of teeth in the gear; the tangent of the pitch cone angle of the gear equals the number of teeth in the gear divided by the number of teeth in the pinion; the tangent of the addendum angle equals the addendum divided by the pitch cone radius; the addendum equals 1.0 divided by the diametral pitch.

Selecting Cutter for Bevel Gears. — The standard bevel gear cutter is made thinner than the standard spur gear cutter because it must pass through the narrow tooth spaces at the inner ends of the teeth. For $14\frac{1}{2}$-degree involute teeth there are eight cutters numbered from one to eight for each pitch and suitable for cutting bevel gears from a twelve-tooth pinion to a crown gear. The cutter to use, in any case, must not only be of the required diametral pitch but the right number in the series. The number of the cutter depends upon the number of teeth in the gear or pinion. When cutting miter gears, only one cutter is needed, but if one gear is larger than the other, two cutters of the same pitch but of different numbers may be required.

The number of teeth for which to select the cutter is not the actual number of teeth in the gear, but is found as follows: Divide the actual number of teeth in the gear by the cosine of the pitch cone angle. For example, what cutter would be used for a bevel gear having 35 teeth of 12 diametral pitch and a pitch cone angle of 60 degrees? The cosine of 60 degrees is 0.5; hence, the number of teeth for which to select the cutter equals $35 \div 0.5 = 70$. The cutter then, would be a No. 2 shape of 12 diametral pitch, the No. 2 shape being used because it is intended for all numbers of teeth between 55 and 134. (See list given in paragraph headed "Cutter to use for Spur Gears.")

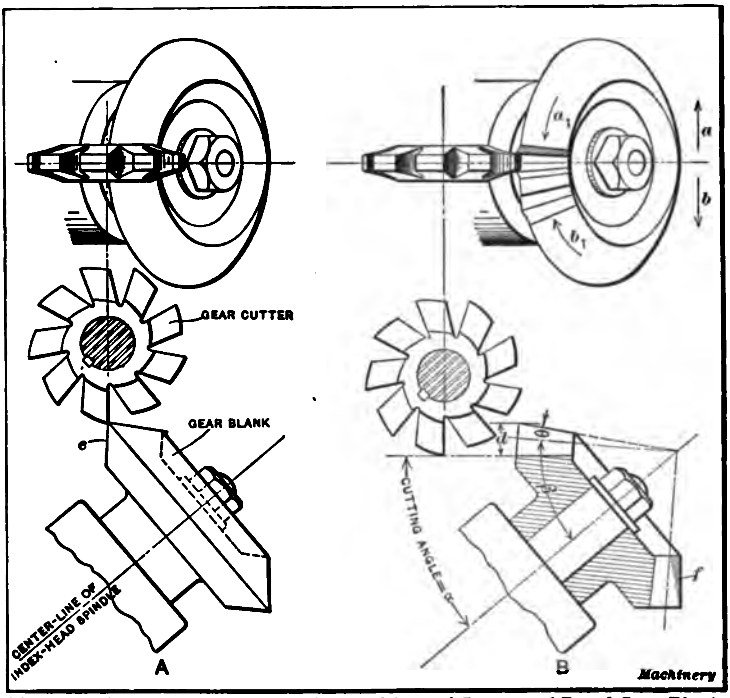


Fig. 15. Diagrams showing Relative Positions of Cutter and Bevel Gear Blank

Setting Cutter and Milling Trial Tooth. — Before cutting the first tooth, the cutter should be centered with the blank. This can be done by placing a true center in the spindle of the dividing head and setting the point in line with the center-line on the gear cutter. A more accurate method was described in connection with Fig. 3. After the cutter is centered, the blank is adjusted vertically (by raising or lowering the table of the machine) until the cutter just touches or "bites" a piece of tissue paper laid over the edge of the blank, thus locating the cutter as shown at *A* in Fig. 15. The dial of the elevating screw is then set to zero and the table is elevated an amount *d* equal to the whole depth of the tooth. This depth will not be exactly right, as it should be measured along the back edge *e* of the tooth, but the error due to this slight angle is negligible. (The whole depth = diametral pitch ÷ 2.157; or circular pitch × 0.687.) Having thus centered the cutter and set it to depth, two tooth spaces should be cut, thus forming a tooth upon which trial cuts can be made to obtain the proper relation between the cutter and work for milling the remainder of the teeth.

Amount of Off-set for Milling Bevel Gear Teeth. — Instead of milling the teeth with the cutter in a central position, it is set off center slightly on first one side and then the other, in order to form teeth which are nearer the correct shape. The amount that the gear blank or cutter should be off-set is usually determined by trial. For the first trial cut the off-set should equal about 5 or 6 per cent of the tooth thickness on the pitch line at the large end. The trial tooth is first moved away from the cutter an amount equal to the off-set, as indicated by arrow *b*, Fig. 15; the dividing-head spindle is then rotated, as shown by arrow b_1, far enough to align the small end of the tooth space previously cut with the cutter. The first trial cut is then taken, after which the blank is indexed to bring the second tooth space into position. The blank is next set over on the opposite side of the central position (as indicated by arrow *a*) the same amount as for the first trial cut, thus moving the opposite face of the trial tooth away from the cutter. The dividing-head spindle is again rotated as shown by arrow a_1, to return the trial tooth toward the cutter until the latter is aligned with the small end of the tooth space, as before. The second trial cut is then taken.

The thickness of the trial tooth at the pitch line is now measured with a vernier gear-tooth caliper, or a fixed gage, the measurements being taken at the large and small ends. If the thickness at both ends is too great, rotate the tooth toward the cutter and take trial cuts until the proper thickness at either the large or small end is obtained. If the large end of the tooth is of the right thickness and the small end is too thick, the blank was off-set too much. Inversely, if the small end is correct and the large end too thick, the blank was not set enough off center and, in either case, its position should be changed accordingly. A trial off-set of 5 or 6 per cent of the tooth thickness at the large end probably will not be enough, so that two or three trial cuts will have to be taken on each side of the tooth before the right amount of off-set is found.

Milling the Bevel Gear Teeth. — When the off-set is determined, tooth spaces are milled around the gear blank by cutting a space and then indexing for each successive cut. The cutter is then off-set on the opposite side, the blank is rotated far enough to mill teeth of the required width, and another series of cuts is taken around the gear. From the foregoing, it will be seen that the gear blank is off-set to produce a tooth shape that is approximately correct, and it is rotated by turning the spindle of the dividing head to mill a tooth of the right thickness. The number of holes it was necessary to move the index pin between the first and second series of cuts to get the correct tooth thickness should be recorded; then if duplicate gears are to be cut, it will only be necessary to off-set the blank the required amount, take a series of cuts around it, off-set the blank on the opposite side of the center-line, rotate the index crank the required number of holes as determined when cutting the first gear, and finish the teeth by a second series of cuts.

When milling cast-iron gears coarser than about 5 diametral pitch, it is advisable to first cut central spaces clear around the gear and then finish the sides by separate cuts, going around the gear three times. These central cuts are sometimes taken by using a roughing or "stocking" cutter. When milling steel gears, the central cuts are usually taken.

When cutting bevel gears of fine pitch and large diameter, the adjustment obtained by moving the indexing crank (for milling the teeth to the required thickness) may not be fine enough; that is, one hole in the index circle may not rotate the blank far enough, whereas if the pin is engaged in the next hole, the blank will be turned too far, thus milling too thin a tooth. To sub-divide the space between the holes, most dividing heads have a fine adjustment for rotating the worm independently of the crank.

Finishing the Teeth by Filing. — When bevel gears are cut as described in the foregoing, the teeth at the small ends are a little too narrow at the bottom and too wide at the top; therefore, they should be finished by filing off a triangular area extending from the point of the tooth at the large end to the point

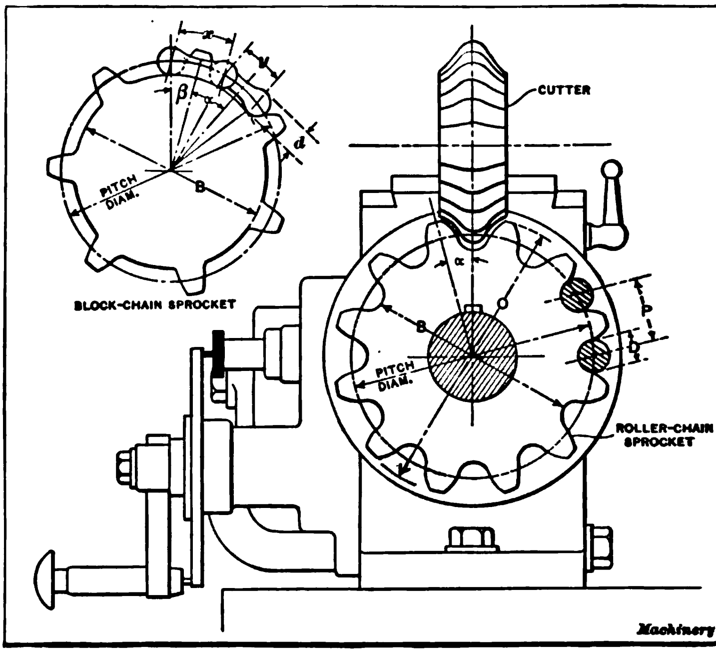


Fig. 16. Cutting Sprocket Teeth in a Milling Machine

at the small end, thence down to the pitch line and back diagonally to a point at the large end, as indicated by the shaded area *f* in Fig. 15. If the amount of set over is reduced, thus milling the teeth too thin at the pitch line at the small end, filing may not be necessary, although better running gears will be obtained by finishing the teeth as described.

Milling Teeth in Chain Sprockets. — The teeth of chain sprockets, such as are used on chain-driven automobiles, etc., are milled with formed cutters. When a number of sprockets are to be cut, several are clamped together on an arbor and milled at the same time. In shops where a great many sprockets must be cut, regular gear-cutting machines are used. When such a machine is not available, a milling machine is often used (as indicated by the diagram, Fig. 16), especially if only a few sprockets are needed. The sprocket blanks are held on an arbor which is mounted between the centers of a dividing head.

Clearance for Sprocket Teeth. — In chain drives there is more or less elongation of the chain due to wear of the rivets and bearings or stretch of the material. To prevent undue interference between the chain and sprocket as the result of the stretch or elongation of the chain, the sprockets are not cut to fit the chain accurately but with a certain amount of pitch line clearance. If a sprocket were cut without clearance, an elongated chain would climb the teeth and the latter would exert a wedging effect, thus subjecting the chain to excessive strains. The operation would also be noisy and the life of the chain greatly shortened.

The amount of clearance should be as large as is consistent with the strength of the sprocket teeth. If there is only a slight clearance, a perfect chain on a perfect sprocket might mesh smoothly at low speeds, but not at high speeds, because the chain tends to shift outward beyond the pitch line after engaging the first tooth and then back again at the parting tooth. By cutting the sprocket with sufficient pitch-line clearance, the teeth are made narrower than the distance between the chain rollers and the wedging effect is overcome. This clearance for roller-chain sprocket wheels should be approximately as follows:

Pitch of Chain, Inches	Roller Diameter, Inches	Clearance, Inches	Pitch of Chain, Inches	Roller Diameter, Inches	Clearance, Inches
1/2–5/8	0.325	1/32	1 1/2	3/4	3/16
3/4	15/32	1/16	1 3/4	1	1/8
1	9/16	3/32	2	1 1/8	5/32
1 1/4	5/8	5/32	....	....	....

Formed cutters may now be obtained which provide this clearance but some cutters have little or no allowance for clearance, and, if the latter kind is used, the sprocket should be milled as follows: First, cut the teeth in the usual manner; then revolve the sprocket an amount equal to the pitch line clearance desired and take an additional series of cuts around the sprocket.

Cutter for Sprockets. — A number of sprocket cutters are made for each pitch the same as for spur gears, and in order to obtain a tooth adapted for high speeds, it is the common practice to use cutters made for fewer teeth than the number in the sprocket to be cut. In this way, the teeth are made more rounding, which facilitates engagement and disengagement of the chain rollers. When using Brown & Sharpe cutters, the cutter numbers for different numbers of teeth are as follows: To cut a 9-tooth sprocket, use the cutter marked 8 teeth; to cut a 10-tooth sprocket, use cutter marked 9 teeth; for an 11-tooth sprocket, use cutter marked 10–11 teeth; for a 12-tooth sprocket a 10–11 tooth cutter; for a 13-tooth sprocket, a 12–13 tooth cutter; for 14- and 15-tooth sprockets, use a cutter marked 12–13 teeth; for 16-, 17- and 18-tooth sprockets, a cutter marked 14 to 16 teeth; for 19- to 25-tooth sprockets, a cutter marked 17 to 20 teeth; for a 26-tooth sprocket and over, use cutter marked 21 to 34 teeth.

Chain Sprocket Diameters. — The pitch diameter of a sprocket wheel for a roller chain equals the pitch of the chain $P \div \sin$ of angle α (see Fig. 16). Angle α = 180 degrees ÷ number of teeth. The base diameter B = pitch diameter − diameter D of chain roller. The outside diameter for sprockets of 17 teeth and over equals pitch diameter + diameter D of chain roller. The outside diameter of smaller sprockets should be reduced from $\frac{1}{32}$ to $\frac{1}{8}$ inch, depending upon the pitch of the chain and number of teeth in the sprocket. This is done so that the sprocket teeth will readily clear the chain rollers at high speeds. If the chain pitch varies from $\frac{1}{2}$ to $\frac{3}{4}$ inch, reduce the diameter $\frac{1}{16}$ inch for 8- to 12-tooth sprockets, and $\frac{1}{32}$ inch for 13- to 16-tooth sprockets. If the chain pitch is between 1 and 2 inches, reduce the outside diameter $\frac{1}{8}$ inch for 8- to 12-tooth sprockets and $\frac{1}{16}$ inch for 13- to 16-tooth sprockets.

For block-center chains the pitch diameter equals the pitch x of the side links ÷ sine β (see detail sketch in upper left-hand corner, Fig. 16). The tangent of β = sine $\alpha \div (y \div x + \cos\alpha)$. Angle α = 180 degrees ÷ number of teeth. Base diameter = pitch diameter $- d$; outside diameter = pitch diameter $+ d$; d = diameter of round part of chain block.

Example of Sprocket Milling. — As a practical example of sprocket milling, suppose a 12-tooth roller-chain sprocket is to be cut for a chain of 1-inch pitch and having rollers 0.5625 inch in diameter. As previously explained, the pitch diameter is found by dividing the pitch of the chain by the sine of angle α (see Fig. 16). $\alpha = \frac{180}{12} = 15$ degrees. Sine 15 degrees = 0.2588; hence pitch diameter $= \frac{1}{0.2588} = 3.864$ inches.

The base diameter $B = 3.864 - 0.5625 = 3.301$ inches; the outside diameter $= 3.864 + 0.5625 - 0.125 = 4.301$ inches. In obtaining this outside diameter, 0.125 inch is subtracted owing to the small size of the sprocket. (This is done to provide extra clearance between the teeth and chain rollers as explained in the preceding paragraph.)

The B. & S. cutter ordinarily used for a 12-tooth sprocket would be one marked 10–11 teeth. The depth of the tooth space for a sprocket having over 16 or 17 teeth would equal the diameter of the chain roller. For smaller sprockets, however, this depth is somewhat less as the teeth are made shorter. The total depth equals one-half the difference between the outside and base diameters, which, in this example, equals $\frac{4.301 - 3.301}{2}$ = 0.5 inch. Therefore when milling the teeth, the cutter, after being set directly over the center of the sprocket blank, is set to this depth when taking the finishing cut.

When turning the sprocket blank, the width of the teeth at the pitch line should be from $\frac{1}{64}$ to $\frac{3}{32}$ inch less than the length of the chain rollers to provide sidewise clearance, and the teeth should be chamfered or rounded from the pitch line outward to the points. This chamfering or rounding is important because if the chain sways while running and the sprockets are not accurately aligned, the chamfered ends easily engage the chain.

CHAPTER VI

VERTICAL, HORIZONTAL AND SPECIAL MILLING MACHINES

WHEN an end mill is driven directly by inserting it in the spindle of a milling machine of the horizontal type, it is difficult to mill some surfaces, 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.

Construction of a Vertical Milling Machine. — A vertical-spindle milling machine is shown in Fig. 1. 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. 1 is driven by a belt pulley *P*, which transmits power through gears and shafts to

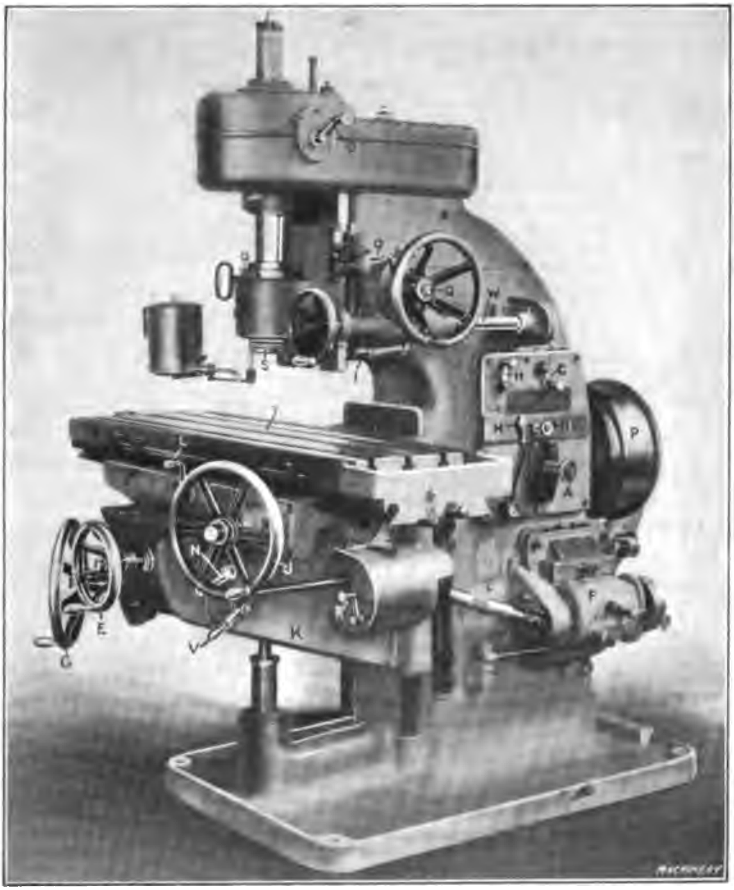


Fig. 1. Brown & Sharpe Vertical-spindle Milling Machine

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 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 handwheel at the front gives a slow feeding movement.

Example of Vertical Milling. — The vertical milling machine illustrated in Fig. 1 is shown at work in Fig. 2. 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 held by 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

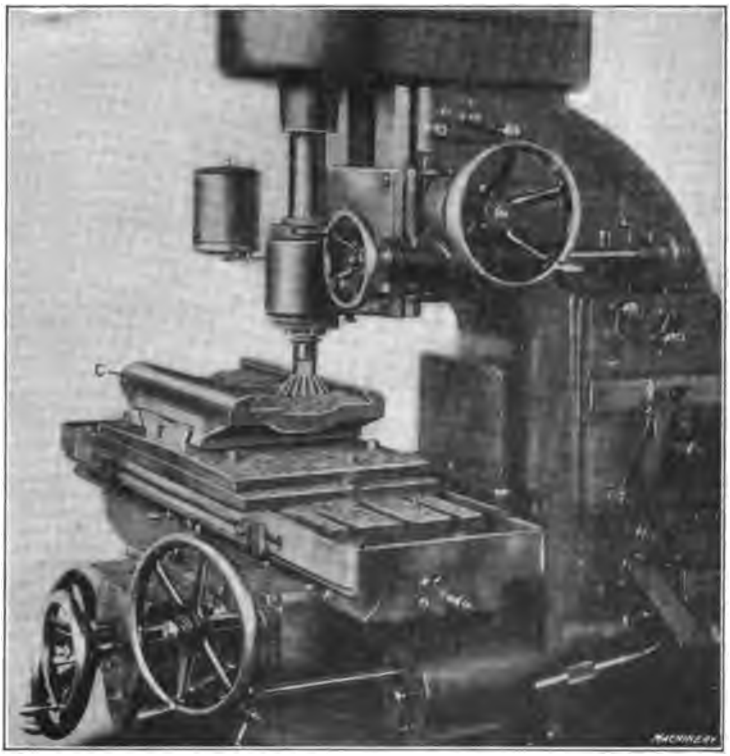


Fig. 2. Example of Milling on Vertical Milling Machine

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 inserted afterward. 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.

Use of Circular Milling Attachment on Vertical Machine. — 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. 3. The table of the

Fig. 3. Milling a Circular T-slot on a Vertical Machine

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.

Milling a Circular T-slot. — The operation illustrated in Fig. 3 is that of milling 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 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 table of the circular milling attachment. 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. 4 shows how a vertical machine is used for milling the bearing brasses of an engine connecting-rod. These brasses are cast with 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.

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,

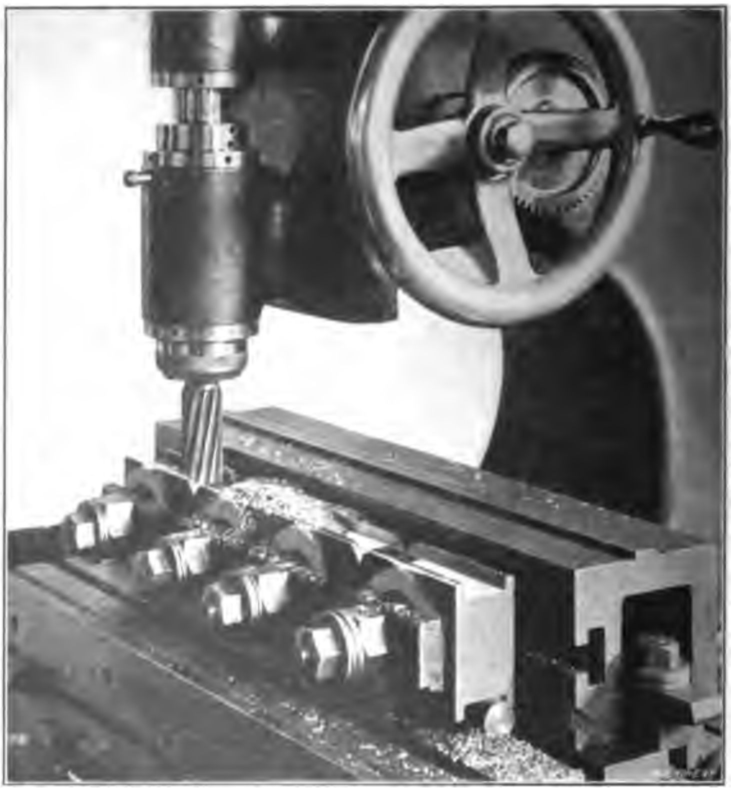


Fig. 4. Milling Connecting-rod Bearing Brasses on Becker Vertical Machine

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 same position. The vertical milling machine used for this operation is not the same as the one previously illustrated, although its construction is 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 alter-

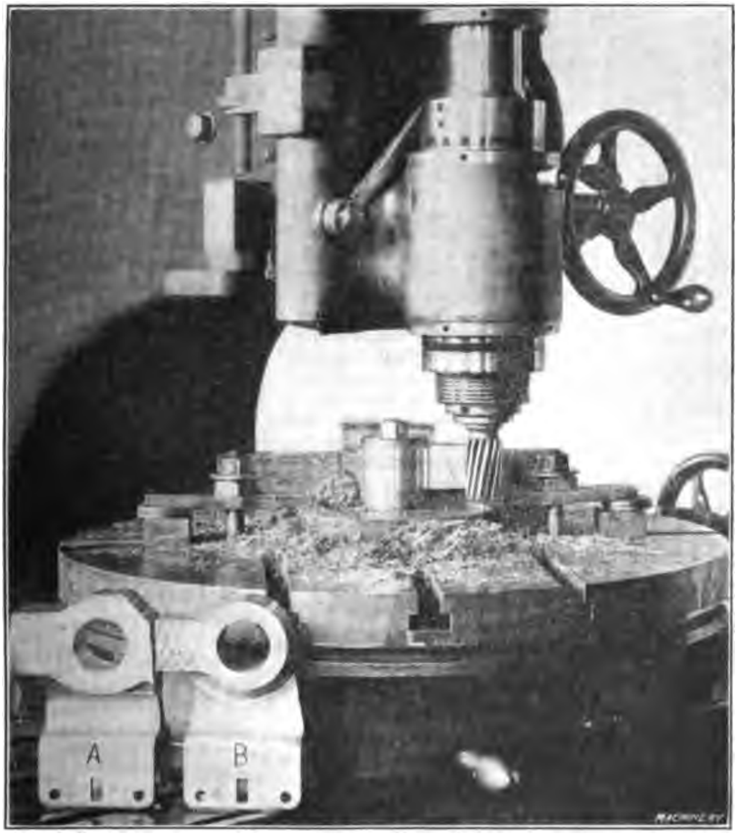


Fig. 5. Milling the Edge of a Steel Forging

nately, as may be required. Of course, if an irregular outline is to be followed, the machine is fed by hand. At *A*, Fig. 5, 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-

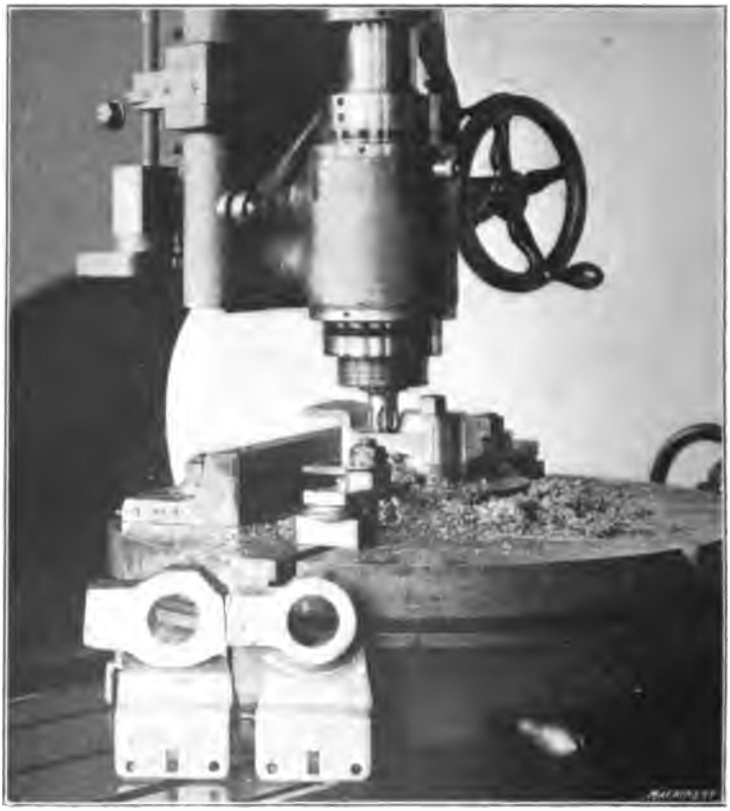


Fig. 6. Finishing a Circular Fillet with a Rose Milling Cutter

fluted end 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. 6) 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 any rough, uneven spots left by the milling cutter, although it is not likely that much handwork will be necessary. 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 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 may be 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 circular slots, straight or curved edges or surfaces of irregular shape, it is also very efficient for finishing plane, 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, a face cutter is used, as shown in Fig. 7. The 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 illustrated in Fig. 2, Chapter III, 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

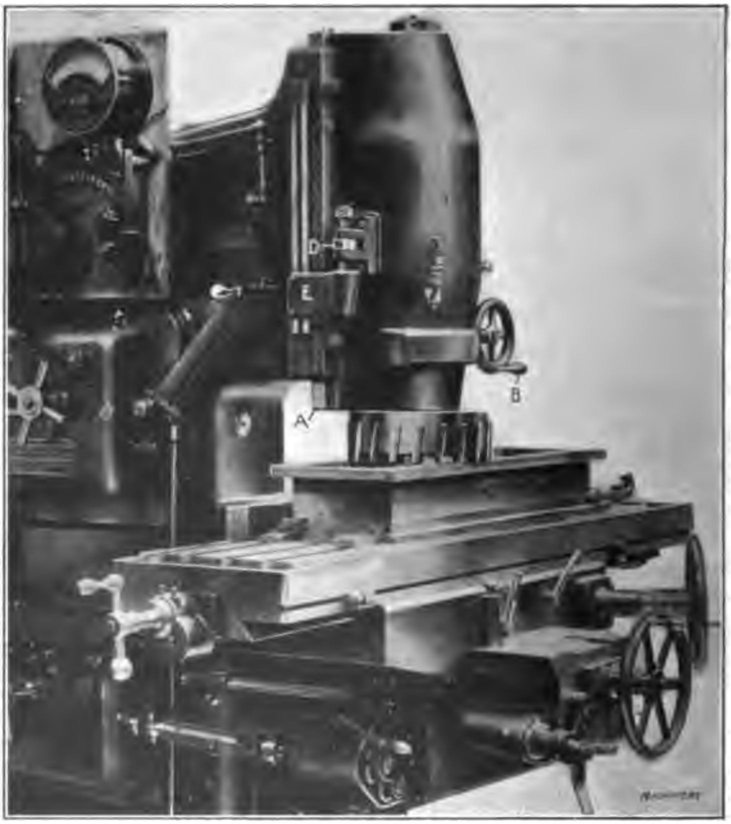


Fig. 7. Finishing Top Surface of a Casting on a Cincinnati Vertical Machine

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.

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.

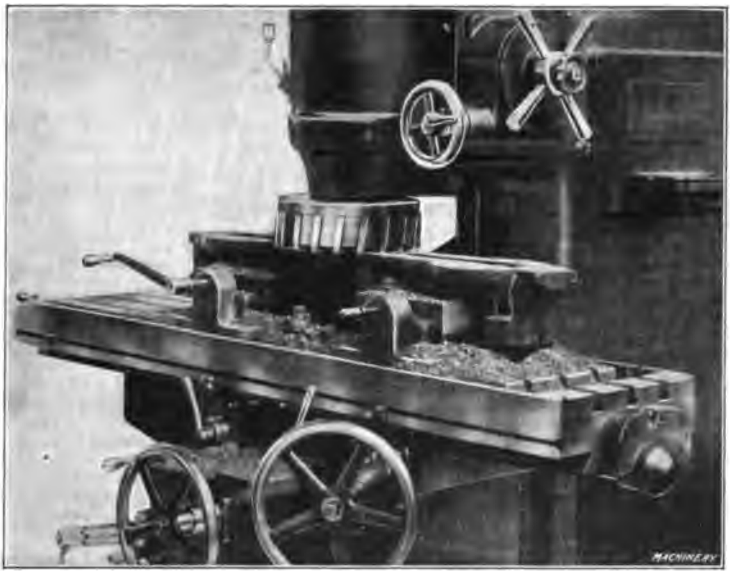


Fig. 8. Machine Equipped with Two Work-holding Fixtures so that One Casting can be Chucked while the Other is being Milled

The example of vertical face milling shown in Fig. 8 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 $\frac{3}{16}$ inch deep, with the table feeding $7\frac{3}{4}$ 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 which is very light. Meanwhile, another casting is placed in the other fixture, and when the cutter reaches it, the feed is reduced to $7\frac{3}{4}$ 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

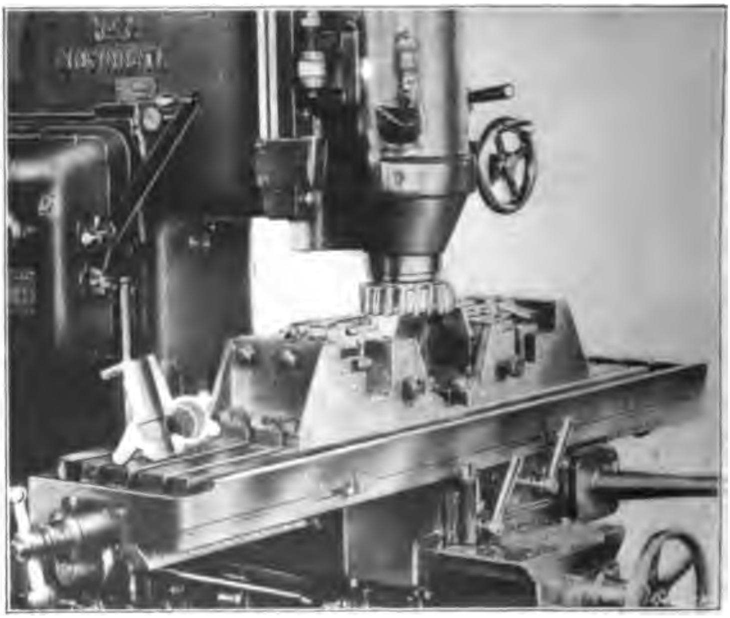


Fig. 9. Another Milling Operation Employing Two Fixtures

vises and have special jaws with angular faces which hold a casting firmly against the base of the vise.

Fig. 9 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 $\frac{1}{16}$ to $\frac{3}{32}$ inch metal is removed, and the table feeds $12\frac{1}{2}$ inches per minute.

Continuous Circular Milling. — Castings or forgings which are so shaped as to be readily clamped or released from a fixture, are sometimes milled by a continuous circular milling operation.

Fig. 10. Continuous Circular Milling Operation

This may be done by the use of a circular attachment or on a special machine equipped with a circular revolving table. The parts to be milled are held in a fixture near the edge of the table and as the latter revolves, one piece after another passes beneath the revolving cutter and is milled or faced.

An example of continuous circular milling is shown in Fig. 10. The operation is that of milling the top surfaces of steel pole-pieces. These pole-pieces are held in a fixture having a capacity for twelve forgings. The table is rotated by power and is set in such a position that the row of forgings will pass beneath the rear side of the cutter which then faces the top surfaces. As the finished parts come around to the front of the machine, they are removed by the operator and replaced by rough forgings without stopping the machine, so that the milling operation is practically continuous.

A fixture for continuous circular milling must be designed so that the work can be removed quickly and without stopping the rotation of the table. In this instance, the forgings are located in the fixture by pins and they are held by the pivoted clamps shown. The inner surfaces of these clamps have fine teeth and are eccentric to the pivot about which the clamps swivel, so that the forging is either released or gripped simply by turning the clamp in one direction or the other.

The face cutter used for this operation has high-speed steel inserted blades and takes an average depth of cut of about $\frac{1}{8}$ inch. While the milling cutter is at work, a stream of cooling lubricant flows onto it from the jointed pipe seen to the left of the spindle. In order to catch the lubricant as it falls from the table, the latter is surrounded by a flanged pan.

Die-sinking Machine. — The die-sinking machine, shown in Fig. 11, is a type of vertical-spindle milling machine especially designed for the use of diemakers in milling out the impressions in drop forging dies, etc., or for finishing recesses of circular or irregular shape. The part to be milled is held in a vise on the machine table which has lateral, longitudinal, vertical and rotary feeding movements effected by the handwheels shown. As die impressions are usually very irregular in form, the feeding movements of the work-table are controlled entirely by hand, because, for most work, the cutter must be made to follow a line the direction of which changes constantly so that an automatic feed would be useless. The handwheel at the front is for the lateral movement, the one at the left side is for the longitudinal movement, and the small wheel placed at an angle is for rotating the table. The large pilot wheel at the side of the knee is for feeding the table vertically.

The cutters used for die-sinking are made in a great variety of shapes for finishing impressions of different forms and they are ordinarily held in a collet or spring chuck which is inserted in the spindle. When milling out a die impression, the diemaker is guided by lines previously laid out on the face of the die block and also by a graduated index on the pilot wheel. The lines

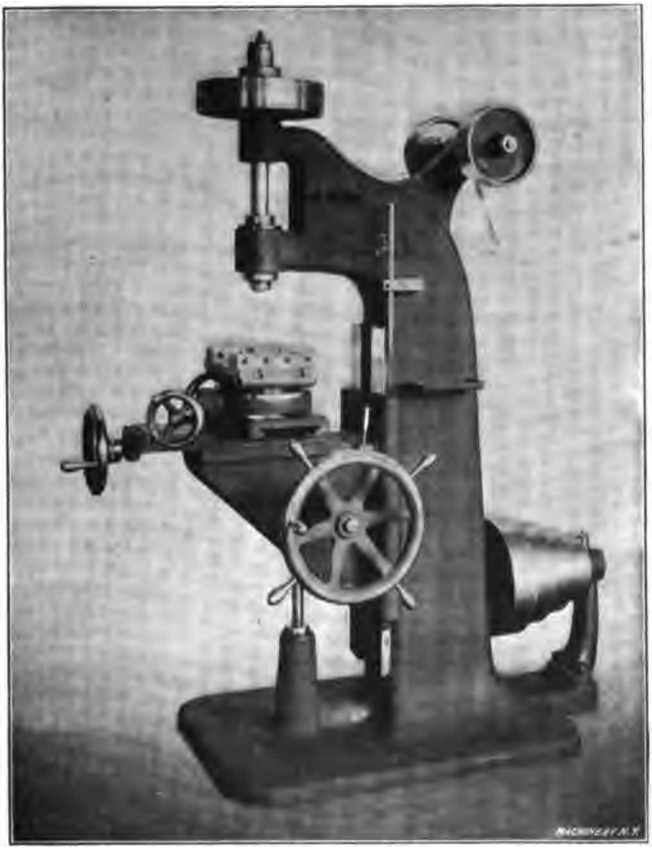


Fig. 11. Pratt & Whitney Die-sinking Machine

show the outline and the index is used for milling to the required depth at various parts of the impression. Circular parts of the die, especially if quite large, are often bored out in a lathe prior to milling, whereas small circular impressions are either cut out by using formed cutters of the required size or by means of the circular attachment which is set concentric with the spindle.

The impression in a die is milled as close to size as possible but in order to finish it, considerable hand work is usually necessary, especially when there are many corners and irregular places. The vertical stop-rod seen attached to the side of the column is used for re-setting the knee to the same vertical position after it has been lowered for inspecting or gaging the die being milled.

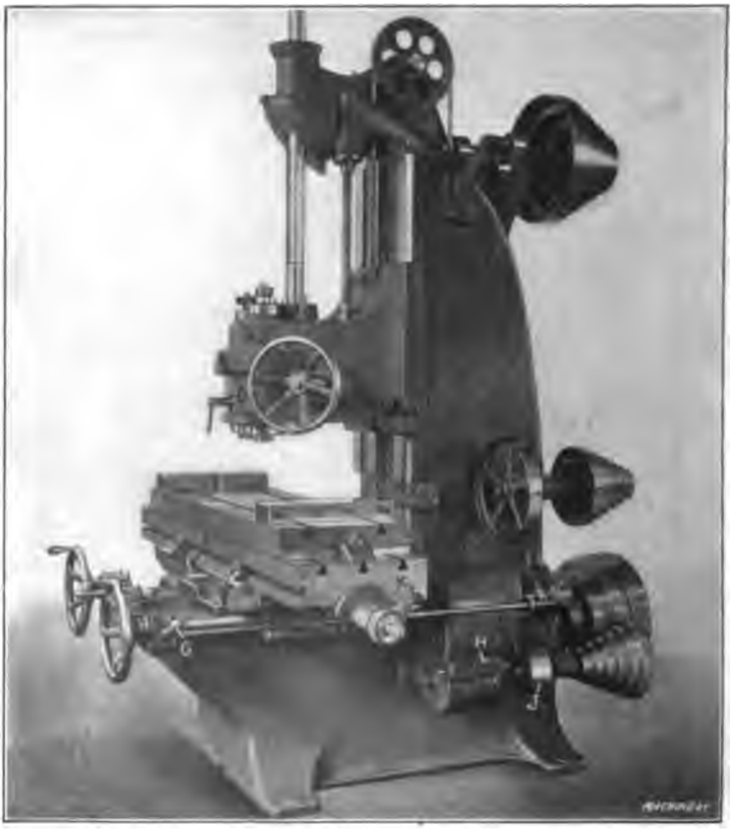


Fig. 12. Pratt & Whitney Two-spindle Die-sinking Machine

Two-spindle Die-sinking Machine. — Some die-sinking machines which are intended for milling large dies are designed so that the cutter spindle moves vertically instead of the work-table, this construction being adopted to avoid elevating the table and the heavy dies which are generally milled on the larger machines. A die-sinking machine of this type, built by the

Pratt & Whitney Co., is illustrated in Fig. 12. This machine is equipped with two cutter spindles, one of which is considerably larger than the other. The reason for this arrangement is that on large die work, it is frequently necessary to take finishing cuts with cutters of small diameter, thus requiring a high spindle speed. Therefore, a large spindle is provided to take the heavy cuts and a smaller one for the lighter cuts at higher speeds. Both spindles are located in the same plane and remain in a fixed position, vertically, in the sliding head.

With the two spindles, speeds varying from 44 to 640 revolutions per minute can be obtained. By means of a four-stepped cone pulley and a two-speed countershaft, each spindle is provided with eight speeds. The larger spindle is driven through spur gearing from the vertical shaft shown, which, in turn, is rotated through bevel gearing. The smaller spindle is driven through gearing from the large spindle, and the drive can readily be engaged or disengaged. Both spindles are provided with "pull-back" rods for holding the cutters securely in place, and they can be locked stationary while tightening the cutter chucks.

The head is counterbalanced and is raised or lowered by handle *A*, which is connected to elevating screw *B* through bevel gears. A micrometer dial enables the adjustment to be accurately measured, and a positive vertical stop *C* is also provided. The table has a hand transverse feed and both hand and power longitudinal feeds. The transverse feed is effected by handwheel *E*, the hand longitudinal feed by handwheel *F*, and the power longitudinal feed is controlled by lever *G*. Micrometer dials enable these adjustments to be accurately gaged. The power feed is operative in either direction, lever *G* being pushed in or pulled out to change the feeding movement. The feed mechanism is contained in the gear-box seen at the right-hand side of the machine. Two gear ratios are obtained by means of sliding gears operated by handle *H*. These gears, in conjunction with the six-stepped feed cone at the rear, give twelve changes of feed.

The travel of the table is controlled by positive stops which are considered superior to ordinary automatic feed trips, owing to the fact that when sinking forging dies, the diemaker works to a line; hence, positive stops are used because it would not be practicable to provide an automatic feed-tripping device which would be sufficiently accurate. The stops are carried on the side of the table, and micrometer screws are provided which makes it possible to obtain very fine adjustments. If the operator should neglect to disengage the feed, the stop comes against an abutment *I* on the saddle, thus stopping the table. A feed friction enclosed at *J* will then slip, thus preventing damage to the machine. This friction is adjusted so as to provide ample feed under ordinary working conditions. Ordinarily, the operator would disengage the feed just before the cutter reached the line on the work, and then bring the table up to the micrometer stop by hand. By releasing the lock-bolt *K* and rotating the feed-screw with a crank, a rapid movement of the table is effected. The vise seen on the table of the machine is pivoted at the center so that it can be swung to an angle of 15 degrees in either direction from the central position. The cherrying attachment for this machine is clamped to the under-side of the head and is driven from the large spindle. The spindle of the cherrying attachment can be located in four different positions.

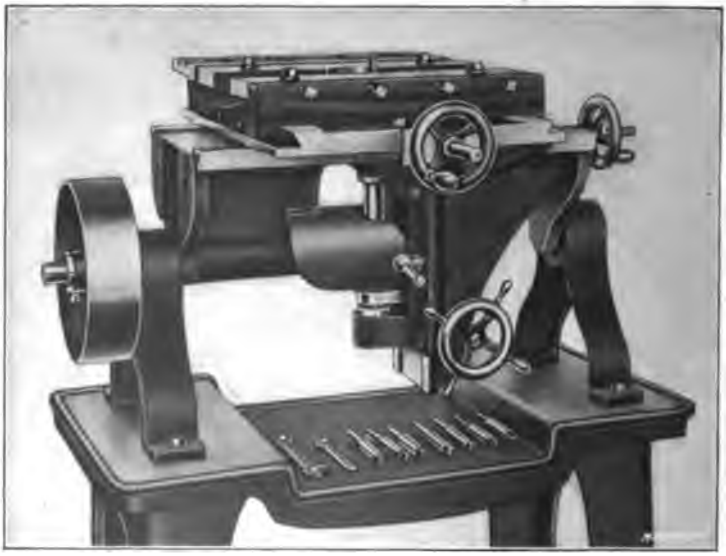


Fig. 13. Thurston Die Milling Machine

Under-cutting Die Milling Machine. — This is a type of die milling machine having a cutter which is driven from beneath the work-table, and extends up into the die opening instead of being held by a spindle from above, in the usual manner. One advantage of this construction is that lines on the die face showing the outline or contour of the die opening are not obstructed by the cutter or spindle. One design of under-cut die milling machine is shown in Fig. 13. This machine is intended for milling various forms of blanking dies, trimming dies, etc. The die to be milled is held on a table which is carried by cross and longitudinal slides. The cutter spindle projects upward through the die opening, and by manipulating the handles which operate the two slides, the work is fed against the milling cutter in the required direction. The vertical spindle is adjustable, and the cutter projects through an opening in the chuck in which the die is clamped. The cutter may either be straight, or tapered to suit the amount of clearance required in the die.

When milling out a die opening, it is necessary to drill a hole through the die to form a starting place for the cutter. The latter is then fed around the outline of the die opening, as previously mentioned, and the entire center is removed in the form of a solid block. The raising and lowering of the cutter-slide is effected by means of the lower handle seen at the front of the machine. The upper handle at the front and the one at the right end of the machine control the cross and longitudinal movements, respectively. There is a pointer on the machine which remains in a fixed position with reference to the cutter, so that when the latter is operating below the surface of the die, the pointer indicates its exact position. The entire frame of the machine is mounted on trunnions so that the work can be inclined to any desired position, in order to give the operator the best possible light on the surface of the die.

Combined Horizontal and Vertical Machine. — The milling machine, a detailed view of which is shown in Fig. 14, has both vertical and horizontal spindles which form an integral part of the machine. These spindles may be run independently or in unison, so that the machine is adapted for either vertical or horizontal milling and on some classes of work both spindles can be used at the same time. The illustration shows how twenty-six cast links are milled. The vertical spindle machines fourteen links on the flat side, whereas the horizontal spindle mills twelve links on the narrow edge, both the vertical and horizontal spindles operating simultaneously. Two 16-inch face milling cutters are used and the depth of cut for each cutter varies from $\frac{1}{8}$ to $\frac{3}{16}$ inch. As will be seen, the links are held in special fixtures in double rows.

This machine is of the column-and-knee type, the work-table being carried by a knee which may be adjusted vertically on the

Fig. 14. Ingersoll Combined Horizontal and Vertical Milling Machine — Both Spindles in Operation

column. The table has automatic longitudinal, transverse and vertical feeding movements, all of which are reversible. The rate of table feed as well as the spindle speed can be varied within wide limits by means of change gears which are shifted by control levers at the side of the machine. The machine is driven either by motor or a single constant-speed belt pulley at the rear which transmits motion to each spindle by shafts and connecting gearing.

Profiling Machines. — A profiling machine or "profiler" is a type of vertical milling machine which is largely used for making parts of guns, pistols, typewriters, sewing machines and for similar work. Profiling machines are adapted to milling duplicate pieces having an irregular shape or contour, especially in connection with interchangeable manufacture. The distinguishing feature of this type of machine is that the spindle and milling cutter, instead of revolving in a fixed position, are guided by a special former plate, the outline of which exactly corresponds to the shape required on the work.

Most of the profilers used at the present time are hand-operated, so far as the feeding movements are concerned, although

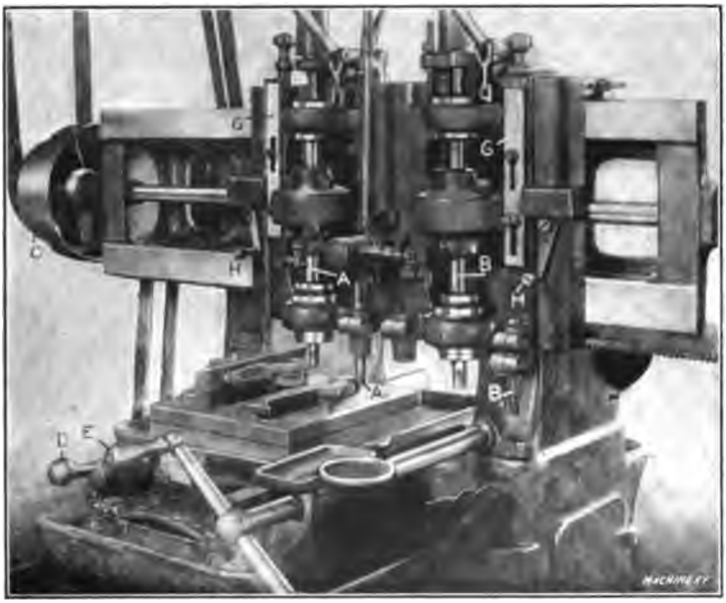


Fig. 15. Pratt & Whitney Profiling Machine Milling Rifle Trigger Guard

machines which are semi-automatic or entirely automatic after the work is placed in position are employed in some shops. Hand-operated machines have either one or two cutter spindles and each spindle has a former pin which is located a fixed distance from the cutter and is guided around the former plate by feeding the cutter-slide and pin laterally and the work-table in a longitudinal direction. By this method duplicate parts of irregular shape can be produced.

A double-spindle type of profiler is shown in Fig. 15. The two cutter spindles *A* and *B* are carried by a saddle that is mounted on a cross-rail, as shown. One spindle is used for taking roughing cuts and the other for finishing cuts. The saddle is traversed along the cross-rail by handle *E* for locating either spindle in the working position, whereas handle *D* is used for moving the table along the ways of the bed at right angles to the cross-rail. Each spindle is carried by a vertical slide and is lowered to the working position by a hand lever at the top. The spindles can be set in the required vertical position each time a new part is profiled by means of plungers or stop-rods operated by handles *H*. These plungers slide out and engage notches in the strips *G* which are attached to the spindle slide and are adjusted in accordance with the position required for the cutter. When one cut has been taken, the locating plunger for that spindle is withdrawn; the spindle is then quickly forced upward by a spring, far enough for the cutter to clear the work so that the other spindle can be moved over to the working position without delay.

As the cutters used for profile milling are usually quite small, they revolve rapidly. The spindles of the machine illustrated are driven through spiral gearing from a horizontal shaft to which cone pulley *C* is attached. The spindles of some profilers are driven directly by belts, especially when exceptionally high speeds are necessary, and also by universally-jointed vertical shafts which transmit motion from an overhead countershaft to the machine.

Example of Profile Milling. — The profiling machine illustrated in Fig. 15 is arranged for milling the outside of a rifle trigger guard. When the machine is in operation, one of the former pins A_1 or B_1 (depending upon which cutter is being used) is brought into contact with the former plate or model *F* attached to the work-table. The pin which is clamped to the cutter spindle slide and moves with it is then made to follow the outline of the former plate by manipulating the lateral and longitudinal feeds, handles *D* and *E* being used for this purpose. In this way, the cutter is made to follow a path which corresponds to the shape of the former plate, thus reproducing this form on the work. Roughing and finishing cuts are taken by bringing first the roughing cutter spindle and then the one carrying the finishing cutter into contact with the former, each spindle being set in the correct vertical position by the stop-rods operated by handles *H*.

The edge of the former plate is beveled or tapered and the pin has a corresponding taper, so that the cutter can be adjusted laterally, within certain limits, by simply adjusting the former pin vertically. For instance, if when setting up the machine it is desired to move the cutter a little toward the work for taking

Fig. 16. Profiling Inside of Finger Lever for a Repeating Rifle

a deeper cut, this can be done by raising the pin slightly; a smaller part of the taper will then come into contact with the beveled edge of the former plate so that the relation between the work and cutter is changed.

The operation of a profiler is comparatively simple after it is properly set and adjusted, but many of the work-holding fixtures and former plates required for certain classes of work are ingenious and interesting. The following examples of profiling will illustrate, in a general way, the nature and variety of work which is done on machines of this type. These examples are operations on rifle and pistol parts and represent the practice at the Savage Arms Co. Owing to the irregular shapes of many rifle and pistol parts, a great many profiling operations are necessary in connection with their manufacture.

Profiling Inside of Finger Lever. — The method of profiling the inside opening of the finger lever of a repeating rifle is illustrated in Fig. 16. A concave cutter is used to form a convex surface on the work. The lever is held in the fixture by clamps *A* which are forced downward by the eccentric clamps *B* and it is located by the two rods *C* and pin *D*. The latter enters the

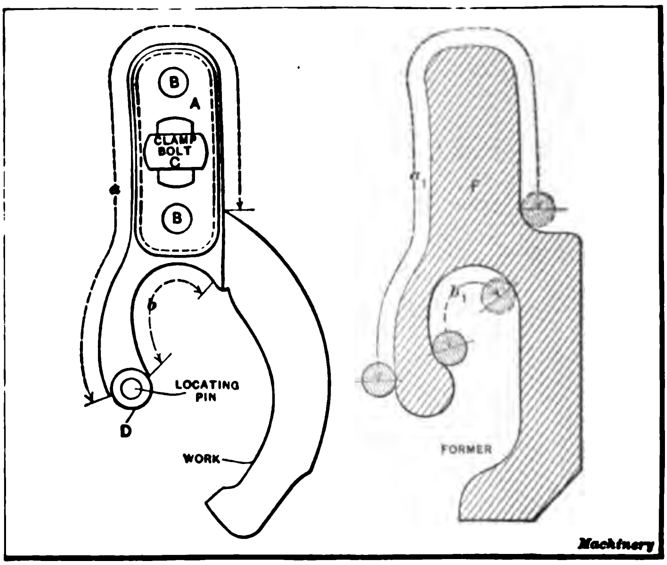


Fig. 17. Diagram showing Method of Profiling Outside of Rifle Finger Lever

pivot hole of the lever, and rods *C* extend beneath the left clamp *A* and bear against the left side of the lever. The opposite side, which has been rough-milled by a previous operation, is held firmly into contact with the fixture by rods *C* which are forced inward by an eccentric lever *E* that bears against a yoke connecting the two rods.

The former *F*, which is engaged by guide-pin *G* and controls the movement of the cutter, has a plain rectangular opening which, of course, conforms to the shape of the hole to be milled in the finger lever. When the profiling operation is completed, clamps

A are withdrawn by means of handles *H* so that the lever can be lifted off of locating pin *D*. As will be seen, the former can be adjusted laterally if for any reason this should be necessary.

Profiling Outside of Finger Lever. — After the inside of the finger lever is milled, as described in the preceding paragraph, the outside surfaces are finished as indicated by the diagram, Fig. 17. As the finger hole end of the finished lever is quite narrow, it is necessary to have the lever accurately located laterally so that one side will not be thicker than the other. The lever is located in the fixture by the inside of the finger hole and the pivot pin hole. Block *A* accurately fits the finger hole and

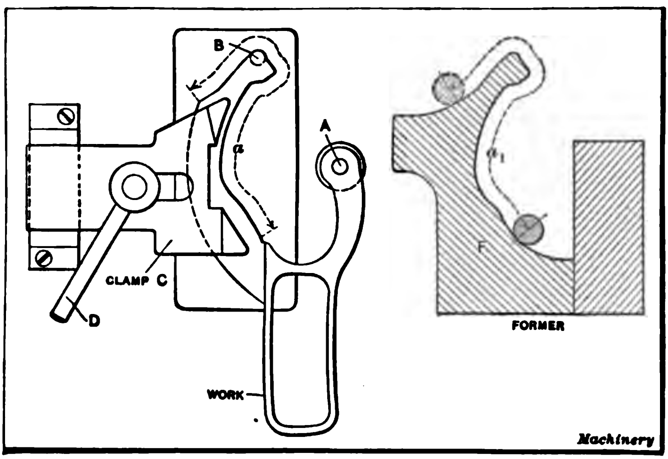


Fig. 18. Another Profiling Operation on Outside of Finger Lever

is located by pins *B* inserted in the base of the fixture. This block has a projecting flange at the top, which is forced down onto the lever by bolt *C*, thus clamping the lever firmly in place. The location and length of the profiling cut are indicated by the arrows *a* and *b* and the surfaces of the former *F* which are followed by the guide-pin are shown by the arrows a_1 and b_1. After a lever is profiled, it is removed from the fixture by loosening bolt *C* and turning it until its flat sides are aligned with the slot in block *A*; the latter is then lifted off of the locating pins. As the end *D* is cylindrical and has small shoulders, it is milled by a formed cutter in a Lincoln type milling machine.

Still another profiling operation on the outside of the finger lever is shown by the diagram, Fig. 18. One continuous cut is taken as indicated by arrow *a* to form the edges of that end of the lever which enters the rifle receiver and connects with the breech-bolt. The surfaces at the extreme end must be accurately machined as this end enters between the breech-bolt and a lug on the receiver (when the action is closed) to form a solid support for the bolt.

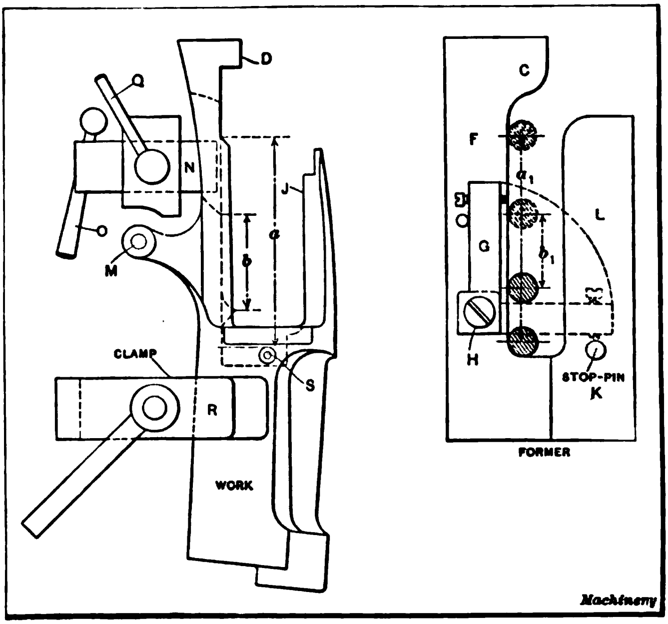


Fig. 19. Plan View of Fixture and Former used for Profiling Operation on Rifle Receiver

The lever is located by pin *A* which enters the pivot pin hole, and also by a small boss or pin at *B* which is solid with the lever and enters a hole in the base of the fixture. (This pin engages a cam slot in the breech-plug when the rifle is assembled.) The lever is held by a clamp *C* which is forced downward by a screw and lever *D*. The circular edge of the lever which is beneath this clamp is machined in a separate operation by a formed cutter, a Lincoln type machine being used. The former *F* is a plain type, shaped to correspond with the surface to be milled, and the path of the guide-pin is shown by the arrow a_1. To remove the finished work, clamp C is withdrawn after being loosened, so that the lever can be lifted off the locating pin.

Profiling Operations on Rifle Receiver. — The profiling operation illustrated by the diagram, Fig. 19, is on the receiver of a rifle, which is that part between the barrel and stock that contains the action. Two separate cuts are taken by different cutters held in the two spindles of the profiler. One cut a forms a guide way for the breech-bolt when the action is being opened or closed, and the other cut b extends from the lever support

Fig. 20. Profiling Cartridge Guide Slot in Rifle Receiver

back to the trigger slot. When taking the longer cut a, a cutter is used that will mill a slot of the required width, and the path of the guide-pin along the former F is shown by the arrow a_1. The projecting part C of the former is simply a guard to prevent the cutter from striking end D of the receiver when it is being removed at the completion of the cut. Plate L also forms a guard and prevents the cutter from striking the tang J.

Before taking the shorter cut b, the plate G is swung across the former slot (as indicated by the dotted lines) and acts as a stop for the guide-pin so that the cut will be started at the correct point. This plate swivels on screw H and rests against a pin K. A small screw in the end of plate G provides an accurate adjustment in case it should be necessary to vary the point at which the cut begins. The curve at the beginning of cut b is equal to the radius of the cutter used.

The receiver is located for this operation by a pin in the base of the fixture at S which enters the sear pin hole, and also by a pin at M which enters the lever pivot hole. The work is further supported and located by a plunger N which is pushed into the trigger slot by lever O. The plunger is clamped in position by the lever Q and the receiver is held down against the base of the fixture by clamp R.

Fig. 20 shows how the cartridge guide slot is milled in the receiver. This is a narrow, straight slot about $\frac{3}{32}$ inch wide and $2\frac{1}{4}$ inches long, on the right side of the receiver, which holds the cartridge guide. (This cartridge guide, in conjunction with the magazine carrier and ejector holds the cartridge in the proper position.) The receiver is located by the left side and the upper surface. A clamp screw operated by handle A forces the receiver against the vertical wall of the fixture and it is held upward against locating lug B by a bar C on the under side which is raised by cam-lever D. As the slot is straight, the former F simply has a straight, rectangular opening. The cutter is located in the correct vertical position by bar G which engages a notch in slide J and is operated by lever H.

The method of milling the mortise or slot which forms a seat for the cartridge ejector is illustrated in Fig. 21. This slot is slightly tapering and is at an angle with the side of the receiver; hence, the latter is held at an angle in the fixture as the illustration shows. The former F has a plain, tapering slot which gives the required shape. Before this seat is profiled, clearance holes are drilled at each end of the slot for the profiling cutter. Roughing and finishing cutters are used. The illustration shows the finishing cutter in position, the roughing cutter having been moved to the left. The cutter is set for depth by the engagement of plunger G with slide J as previously explained. When plunger G is withdrawn by handle H, the slide is forced upward by a spring, far enough to clear the fixture so that it can quickly be moved away from the working position when the cut is completed.

Profiling with Combination Former. — A very interesting and unusual profiling operation is shown by the diagram, Fig. 22. The work is the action slide for a rifle. The operation consists in taking first a shallow cut as indicated by the shaded area at *A*, and then a second cut as indicated at *B*. These surfaces must be accurately machined both as to location and depth. A combination type of former is used and when taking the first cut *A*, plate *F* on the former is in the working position. This plate

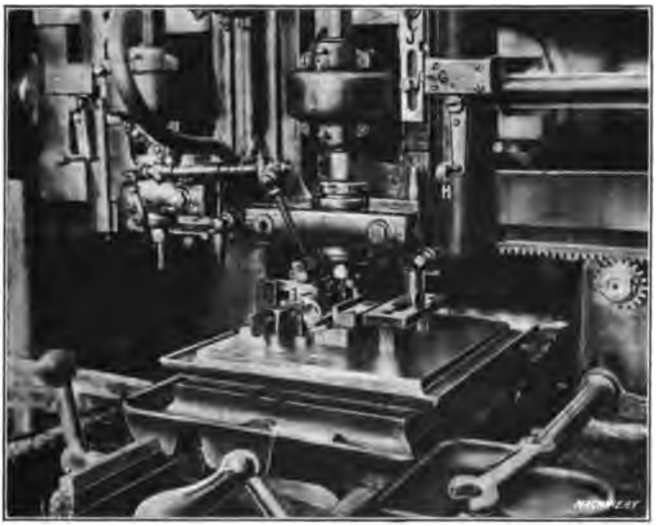


Fig. 21. Profiling Slot in Receiver for Cartridge Ejector

swivels about screw *G* and is located by a pin *H* which is inserted through the plate and into the former base. The path of the guide-pin is indicated by the arrow *a*.

When the first cut is completed, plate *F* is swung back out of the way, and plate F_1 is placed in the working position, as indicated by the dotted lines. The same pin *H* is also used for locating this plate. The second cut *B* is now taken, the guide-pin following path *b*. The hook-shaped end *J* on the former prevents the cut from running out at *K*. There is a long guard plate near the right-hand side of the former (not shown in the illustration), which prevents the operator from moving the cutter over into contact with the left side of the former base. By having guards of this kind, the operator can shift the cutter-slide rapidly and without fear of feeding the cutter against some part of the work or fixture. The slide is located in the fixture by pin *L* at the end and the three half-pins along the right-hand edge, and it is held by a single clamp which is cut away and beveled to clear the cutter.

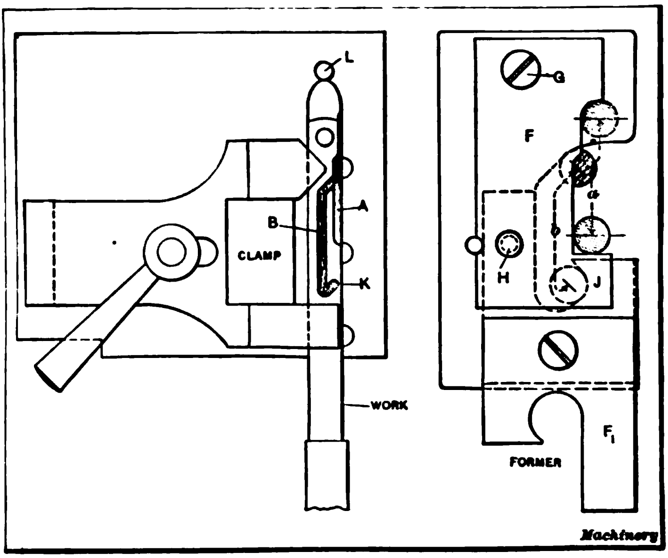


Fig. 22. Diagram showing Combination Former used for Profiling as Indicated by Shaded Areas A and B

Profiling Bolt of Automatic Pistol. — An interesting profiling fixture and former is shown by the plan view, Fig. 23. The operation is on the bolt of an automatic pistol and consists of beveling the corners *M* of the opening and cutting a round groove, as shown by the shaded area *N*. The bolt is held between the plug *A* and the end *B* of the fixture, and it rests on block *C* which has a circular seat. End *B* is counterbored to receive the end of the bolt, and plug *A* has a pilot or small projecting end which enters the bore of the bolt. Lever *D* attached to plug *A* passes through a cam slot (similar in form to a bayonet lock) and is used to force the bolt back into the counterbored seat in block *B*. The opening or channel which is to be beveled is located in a central position by a close-fitting finger *E* which is turned down into the opening by lever *G*.

A double former plate is used for this operation. When beveling edges *M*, plate *F* is in the working position as shown by the full lines. This plate swivels about screw pin *H* and is located by pin *J* which passes through it. When the edges have been beveled by the tapering cutter used for this operation, the other

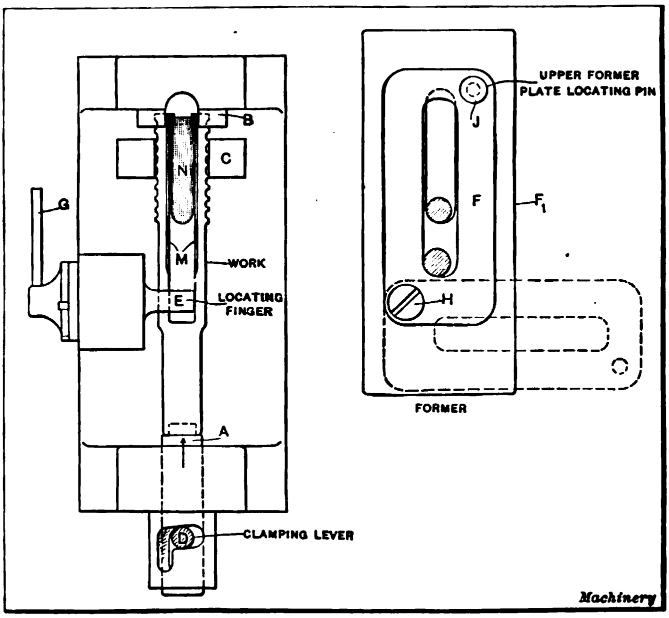


Fig. 23. Plan View of Profiling Fixture and Former for Bolt of Automatic Pistol

spindle carrying a cutter of different shape is moved over to the working position and plate *F* is swung back as indicated by the dotted lines. The lower slot in the main former F_1 is then used for profiling the seat *N* at the bottom of the bolt.

Profiling Dovetail Seat in Pistol Frame. — The vulcanized rubber side plates for the handle of a Savage automatic pistol are inserted into close-fitting dovetail seats. The plan view, Fig. 24, illustrates how the seat on the right-hand side of a frame is milled on the profiler. The frame is located by the angular strip A and the boss B on the side of the frame, which enters a circular seat in the projecting lug shown. The frame is clamped against the bottom of the fixture by two hook clamps C and C_1. These clamps enter the magazine opening and the lower ends are attached to a connecting bar that is forced downward by a cam lever D. To insure contact between the frame and the end strip A, bolt C and the work is forced against A (as indicated by the arrow) by tightening clamp E.

The path followed by the cutter is shown by arrow a and the movement of the guide-pin along the former F is indicated by

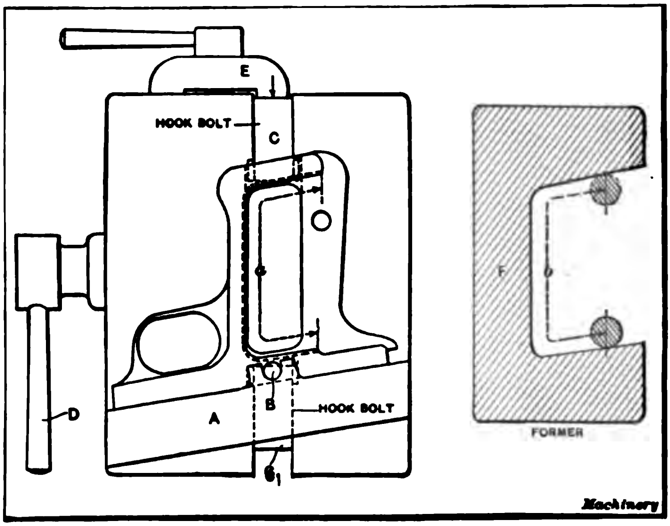


Fig. 24. Fixture and Former for Profiling Dovetail Seat in Side of Pistol Frame

arrow b. Roughing and finishing cuts are taken. The cutters are small and revolve very rapidly. The actual time required for taking one of these dovetail cuts is only about five seconds. The former F is open on the right-hand side so the guide-pin can enter while the cutter is in the working position.

The fixture used for milling the dovetail seat on the opposite side of the frame is similar to the one just described, except that the method of locating the work is different because the circular locating bosses are on the lower side and enter holes in the base of the fixture; consequently locating strip A and the auxiliary clamp *E* are not required. (These bosses are used to locate the frame for practically all operations, thus insuring accuracy as to the relation between the different surfaces. After the frame is finished the bosses are removed.) The frame is clamped downward against the fixture by hook bolts at each end the same as in the other fixture.

Profiling Outside of Pistol Frame. — The former and fixture used for milling the outside of an automatic pistol frame is shown by the plan view, Fig. 25. The cut extends down the handle on one side as indicated by arrow *a* and is then continued on the opposite side and around the trigger guard as shown by arrow *b*.

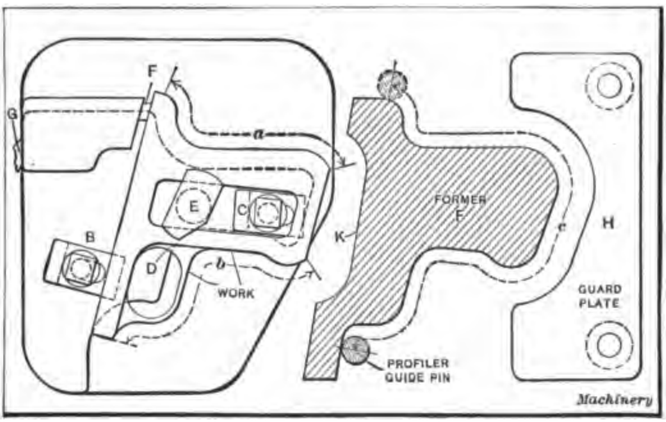


Fig. 25. Fixture and Former for Profiling Outside of Automatic Pistol Frame

(The side of the trigger guard and surface *D* is finished by a separate profiling operation.) The frame is located by circular bosses on the lower side which engage holes in the fixture base, and it is held by clamps *B* and *C*, the T-head bolt *E* and the plunger *F* which is pushed in between the top sides of the frame by lever *G*.

The cutter is concave for producing round edges, and roughing and finishing cuts are taken. The former *F* has a guard plate *H* on the right-hand side. When cut *a* is completed and the guide-pin and cutter are being moved past the end of the handle to the opposite side for taking cut *b*, this guard plate prevents the slide and cutter from being moved far enough to the right to cause the cutter to strike the former along the side *K*. The movement of the guide-pin around the former is indicated by the dotted line *c*.

Indexing Type of Profiling Fixture. — A profiling fixture of the revolving or indexing type is shown in Fig. 26. The operation is that of milling the top and bottom ends of the magazine opening in the pistol frame, to a depth of about $\frac{3}{4}$ inch. The frame is located on the circular faceplate of the fixture by the locating bosses previously referred to, and it is held by a T-head clamp bolt *A* which passes through it and is tightened by the handle *B*.

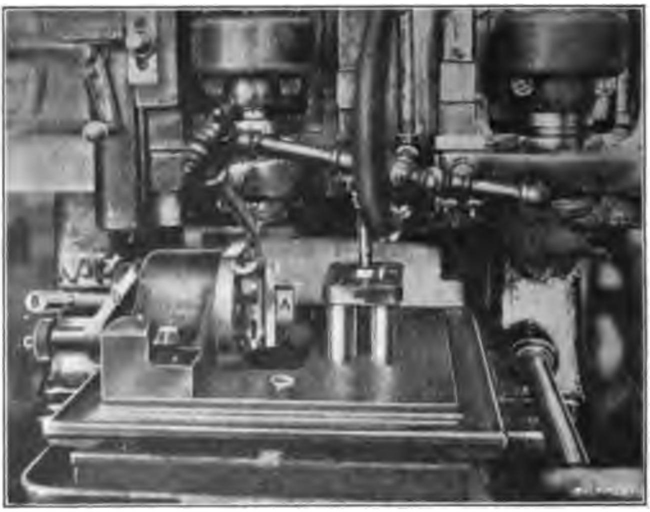


Fig. 26. Indexing Type of Profiling Fixture

When one end of the magazine is milled, plunger *C* is withdrawn and arm *D* with the work is turned a half revolution by swinging arm *D* over to the opposite side of the fixture, where plunger *C* engages another hole, thus locating the frame for the operation on the opposite end of the magazine opening. The profiling operation is simply that of forming a plain rectangular surface, former *F* being used to guide the cutter. The metal between these milled surfaces at the ends is afterwards removed by a shaving operation in the shaper.

Profiling with Indexing Former Plate. — The profiling operation illustrated in Fig. 27 is that of forming the sear trip seat in an automatic pistol frame, and the surfaces above the sear trip seat. The nature of the operation is illustrated by the diagrams *A*, *B* and *C*. The sear trip seat, which is about $\frac{1}{4}$ inch deep, is formed by two separate cuts as shown by the sketches *A* and *B*; the surfaces above this seat, which are represented by the shaded area at *C*, are then milled.

A cutter in one spindle is used for the sear trip seat, and another cutter in the other spindle for milling the top surfaces. The

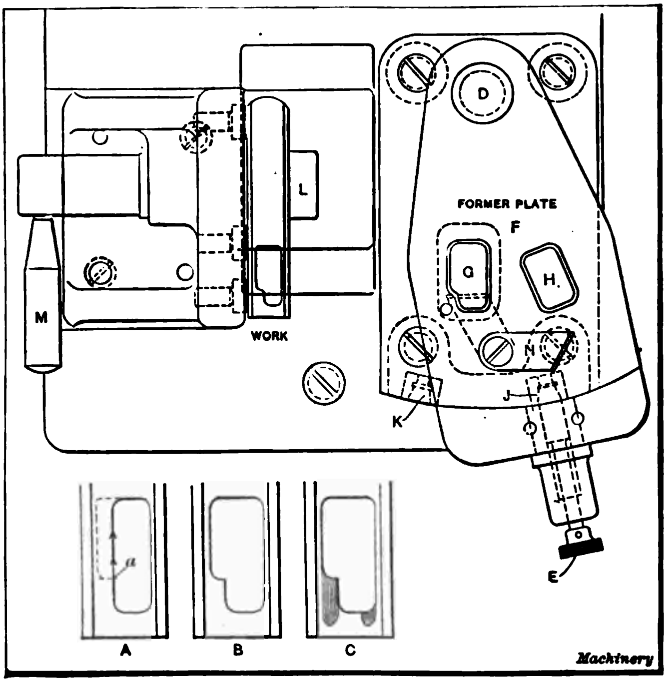


Fig. 27. Profiling Operation requiring an Indexing Former Plate

former plate *F* contains two guide-pin holes *G* and *H*. Hole *G* is used when profiling the seat (as at *A* and *B*) and hole *H* for the other operation, the former plate *F* being indexed to locate either of these holes in the working position. This plate swivels about the screw pin *D* and is located by the spring plunger *E* which enters holes *J* and *K* in the former base.

The frame to be profiled is held against an angle-plate (attached to the base of the fixture) by T-head clamp bolt *L* which passes through the frame and is tightened by lever *M*. Circular locating bosses on the side of the frame engage holes in the angle-plate and locate the frame in the proper position. When milling the seat, the former plate is in the position shown in the illustration; that is, with plunger *E* engaging hole *J*, thus locating the former hole *G* in the working position. The cutter is dropped down to the proper depth by the vertical locating device for the spindle slide. The guide-pin is then traversed around hole *G*, but when the cutter reaches corner *a* (see sketch *A*) the movement is continued along a straight line, as indicated by the arrows, thus forming a rectangular slot as the diagram shows.

The auxiliary plate *N* on the former is then swung across the end of hole *G*, as shown by the dotted lines, thus blanking off this end. The seat is then finished as at *B*. If plate *N* were not used and the guide-pin simply followed the slot in the former, the corner at *a* would be rounding instead of square. The end of the plate *N*, however, causes the guide-pin and cutter to move straight in, thus milling a square corner.

When the sear trip seat is finished, plunger *E* is withdrawn and the plate is indexed to locate hole *H* in the working position, plunger *E* being engaged with hole *K*. A cutter in the opposite spindle, which is located at a higher level, is then used to mill the upper surfaces as indicated by the shaded areas in sketch *C*.

In practically all of the profiling operations described in the foregoing, both roughing and finishing cuts are taken. Some of the roughing cuts are quite heavy, but the light finishing cuts which follow insure accurate and smooth surfaces.

Semi-automatic Profiler. — In armories, etc., where large numbers of irregular-shaped parts must be milled, semi-automatic profiling machines are used to some extent in place of the hand-operated type previously described. The Pratt & Whitney machine is illustrated in Fig. 28. The head in which the cutter spindles are mounted is stationary while the machine is operating, and the required form or contour is obtained by the movement of the table. The latter is carried at the front end of a swinging arm which is journaled in the bed between the uprights.

The table is rotated by means of worm gearing, and the rotary motion is accompanied by an oscillating movement due to cam plate *A* which is held against a stationary roller *B* by weight attached to chain *C*. There are two cutter spindles, either of which can be set in the working position. One spindle is used for roughing cuts and the other for finishing. The spindle to the left is shown in the working position, and the one to the right

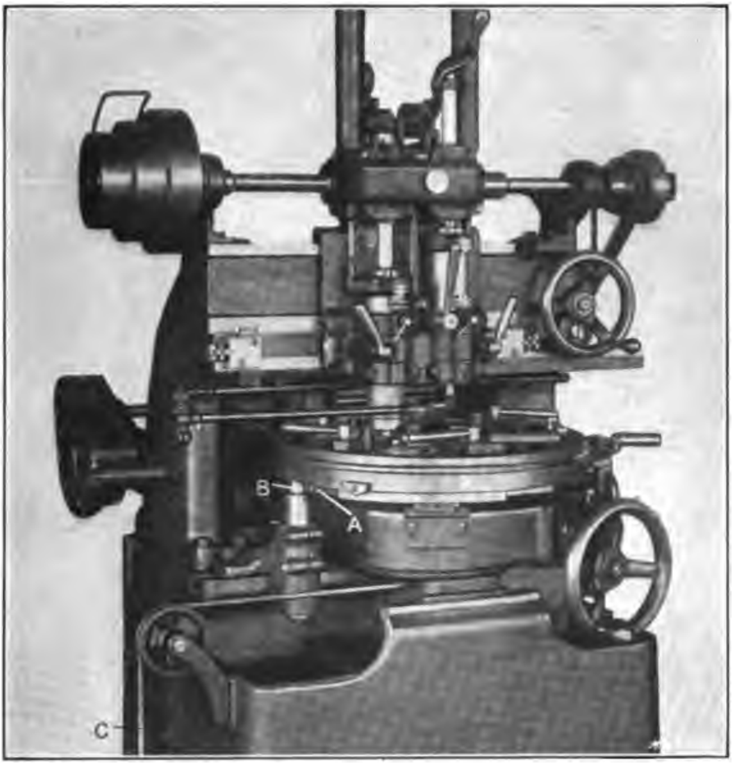


Fig. 28. Pratt & Whitney Semi-automatic Profiling Machine

is raised to clear the fixture and work. The cam or former *A* is made to suit the profile of the parts to be milled. The number of pieces that can be milled at one time depends upon their size and the length of the profile which requires machining. The parts to be milled are held in a special fixture attached to the top of the table, and the cutter passes from one part to the other as the table revolves and is guided by the cam.

Fig. 29 shows a detail view of this machine arranged for milling the steel frames of automatic pistols. The operation illustrated is that of profiling the outside of the grip or handle. (The under side of the barrel, the trigger guard, and the inside of the grip are also milled in this same machine, by the use of a different fixture and cam.) The blanks are located in the correct position by pins, as the illustration shows, and they are held by screw-operated clamps. The rounded edge is formed by the concave

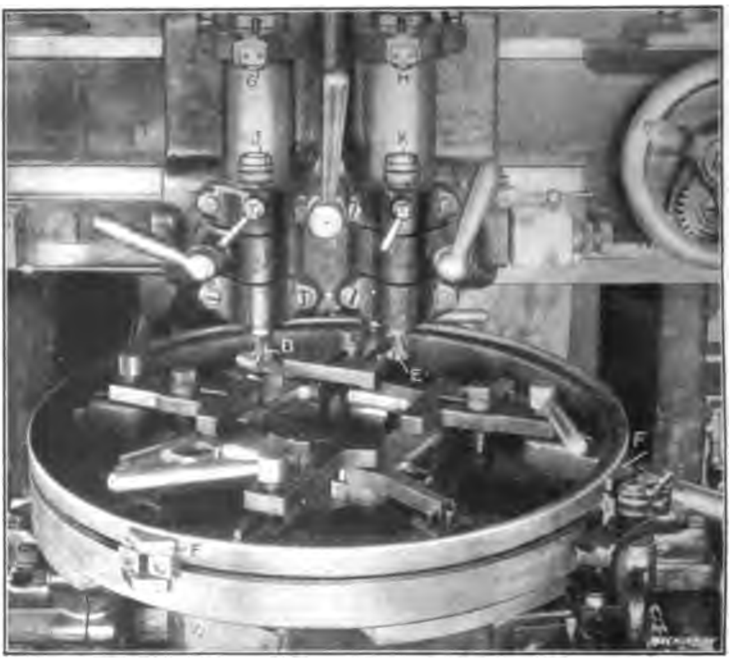


Fig. 29. Semi-automatic Profiling Machine milling Automatic Pistol Frames

cutters *D* and *E*, one being used for roughing and the other for finishing. The roughing and finishing cutter spindles are set in the working positions by means of the stops *G* and *H* and the stop-screws *J* and *K*. The latter are adjustable for aligning the cutter with the work.

When the cutter is traversing the spaces between the work, the table speed is automatically accelerated. This change of speed or feed is controlled by adjustable dogs *F* mounted on the periphery of the table. After the parts are rough-milled by one of the cutters, the other spindle is placed in the operating position for finishing the surfaces. The speed of table rotation or the feed can be varied by means of a change-gear mechanism. The spindle speeds can also be varied to suit the size of the milling cutters and the material being milled.

Milling Master Cam for Semi-automatic Profiler. — When a master cam or former *A*, Fig. 28, is required for profiling a certain part, it is produced as follows: Roller *B*, against which the cam bears when the machine is in operation, is replaced with a milling cutter of the same size. The spindle of the cutter is connected by a belt with the main shaft and a model of the work is located in the fixture. A former pin of the same size as the roller and cutter is then inserted in the cutter spindle and placed in contact with the model. The cam blank attached to the table is then milled as the table feeds around. The cutter is revolved by an independent drive. The former pin in the spindle does not rotate while the cam is being milled. Several cuts are usually required for this operation.

Lincoln Type of Milling Machine. — The milling machine shown in Fig. 30 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, 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 construction 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. A friction clutch is located in this driving pulley and provides means for starting

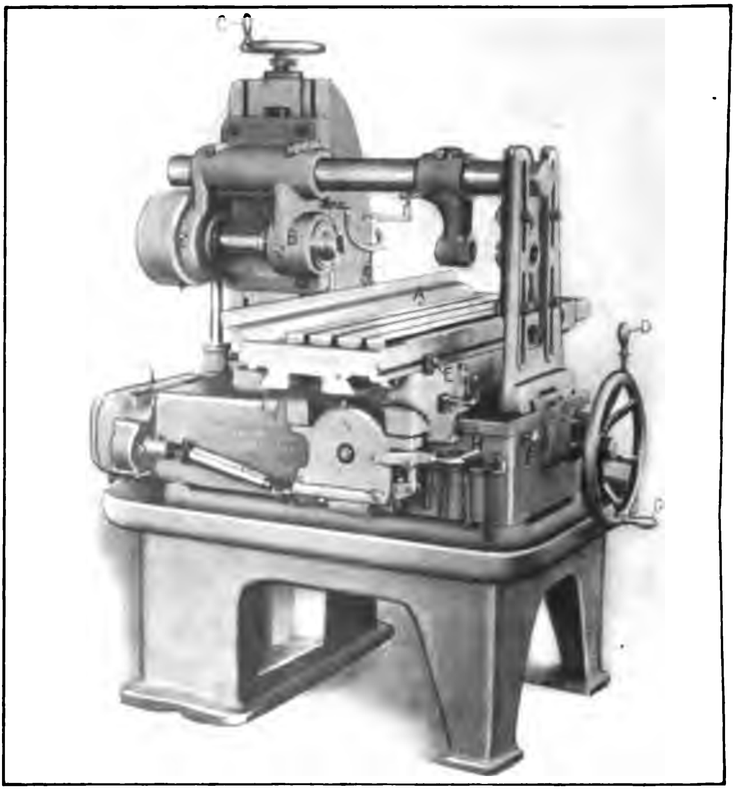


Fig. 30. Brown & Sharpe Plain Milling Machine of the Lincoln Type

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 same general character, so that a great capacity or "range" is not needed. The Lincoln type is used extensively in connection with the manufacture of firearms, sewing machines, electrical instruments and many other kinds of machinery.

Castellating Nuts on Lincoln Milling Machine. — An example of milling on a machine of the Lincoln type, but of a different make from that described in the foregoing, is illustrated in Fig. 31. The operation is that of milling the castellations or slots across the tops of hexagonal nuts. (These slots are engaged by cotter pins when the nuts are tightened to prevent them from working loose.) A special fixture is used which holds thirty-one nuts at a time, arranged in rows as shown by the view of the duplicate fixture at the left.

The slots are cut across the seven rows simultaneously by a gang of seven cutters. After a cut is taken in one direction, the swing bolts which hold the upper plate of the fixture are loosened and the plate is turned 60 degrees or $\frac{1}{6}$ of a revolution. Another cut is then taken, thus slotting four of the six sides of the nut. The plate is then indexed 60 degrees more, thus finishing the two remaining sides. While these cuts are being taken, the duplicate fixture is loaded with unslotted nuts. The latter are held onto the plate by studs and are prevented from turning by small blocks located between them. Lubricant for the gang of cutters is supplied through the pipe seen just above the cutter arbor, which has a number of openings. This example of gang milling illustrates the special fixtures which are commonly used in connection with milling operations.

Semi-automatic Lincoln-type Machine. — The semi-automatic type of Lincoln milling machine, as built by the Cincinnati

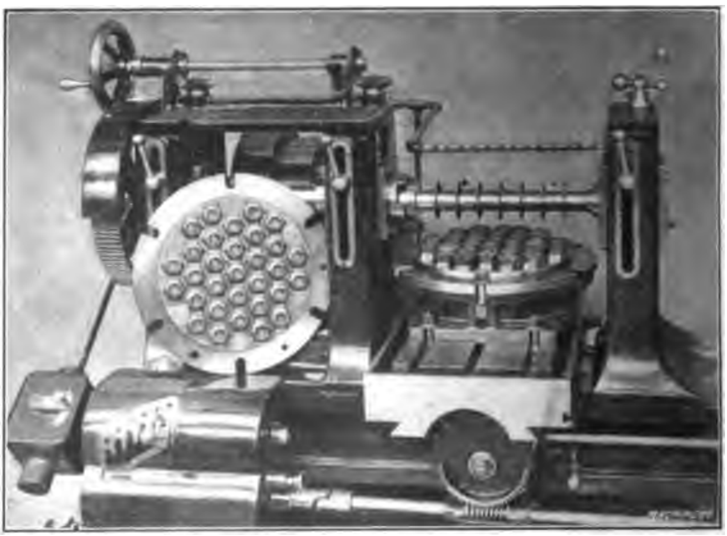


Fig. 31. Castellating Nuts on a Hendey Lincoln-type Milling Machine

Milling Machine Co., is provided with an automatic intermittent feed and a power quick return for the work-table. By means of trip dogs, a variety of cycles of movement can be obtained. The simplest of these is the one that would be used for milling a number of surfaces with spaces between. For an operation of this kind, the machine is set to bring the work up to the cutter at a rapid rate; the feed then slows down while the surface is being milled, after which it is accelerated while the cutter is moving across the space to the next piece. The feed is then reduced again for milling, and this operation is repeated until the last surface has been milled; the table then automatically reverses and quickly returns to the starting point. This feature greatly reduces the idle or non-cutting period and increases the production.

Horizontal Milling Machines. — The machine illustrated in Fig. 32 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

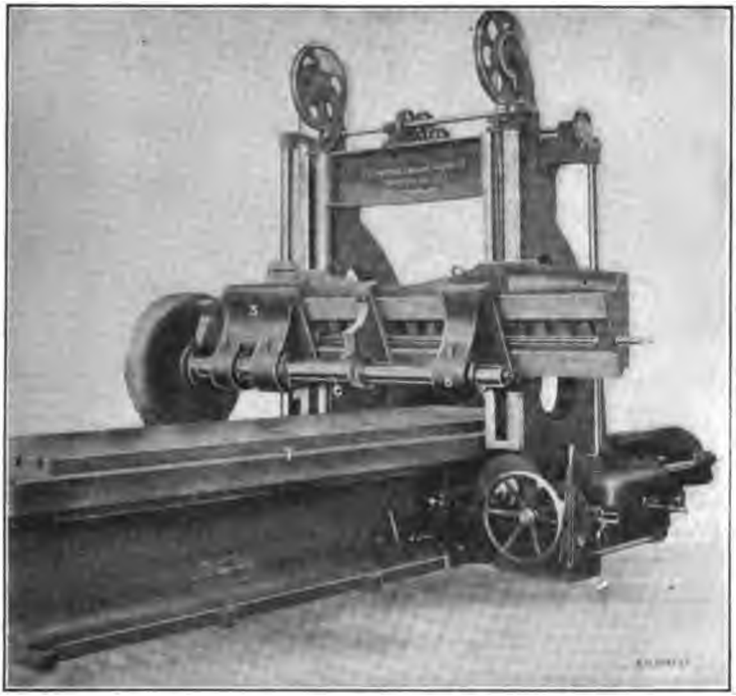


Fig. 32. Ingersoll Horizontal or Planer-type Milling Machine

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 spindle 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 cutter 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 it is counterbalanced by weights attached to wire ropes that pass over the pulleys at the top of the housings.

Fig. 33 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-

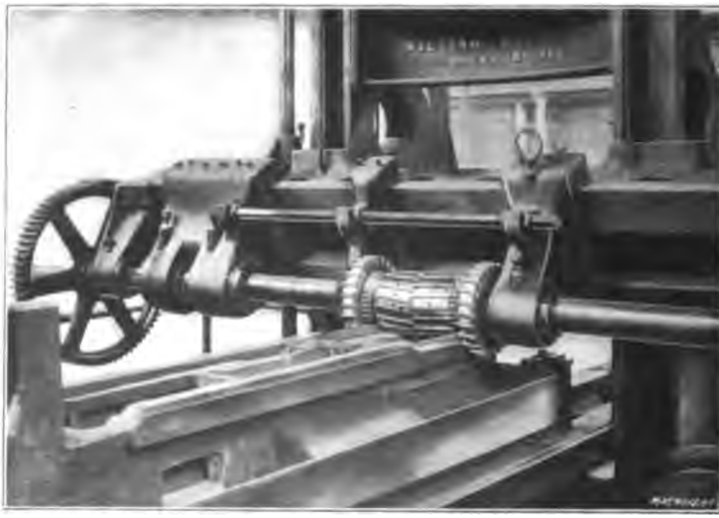


Fig. 33. Milling the Ways of a Turret Lathe Bed on a Horizontal Machine

shaped ways, 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 in a clockwise direction, as viewed from the operating side of the machine, and the table feeds to the right or against the cutter rotation.

Planing vs. Milling. — The great advantage of machining a casting by the method illustrated in Fig. 33 is that all the surfaces are milled to shape at one passage of the cutters, which not only reduces the time required for the machining operation, but insures accuracy and uniformity in the production of duplicate parts. 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 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.

Channeling Connecting-rods on Horizontal Machine. — 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. 34 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 considerably but leaves it strong enough to resist the various stresses to which it is subjected.

These channels are milled from the solid, and the cutters used for this work have inserted spiral teeth which incline in opposite directions to neutralize the endwise thrust. They are $8\frac{1}{4}$ inches in diameter and their width is $4\frac{1}{2}$ inches, which corresponds to the width of the channel. When milling, these cutters revolve 36 revolutions per minute, giving a peripheral speed of 77 feet per minute. The channel or groove is $1\frac{3}{4}$ inch deep, and it is

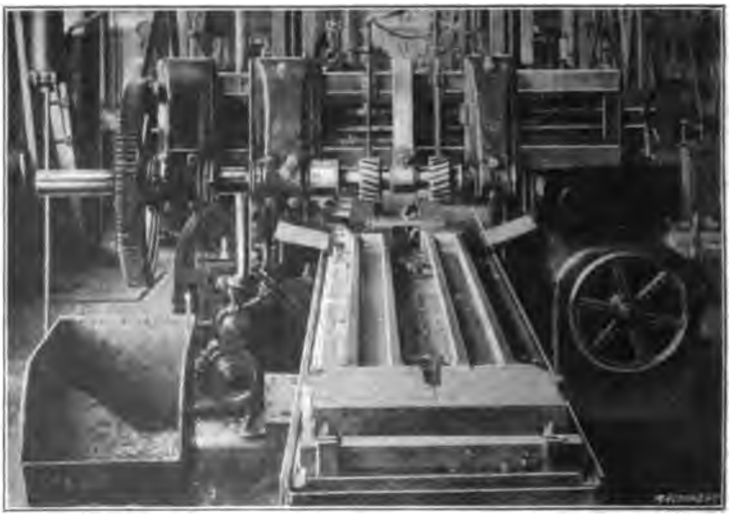


Fig. 34. Channeling the Sides of Locomotive Main-rods on Horizontal Machine

milled in two cuts, each having a depth of $\frac{7}{8}$ 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.

Milling Locomotive Trailer Frames. — The powerful milling machines used in modern shops make it possible to remove metal very rapidly, especially when the machine is equipped with properly designed cutters. Fig. 35 illustrates how a milling machine of the horizontal type is used in the Juniata shops of the Pennsylvania Railroad, for milling the "trailer" or rear frames of locomotives. These trailer frames are only used on locomotives of the passenger type having "trailing" wheels, which differ from the driving wheels in that they simply carry weight and are

Fig. 35. End View of Horizontal Machine arranged for Milling Eight Locomotive Trailer Frames

not connected to the side-rods. The frames are forged and are not made very close to the finished size, because the metal is removed so rapidly by milling that it would not be economical to forge too close to the finished dimensions. The amount of metal removed in machining these frames is indicated by the fact that a rough frame weighs about 2212 pounds, whereas one that is finished weighs only 1725 pounds.

The frames are first milled on the sides, two being placed on the machine at one time. The work is shimmed up with liners or thin wedges and is held by ordinary clamps. A stop-bar is placed across the outer end to take the thrust of the cut and as the milling cutter advances, the clamps are shifted from one point to another.

After both sides of all the frames in a lot have been machined, the edges are milled to the proper contour. Eight of these frames are milled on the edges simultaneously, and the way the work is set up is indicated in the illustration. Two broad clamps are placed across the top and the frames are held laterally by screw-stops along the sides. The rear clamp is provided with eight set-screws which insure a bearing on each frame section. The outer frame on the operator's side has lines showing the required outline for the finished edges. These lines are transferred from a steel templet before the frames are placed on the machine. The frames are first set up as shown and are then turned over for milling the opposite edges. The cutter used is 33 inches wide, and practically the entire width of this cutter is in use when milling the edges of the eight frames. The cutter consists of three 11-inch units having inserted blades which are held in helical or "spiral" grooves, giving a constant cutting action along the full width of the cutter.

The following figures will show the rate at which these rough forgings are machined. The length of the section beyond the second clamp is 5 feet $8\frac{1}{2}$ inches; this section is milled in 56 minutes, and the average depth of cut varies from $\frac{1}{2}$ to $\frac{3}{8}$ inch. (It will be understood that the time specified is for eight frames.) The lengths of some of the other sections together with approximate depths of the cuts and time required for milling them are as follows: Length, 19 inches, depth of cut, $\frac{3}{4}$ to $\frac{7}{8}$ inch, time, 21 minutes; length, $49\frac{1}{2}$ inches, depth of cut, $\frac{3}{4}$ to $\frac{7}{8}$ inch, time, 1 hour 6 minutes; length, $33\frac{1}{2}$ inches, depth of cut, $\frac{1}{2}$ to $2\frac{1}{2}$ inches, time, 1 hour 40 minutes; length, $35\frac{1}{2}$ inches, depth of cut, $\frac{3}{8}$ to 1 inch, time, 28 minutes; length, 50 inches, depth of cut, $\frac{1}{4}$ to $\frac{7}{8}$ inch, time, 34 minutes.

The amount of metal removed from the edges of the eight frames is approximately 1356 pounds, whereas 2542 pounds are removed from the sides, giving a total of 3898 pounds. The total time required for milling the edges is 6 hours 29 minutes and for the sides, 8 hours 40 minutes, giving a total cutting time of 15 hours 9 minutes for eight frames, so that the amount of metal removed per hour of cutting time is approximately 257 pounds. It should be mentioned that the foregoing figures do not cover the time required for setting and clamping the work on the machine.

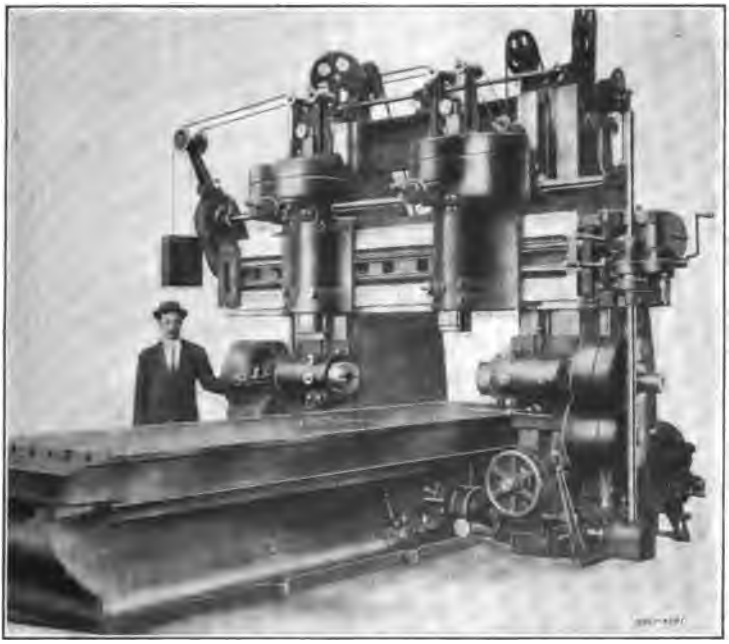


Fig. 36. Ingersoll Four-head Milling Machine

Multiple-head Milling Machine. — Horizontal machines are built in many different designs which are modified to suit different classes of work. Fig. 36 shows a large 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

Fig. 37. Three-head Machine Milling Aluminum Castings

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.

An example illustrating the nature of the work done on a multiple-head machine is shown in Fig. 37. This particular machine has three heads and a fixed cross-rail, the latter being cast solid with both housings in order to secure a more rigid construction. One spindle is carried by the cross-rail and the other two are mounted on the front faces of right and left housings. This general type of machine is extensively used for milling the surfaces of duplicate parts, such as gasoline engine cylinders, crank cases, etc.

The milling operation shown is that of finishing the surfaces of aluminum castings for automobile engines. As will be seen, these castings are clamped to the sides and top of a cast-iron fixture, and the three rows of castings are milled simultaneously as they are fed past the cutters. The cutters at the sides are 14 inches in diameter, and the one attached to the vertical spindle has a diameter of 10 inches. They are rotated for this operation at a speed of 100 revolutions per minute, and the feed of the table is $\frac{3}{32}$ inch per revolution of the cutters, or over $9\frac{1}{4}$ inches per minute. Obviously, it is possible to mill these castings rapidly after the machine is adjusted.

The principal difficulty in machining aluminum and aluminum alloys is caused by the clogging of the chips which tend to wedge between the teeth of tools, such as milling cutters, etc. This difficulty can be largely avoided by the use of the right kind of cutting lubricant. Soap water and kerosene are often used. The latter enables a fine finish to be obtained, provided the cutting tool is properly ground. For milling flat surfaces, it is preferable to use end or face milling cutters rather than the cylindrical forms. The cutting edges or corners should be sharp instead of rounded, and the mill will cut better if a high cutting speed and moderate feed are employed. The depth and width of the cut are of minor importance. A cutting speed of 325 feet per minute is practicable, and from $2\frac{1}{2}$ to 4 cubic inches of aluminum can be removed per minute.

According to one manufacturer who machines aluminum parts in large quantities, the cutting speed for aluminum can be from 50 to 60 per cent faster than the speeds and feeds for cast iron. The lubricant used by this manufacturer is composed of one part aqualine and twenty parts water. This lubricant not only gives a smooth surface but insures a keen cutting edge and allows tools to be used much longer without regrinding. Formerly a lubricant composed of one part of high-grade lard oil and one part of kerosene was used. This mixture costs approximately 30 cents per gallon, whereas the cost of the aqualine-and-water mixture is less than 4 cents per gallon, and it has proved more effective than the lubricant formerly employed.

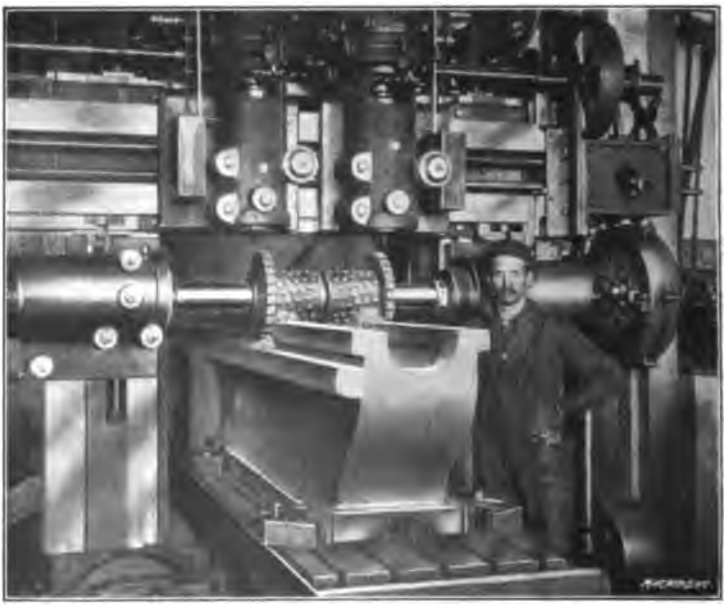


Fig. 38. Milling the Ways of a Milling Machine Bed Casting

Fig. 38 shows how two spindles of a four-spindle machine are used for rough-milling the top surfaces of a milling machine bed casting. A gang of four cutters is used, consisting of two side mills for the edges of the ways and two cylindrical cutters for the top surfaces. These cutters are mounted upon an arbor which is driven by the right- and left-hand horizontal spindles. The cylindrical cutters have round, inserted teeth which are driven into holes in the cutter body. These holes are so located that the cutters incline at an angle to the axis of the arbor, and the teeth of one row are in line with the spaces between the teeth of the preceding row, so as to cut away the metal left by these tooth spaces and produce a flat surface. This form of cutter is a development of the nicked cutter illustrated at *B*, Fig. 8, Chapter III, and it is intended for taking roughing cuts.

When selecting the cutters for a gang milling operation, such as the one illustrated, it is advisable to use fairly large cutters, if possible, in order to reduce the disproportion of the diameters. For instance, when a 3-inch mill is working in the same gang with a 6-inch mill, the peripheral speed has to be kept within the maximum speed capacity of the larger cutter, which means that the 3-inch size is running much below its maximum peripheral speed. On the other hand, the feed is limited to the capacity of the 3-inch mill; consequently, one cutter may be working at one-half its maximum peripheral cutting speed whereas the other is operating at one-half its feed capacity. Now, if the diameter of the small mill were six inches and that of the larger one, nine inches, the same form would be produced, because the difference between the radii of the two cutters is the same, and the output would also be greatly increased. The same condition has been observed in the use of dovetail cutters, when the width of the dovetail affords plenty of room for a cutter of large diameter. Examples of dovetail cutters have been noted having a small diameter of 1¼ inch and a large diameter of 3 inches, when it would have been possible to use a very much larger size. In this case, the loss of efficiency is probably greater than for the first case mentioned.

Open-side Horizontal Milling Machine. — For some classes of milling, the open-side horizontal spindle type of milling machine illustrated in Fig. 39 is very efficient. An example of the kind of work milled on this machine is shown in the illustration. The operation is that of facing the flanges of the pump castings shown. A large cutter-head having inserted tools mills the flanges as the table and work feed along at right angles to the cutter spindle. The feed motion of the table is transmitted through a worm and rack. The main driving gear for the spindle, instead of transmitting the power through the spindle, drives the cutter directly through a hardened steel driving pinion.

The function of the spindle when driving in this way is simply that of supporting the driving gear, this being the arrangement when cutters varying from 18 to 36 inches in diameter are used. Cutters of smaller diameter are attached to the spindle by means of a shank and draw-in bolt, and the machine is driven by the main spindle gear.

Fig. 39. Open-side Horizontal Milling Machine Facing Pump Castings

The saddle has an in-and-out movement by hand and in order to provide a fine adjustment, it is equipped with a micrometer stop which gives accurate adjustments for any position within the limits of the saddle travel. This machine is driven by a motor located on the opposite side of the vertical column. The table has twelve feed changes and a rapid power traverse in either direction of thirty feet per minute. The open-side type of milling machine can often be used for milling large or long parts which could not be handled on a machine having a housing on each side of the table, owing to the interference between the work and the machine. Open-side milling machines are also built with vertical spindles which are mounted upon a short heavy cross-rail, which projects from the column over the table.

Duplex Milling Machine. — The duplex type of milling machine has been developed more particularly for manufacturing operations which require two sides of a piece to be milled parallel and to a given width. A duplex machine is shown in Fig. 40

Fig. 40. Example of Parallel Face Milling on a Duplex Machine

milling both sides of a vise jaw casting. As will be seen, it has two horizontal spindles *A*, each of which carries a face cutter *B* for this particular operation. The work is clamped in a fixture so as to clear each cutter, and both surfaces are milled simultaneously as the table and work feed automatically at right angles to the cutter spindles.

Machines of this type are particularly adapted to such operations because parts can be milled quickly and the accuracy of the work is not dependent upon the care and skill with which the work is reset for milling the second surface. Inasmuch as the two surfaces are milled at the same time, thus avoiding a second setting of the work, it will be evident that a considerable increase of production is also obtained.

The spindles of the duplex machine shown in Fig. 40 are driven by cone pulleys at the rear which are connected through gearing. These spindles have independent vertical adjustments in order to locate the cutters in accordance with the height of the work, and the distance between the ends of the spindles can also be varied for milling different widths. The rate of the table feed is changed by shifting gears in the feed-box *C*. A machine of

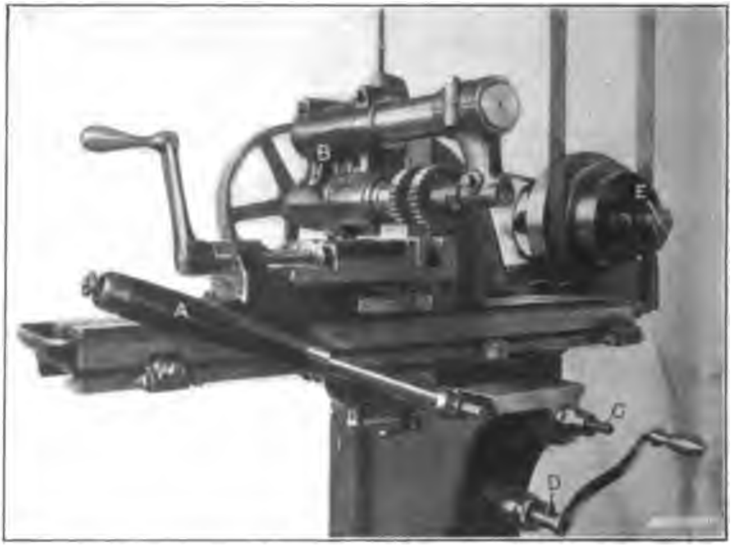


Fig. 41. Whitney Hand Milling Machine

this type is often used exclusively for one or two operations in manufacturing plants requiring many duplicate parts.

Hand Milling Machine. — The hand milling machine is so named because the table or cutter is fed by hand instead of by an automatic power feed. A typical design is shown in Fig. 41. The table can be fed in a lengthwise direction by hand lever *A* or by turning the feed shaft with a crank. The spindle head also has a vertical lever feed, the lever being inserted at *B*. The table can be adjusted laterally and vertically by turning the squared shafts *C* and *D*, respectively. The cutter spindle is driven by a belt at the rear from cone pulley shaft *E*. The rear driving pulleys are interchangeable so that the three speed changes obtained from the cone pulley can be doubled. Adjustable stops are provided for limiting the travel of both the spindle head and table in either direction.

This type of milling machine is adapted to short milling operations, especially when it is desirable to take light cuts which are not of sufficient length to warrant using a milling machine having an automatic feed. The operation illustrated in Fig. 41 is that

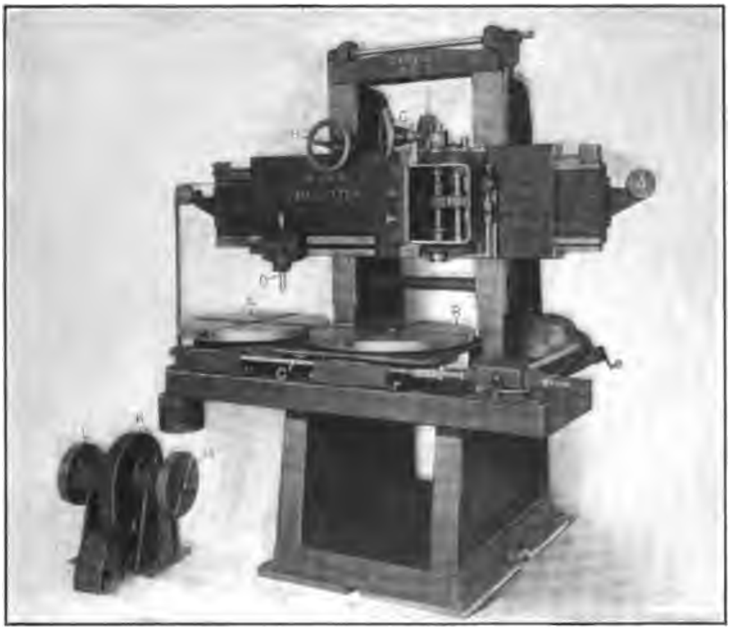


Fig. 42. Garvin Cam or Form Milling Machine

of milling the ends of a steel block to a given width. Two side mills are used and the work is held in a vise attached to the table. As the cut is comparatively short, the surfaces can be milled quickly and easily by using a hand-operated machine. Quite a variety of milling is done on machines of this type. For some operations a weight is suspended at the end of the feed lever and in this way an automatic gravity feed is obtained.

Cam or Form Milling Machine. — The milling machine illustrated in Fig. 42 operates on the same general principle as an ordinary profiling machine, although the construction is different. This machine is used for milling disks, face and cylinder cams of various forms, and for all kinds of rotary and irregular form milling. The two tables *A* and *B* are driven in unison by means of shaft *C* and worm gearing. Table *A* carries the former or model and table *B* the part to be milled. The cutter spindle and its slide is mounted on a cross-rail, and a former pin *D* is attached to the slide a certain distance from the spindle which distance can be varied to suit the work, by adjusting the pin-holder horizontally. When the machine is in operation, pin *D*

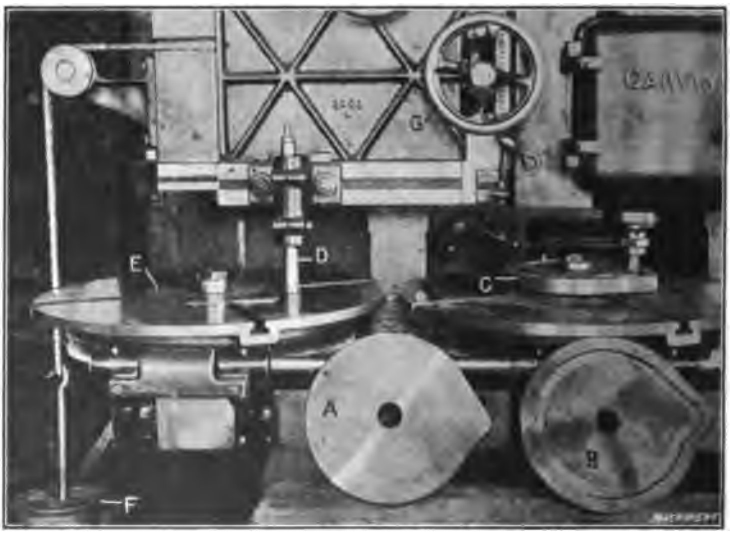


Fig. 43. Milling Face Cam on Garvin Cam or Form Milling Machine

bears against the former plate or model and, as the table revolves, the cutter is caused to move laterally so as to reproduce the required outline on the work. At the right-hand end of the driving shaft *C* for the tables, there is a reversing mechanism so that the tables can be rotated in whichever direction presents the least abrupt angles for the former pin and cutter to pass over. For instance, if a cam were being milled having a sudden rise at one point, the direction of rotation should be such that the former pin will approach the rise from that side which has the most gradual ascent.

Milling a Face Cam. — The type of cam or form milling machine illustrated in Fig. 42 is shown in Fig. 43 arranged for milling a face cam. The unmilled cam blank is shown at *A* and the finished cam at *B*. The blank is clamped to the right-hand table, as at *C*, and the former plate *E* on the table to the left. Both the model and work are centered by means of bushings which are fitted to holes in the centers of the tables. The pin *D* on the cutter slide is held firmly against the model by counterweight *F*, and the cutter and pin follow the same path as both tables revolve in unison. The cutter spindle is adjustable vertically for setting the cutter, by means of handwheel *G* (see also Fig. 42), and horizontally along the cross-rail by handwheel *H*, when setting up the machine. Stops are provided for both horizontal and vertical movements. The cross-rail of the machine illustrated in Fig. 42 can be adjusted vertically on the front of the uprights by means of elevating screws that run on ball-thrust bearings. The method of mounting the slide on cross-rail is noteworthy. The upper horizontal surface of the rail has a hardened and ground tool-steel ball race carrying a long row of balls. The opposing surface of the slide has a similar race, thus supporting the weight. At the lower edges of the slide and rail are two opposed tool-steel surfaces, between which are two rows of balls that take up the thrust, thus making the slide travel back and forth with little friction, so that the cutting of sharp-angle cams is greatly facilitated.

When milling small parts of irregular shape, sometimes several can be placed on the table at one time in order to mill them successively. The parts are held near the circumference of the table in a suitable fixture and a series of duplicate formers is arranged similarly on the other table. The milling operation is continuous, the finished part being removed and replaced with rough blanks while the others are being machined.

Milling a Cylinder Cam. — The machine shown in Fig. 42 can be used for cutting cylinder or "barrel" cams by replacing the circular tables *A* and *B* with the attachment *K* seen on the floor. The horizontal spindle of this attachment is rotated by gearing connecting with shaft *C* on the machine. The cylindrical former or master cam is attached to faceplate L and the cam to faceplate M. Pin D engages the former, and the cutter in the spindle mills grooves of the required curvature as the attachment rotates.

Fig. 44 shows a cylinder cam attachment in place on another machine which is similar to the one just described, except for minor details. Shaft C connects with shaft N by a chain and

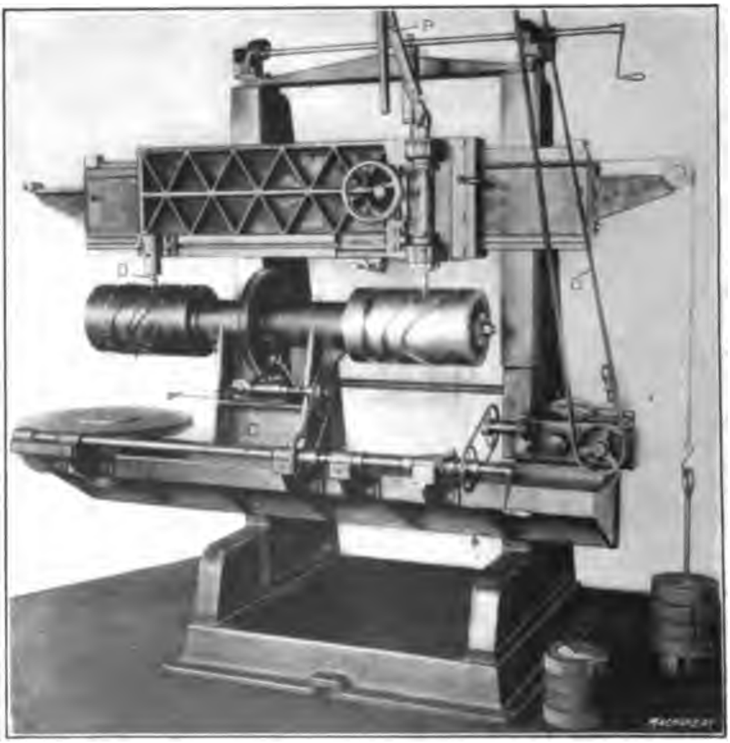


Fig. 44. Milling Cylinder Cams on Garvin Machine

sprocket and shaft N, in turn, drives the horizontal spindle of the attachment through the worm gearing shown. The cylindrical former has cam surfaces corresponding in shape or curvature to those required and it is engaged by pin D attached to the cutter slide; hence, the cutter mills a groove corresponding to the cam surface engaged by the pin. The mechanism for driving the attachment is operated by belt O, and the cutter spindle is rotated by rod *P* connected to both the spindle and the overhead drive by universal joints to allow movement of the spindle slide.

Vertical Type of Cam Milling Machine. — The cutter head of the cam milling machine shown in Fig. 45 is carried on a slide which moves vertically on the column at the left. The movement of the cutter slide is controlled by a former plate or master cam which engages roller *H*. This roller is mounted on an auxiliary slide which is connected to the main cutter slide by an

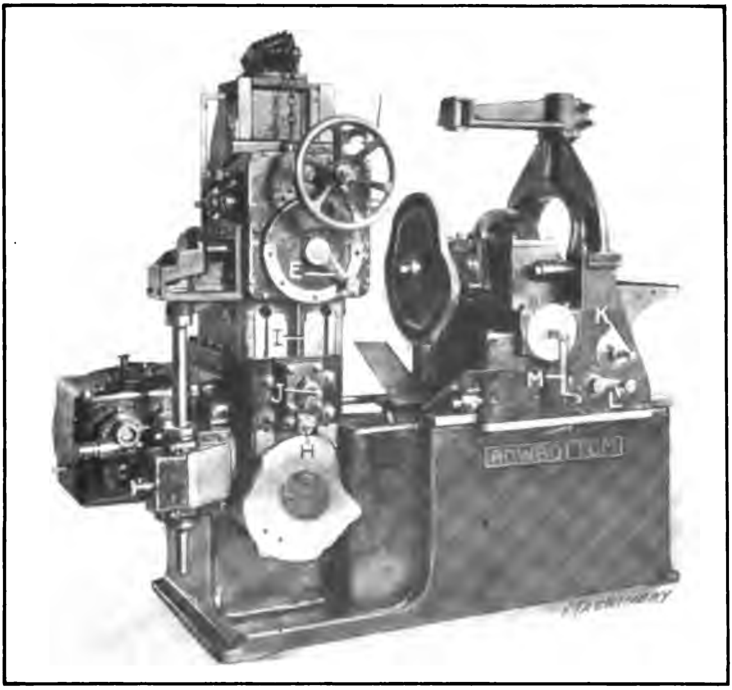


Fig. 45. Rowbottom Cam Milling Machine arranged for Milling a Face Cam

adjustable screw *I*. This screw is turned by placing a crank on squared shaft *J* when it is desired to move the cutter slide on the column for varying the distance between the cutter and the center of the work spindle. A scale on the column shows the distance that the cutter has been set off center.

The cam to be milled is held on a mandrel carried by the work-head which can be set either in a horizontal or vertical position. For milling plate or face cams the mandrel is held horizontally as shown in Fig. 45. For cutting cylinder or "barrel" cams the mandrel is held in a vertical position as shown in Fig. 46, and an outboard support is used for steadying the upper end. Flat former plates are used for cutting all types of cams.

Power is transmitted to the work-head by means of a shaft at the rear of the machine, and the horizontal movement of the head along the ways of the bed is effected by a screw. The machine is driven by a single belt pulley at the rear. Speed

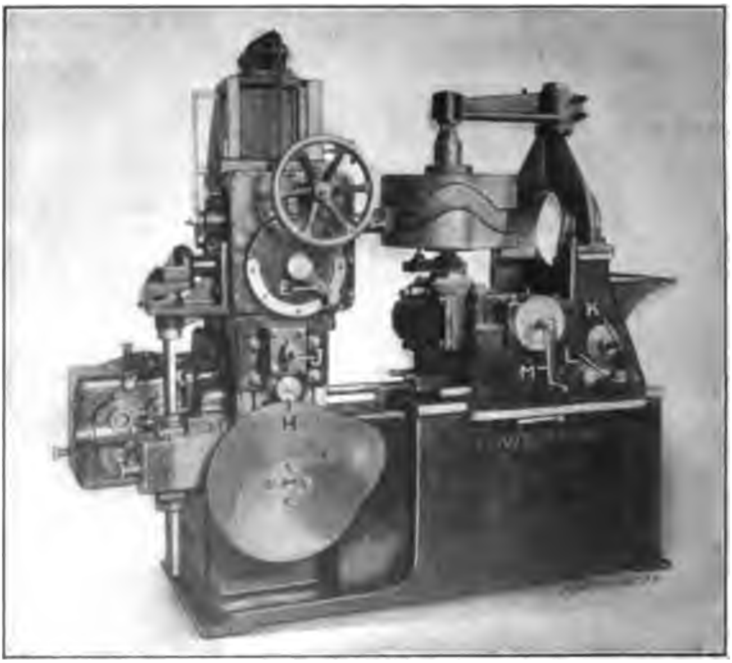


Fig. 46. Rowbottom Machine Milling a Cylinder Cam

changes are obtained by means of a gear box, corresponding variations being made for the former plate and work arbor, in order to retain the proper relation between the cutter and the cam being milled. The cutter speed can also be changed to suit the size of the mill and material being cut. These speed changes for the cutter spindle are effected by lever *E*. The adjustment for the depth to which the cutter enters the work is made on the work slide, the squared shaft *K* being provided for this purpose. This shaft has a micrometer collar for accurately gaging the depth of the milled groove.

If necessary, the relative position between the cutter and cam blank can be varied. Suppose it is desired to alter the position of the cam groove slightly from that arbitrarily fixed by the location of the driving pin which passes through the work into the faceplate. The first step would be to move lever *L* to the neutral position which disengages the clutch which drives the work spindle. Lever *M* is then turned through one-twelfth of a revolution, after which the clutch is re-engaged by lever *L*. This clutch has twelve teeth and the result of this operation is to re-mesh the clutch one tooth ahead of its former position. By means of gearing in the work head, the resultant movement of the cam relative to the cutter amounts to one-fourth degree.

This machine has a pump for supplying lubricant to the cutter, but a strong blast of air for removing the chips and cooling the cutter has been found an excellent substitute for a lubricant, even when milling steel cams.

Thread Milling. — In many lines of manufacture threads which were formerly cut with a single-pointed tool in an engine lathe are now formed by milling in machines designed for thread milling. The thread is milled by a cutter of the required shape which is set to correspond with the helix angle of the thread. Some machines are so designed that the work rotates in a fixed position and the cutter slide is moved along the machine bed by a lead-screw that is connected with the work-spindle through suitable change gears. There is also another type of machine, the cutter of which rotates in a fixed position while the work revolves and at the same time feeds forward at a rate proportional to the lead of the thread being milled.

Pratt & Whitney Thread Milling Machine. — This machine, which is shown in Fig. 47, is the type in which the part to be threaded rotates in a fixed position while the thread is milled by a cutter mounted on a cutter head which is fed along the bed at the proper rate by suitable gearing. The cutter is set in line with the angle of the thread by means of a worm and worm-gear adjustment. This particular machine is designed for milling large screws of coarse pitch, such as elevator worms, worms for gun mounts and for other heavy threading operations. It is driven from a cone pulley (seen at the left-hand end of the machine) which is mounted on the end of a horizontal splined shaft extending along the rear of the bed. From this shaft the cutter spindle, headstock spindle and lead-screw are rotated. Motion is transmitted to the cutter spindle through a vertical telescopic shaft and bevel gears, and to the headstock spindle through a gear-box which enables the speeds to be varied.

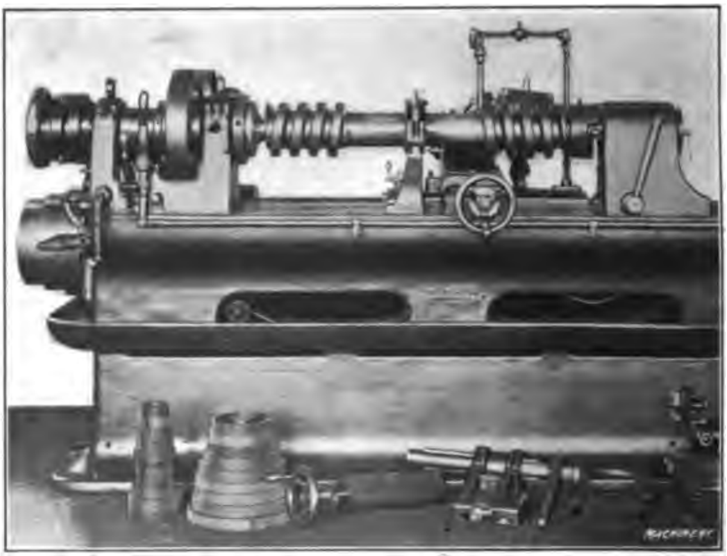


Fig. 47. Pratt & Whitney Thread Milling Machine

The lead-screw, which traverses the carriage and the cutter head along the bed at the required rate, is rotated through change gears so that threads or spirals, in a great variety of pitches or leads, can be milled. The headstock and the tailstock spindles are made hollow so that work up to $3\frac{1}{2}$ inches in diameter can pass through. This feature makes it possible to mill screws of almost any length, provided the overhanging ends are suitably supported. The part to be threaded is gripped by a chuck of the drawback collet type, in the headstock spindle. Whenever possible, the outer end of the work should be supported by a bushing in the tailstock, instead of by a center. When threading exceptionally long parts which extend considerably beyond the tailstock, an outboard support should be employed. The maximum length of thread that can be cut at one setting with the machine illustrated in Fig. 47 is 48 inches, when the tailstock has a full bearing on the bed. For milling longer threads, the work is shifted after cutting a thread equal in length to the full capacity of the machine.

This machine is capable of milling threads having a maximum radial depth of $1\frac{5}{8}$ inch. For threads having a depth of over 1 inch, the manufacturers of the machine recommend the taking of two cuts. For the roughing cut a special cutter made narrower at the points of the teeth is preferable. A mechanism is provided for indexing the work-spindle when cutting multiple threads or spiral gears. The travel of the carriage is controlled automatically by adjustable stops mounted on a rod seen extending along the front of the machine. The vertical hand lever to which this rod is attached is also used to engage, disengage or reverse the carriage travel.

Lees-Bradner Thread Milling Machine. — The thread milling machine shown in Fig. 48 differs from the design described in the foregoing, as the illustrations show, although it operates on the same general principle, in that the part to be threaded rotates in a fixed position while the thread is milled by a cutter held in a carriage which is traversed by a lead-screw that is rotated through suitable change gears. The machine is driven by a single belt pulley at the rear. This pulley, through a suitable clutch mechanism, drives a back shaft which transmits power to the cutter, and, through change gearing, also rotates the work spindle and lead-screw. There is one system of change gears for regulating the work speed and another system for varying the traverse of the carriage according to the lead of the thread.

The cutter is held on a spindle *A* which is swiveled to align the cutter with the helix angle of the thread. Angular graduations and a vernier scale at the rear of the cutter head (which is of cylindrical design) are used when making this adjustment. Handwheel *B* at the front of the cutter slide is used for adjusting the cutter for depth of cut, and it is provided with a micrometer dial graduated to thousandths of an inch. There is also a stop at *C* which can be used for locating the cutter in the same position or at the same depth, either when milling duplicate threads or the grooves of multiple-threaded worms or screws. The traverse of the carriage is automatically controlled by two stops seen on the rod extending along the front of the machine. The hand lever *D*, to which the trip-rod is connected is used to con-

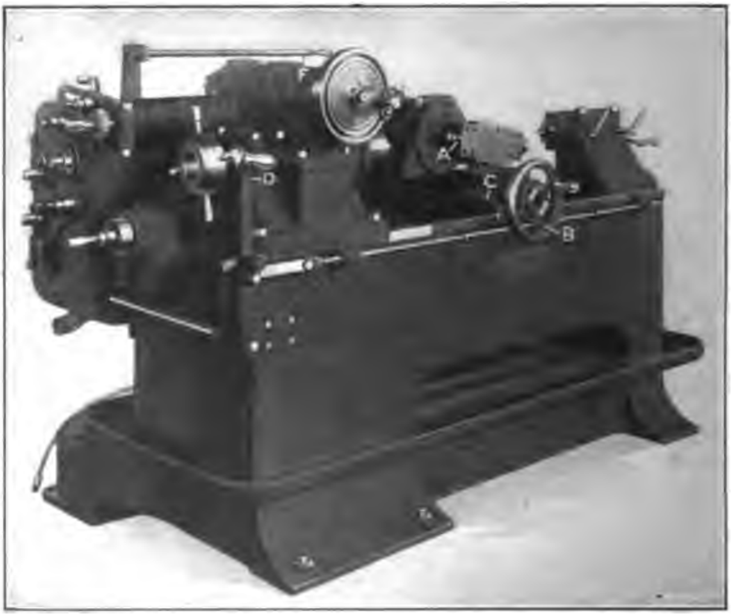


Fig. 48. Lees-Bradner Thread Milling Machine

trol the traverse of the carriage. When this lever is in the neutral position, as shown, the carriage remains stationary, and when it is thrown to the right, the carriage moves to the left. When the small stop collar is engaged by the carriage the feed clutch is disconnected; then if a thread were being milled, the cutter would be backed out of the thread groove and lever *D* thrown to the left, thus causing the carriage to return to the starting point for another cut. The stop collar at the right of the handwheel should be set for stopping the return movement at the proper point, by throwing the lever *D* to the neutral position.

The work is either held on the centers or in a collet chuck at the headstock end and on a center at the tailstock end. The collet chuck should be used if possible. The index plate *E* is for indexing when cutting multiple threads or spiral gears. The starting and stopping of the machine is controlled by hand lever *F*. When milling very fine threads a hob type of cutter is used instead of a regular formed cutter. A follow-rest is supplied with this machine for supporting flexible parts. This is attached to the cutter slide and has an independent side adjustment so that the work can be supported either ahead of or behind the

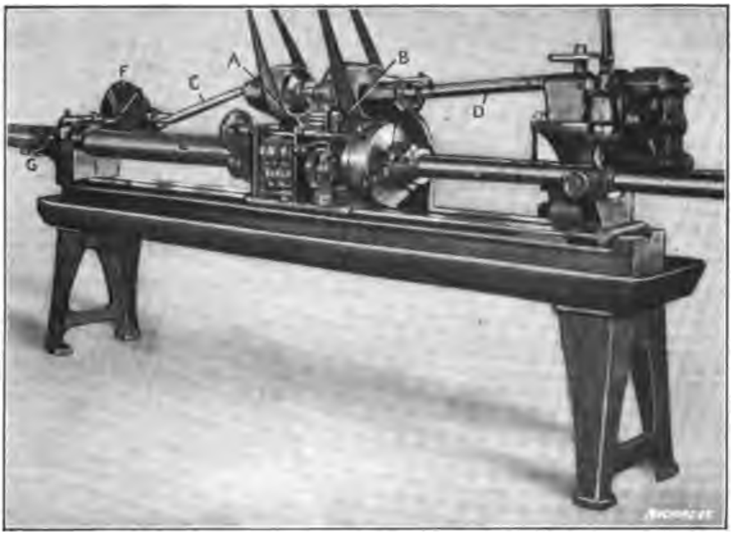


Fig. 49. Universal Thread Milling Machine

cutter. This machine will mill threads or grooves varying in lead from $\frac{1}{20}$ inch to 96 inches.

Universal Thread Milling Machine. — The thread milling machine illustrated in Fig. 49 is the type in which the lead-screw and work revolve and feed forward together, while the thread is milled by a cutter rotating in a fixed position. The lead-screw *L* is mounted over the center of the bed and in direct line with the screw that is being milled. The latter is gripped in a chuck mounted upon a carriage which slides along the ways of the bed. The cutter-head is located at the right-hand end of the machine, and the work is supported near the point where the milling cutter operates by an expansion bushing or steadyrest.

The machine is driven by two pulleys *A* and *B*, which transmit power to the lead-screw and cutter, respectively, by the universally-jointed shafts *C* and *D*. Shaft *C* connects with a shaft on which a friction roller is mounted, and this roller, in turn, bears against and rotates disk *F*. The shaft carrying the friction disk transmits power through a worm to a worm-wheel having a threaded hub through which the lead-screw passes. A key in the worm-wheel engages a spline in the lead-screw, thus causing the latter to revolve. The lead-screw also passes through a split nut, the position of which is fixed so that the rotation of the lead-screw results in a longitudinal movement. The handle *G* serves to engage or disengage the split nut and the lead-screw.

The speed at which the lead-screw rotates can be varied by changing the radial position of the friction driving roller by means of a connecting screw and crank. This change does not affect the lead or pitch of the thread being milled, but serves to vary the milling speed. Different pitches are obtained by means of a gear-box on the carriage through which motion is transmitted from the lead-screw to the work. There is a gear on the end of the lead-screw which drives, through the gear-box, a large spur gear located back of the chuck. This last gear of the train is fastened to a cylindrical part to which the chuck is also attached, and it rotates both the chuck and work. Obviously, the speed at which the work revolves and, consequently, the pitch of the thread that is milled, depends upon the ratio of the gears in the gear-box. For instance, if the gears were so proportioned that the lead-screw and work rotated at the same speed, a thread would be milled having the same lead as the thread on the lead-screw. If the work rotated faster than the lead-screw, a finer lead of thread would be obtained, whereas, if it rotated slower, the lead or pitch would be coarser than that of the lead-screw.

The cutter arbor is driven from shaft *D* through bevel and spur gearing, so arranged that the cutter can be swiveled about a pivot, 90 degrees either to the right or left of the central position, in order to align the cutter with the angle of the thread. The length of a single continuous cut which can be taken on this machine is limited by the traverse of the carriage, but a longer thread than is represented by this traverse can be cut by releasing the chuck, disengaging the lead-screw nut and moving the carriage back to its original position. The nut is then re-engaged and the chuck re-tightened upon the work, after which the machine is ready to continue milling the thread. This operation can be repeated as many times as is necessary to mill a screw of the required length. When the position of the carriage is

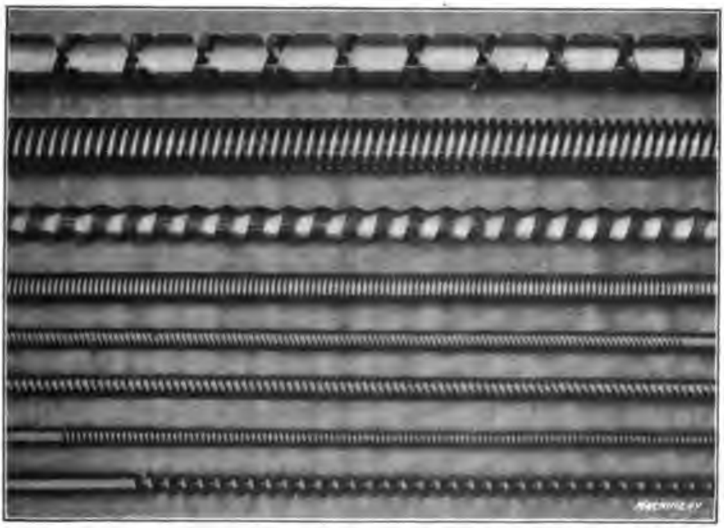


Fig. 50. Examples of Work done on Universal Thread Milling Machine

being changed, care should be taken to clamp the work securely in the supporting bushing beneath the cutter, in order to prevent altering the relative positions of the cutter and work.

The work-holding chuck is attached by a coupling so that multiple threads can be cut, as this coupling enables the chuck and work to be indexed after milling a thread groove. The flanges of the coupling are graduated so that the chuck can be turned whatever fractional part of a revolution is required, which will depend, of course, upon the form of thread; that is, whether double, triple, etc. Obviously, when milling multiple threads, it is necessary to take as many separate cuts as there are single or independent threads or grooves in the screw. For instance, a double thread would require two cuts, a triple thread three cuts, and so on. In order to hold the blank securely and prevent it from slipping in the chuck, an auxiliary dog or coupling is secured to the work and fits over one of the chuck jaws to give a positive drive.

Fig. 50 illustrates examples of work done on the universal machine, which can be used not only for thread milling but for many other spiral milling operations. The same general type of machine, illustrated in Fig. 49, is also made in a simpler form which is not equipped with a gear-box for varying the pitch of the thread milled, but must be provided with a lead-screw having a pitch corresponding to the pitch of the thread to be milled. This "duplicating" type of machine is especially adapted for milling large numbers of screws of the same pitch. It is provided with an indexing coupling similar to the one previously referred to, for use when milling multiple threads.

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