MACHINERY'S REFERENCE SERIES

EACH NUMBER IS A UNIT IN A SERIES ON ELECTRICAL AND
STEAM ENGINEERING DRAWING AND MACHINE
DESIGN AND SHOP PRACTICE

NUMBER 96

OPERATION OF MACHINE TOOLS

By FRANKLIN D. JONES

SECOND EDITION

MILLING MACHINES—PART I

CONTENTS

49-55 Lafayette Street, New York City

CHAPTER I

PLAIN TYPE OF MILLING MACHINE

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

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

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

Plain Milling Machine of the Column-and-Knee Type

A type of milling machine that is widely used, especially for milling large numbers of duplicate parts, is shown in Fig. 2. This is known as a plain, horizontal milling machine of the column-and-knee type. The principal parts are the column *C* and knee *K*, the work table *T*, the main spindle *S* which drives the cutter, and the speed- and feed-changing mechanisms encased at *A* and *B*, respectively. The spindle receives its motion from belt-pulley *P* at the rear. This pulley is connected to the driving shaft by a friction clutch operated by lever *M* which is used for starting and stopping the machine. When the friction clutch is engaged, power is transmitted to the main spindle *S* through gearing, and, by varying the combination of this gearing, the required speed changes are obtained. Knee *K* is free to slide vertically on the front face of the column, and it carries saddle *Z* and the table *T*. The saddle has an in-and-out or cross movement on the knee, and the table can be traversed at right-angles to the axis of the spindle. Either of these three movements, that is, the longitudinal, cross, and vertical movements, can be effected by hand or power. The hand movements are used principally for adjusting the table and work to the required position when starting a cut, whereas the automatic power feed is employed when milling. The hand-crank *D* is used for raising or lowering the knee with its attached parts, handwheel *E* is for the cross feed of the saddle and table, and handle *F* is for the longitudinal adjustment of the table. The table can also be traversed rapidly by the large handwheel *N* at the front of the machine.

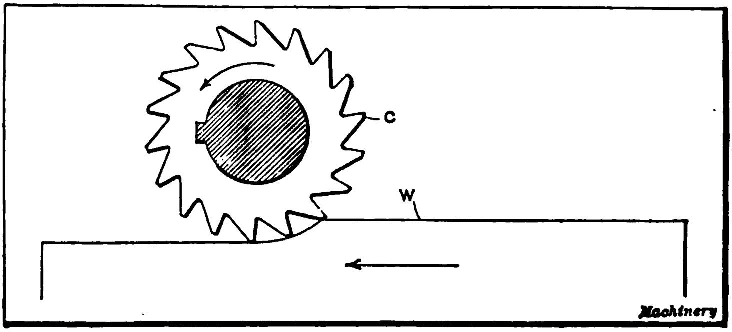

Fig. 1. End View of Cylindrical Cutter Milling Flat Surface

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

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

Fig. 2. Cincinnati Plain Milling Machine

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

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

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

CHAPTER II

ADJUSTING AND OPERATING A MILLING MACHINE

Before a milling machine can be used, it is necessary, of course, to arrange it for doing the work in hand, which includes mounting the cutter in position, and adjusting the driving and feed mechanisms for giving the proper speed to the cutter and feed to the work. The part to be milled must also be securely attached to the machine, so that it can be fed against the revolving cutter by moving the table in whatever direction may be required. The way a milling machine is arranged, and the kind of cutter used, depends on the nature of the milling operation. The character of the work, and other considerations which will be referred to later, also affect the speed and feed, as well as the method of clamping the work to the table; hence, judgment and experience are needed to properly decide the questions that arise in connection with milling practice, and no definite rules or methods of procedure can be given. We shall explain, however, in a general way, how milling machines are arranged and used under varying conditions, by giving illustrated descriptions covering typical examples of work representing the various classes that are machined by the milling process.

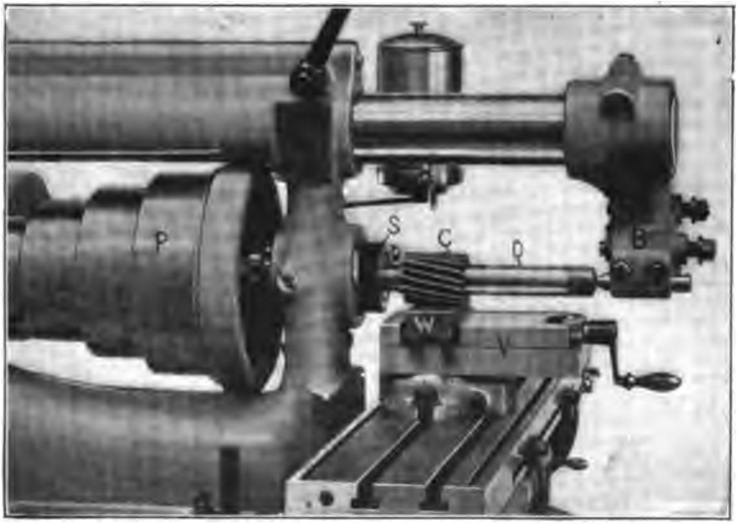

Fig. 3. Milling a Small Rectangular Block

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

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

Method of Holding and Driving the Cutter

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

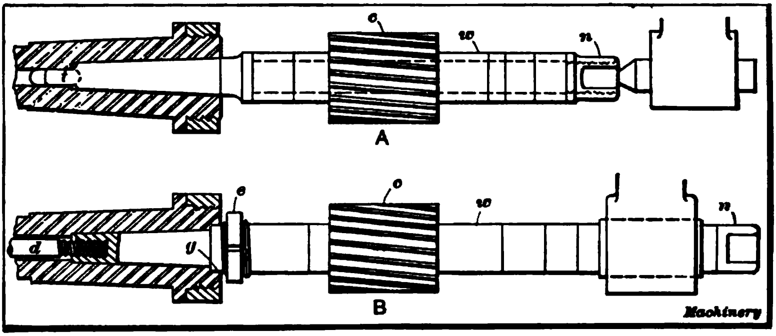

Fig. 4. Cutter Arbors

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, in order to give a strong drive and reduce the torsional strain on the arbor.

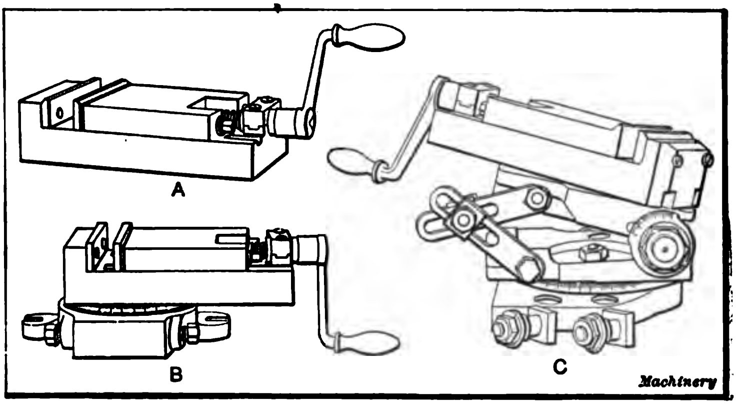

Fig. 5. Milling Machine Vises

Holding Work on the Milling Machine

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

Three types of milling machine vises which are commonly used, are shown in Fig. 5. The one illustrated at *A* is called a plain vise. It is held to the table by a screw which passes through the vise bed and threads into a nut inserted into one of the table T-slots. This same style is also made with flanges so that it can be secured by ordinary clamps. The vise shown at *B* has a swiveling base and it can be adjusted to any angle in a horizontal plane, the posisition being shown by graduations. This adjustment is used for angular milling. The vise shown at *C* is known as the universal type. It can be swiveled in a horizontal plane and can be set at any angle up to 90 degrees in a vertical plane, the position, in either case, being shown by graduations. The hinged knee which gives the vertical adjustment, can be clamped rigidly by the nut on the end of the bolt forming the hinge, and by bracing levers at the left which are fastened by the bolts shown. This style of vise is used principally by die- and tool-makers, and, owing to its universal adjustment, can often be utilized in place of a jig or fixture. When large quantities of duplicate pieces are to be milled, they are usually held in special fixtures which are so designed that the work can quickly be clamped in position for milling. The arrangement or form of a fixture depends, of course, on the shape of the part for which it is intended and the nature of the milling operation. A number of different fixtures will be shown in connection with the examples of milling given in succeeding chapters.

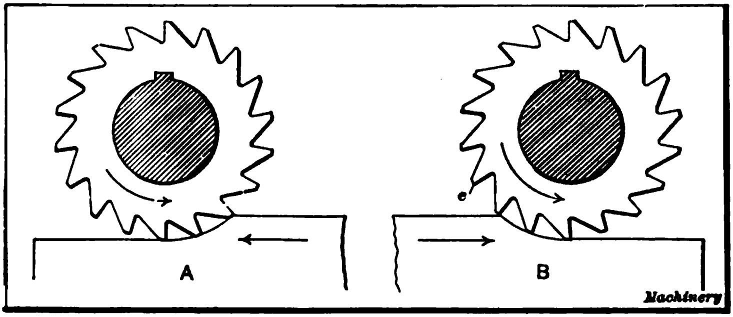

Fig. 6. (A) Work feeding against Rotation of Cutter. (B) Work feeding with Rotation of Cutter

Direction of Feeding Movement and Relative Rotation of Cutter

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

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

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

The Cutting Speed and Feed

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

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

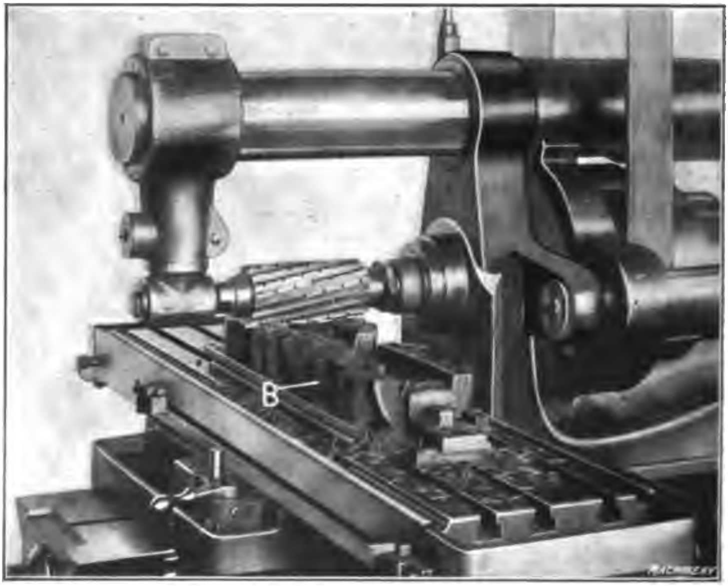

Fig. 7. Milling Cast-iron Bearing Caps

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

Milling Cast-iron Bearing Caps

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

CHAPTER III

DIFFERENT TYPES OF MILLING CUTTERS

As the processes of milling can be applied to an almost unlimited range of work, the cutters used on milling machines are made in a great variety of forms. Some of the different types can be used for general work of a certain class, whereas other cutters are made especially for milling one particular part. Of course, the number of different types that are used on any one machine, depends altogether on the variety of milling operations done on that machine. When the nature of the work varies widely, the stock of cutters must be comparatively large, and, inversely, when a machine is used for milling only a few parts, a large cutter equipment is not necessary.

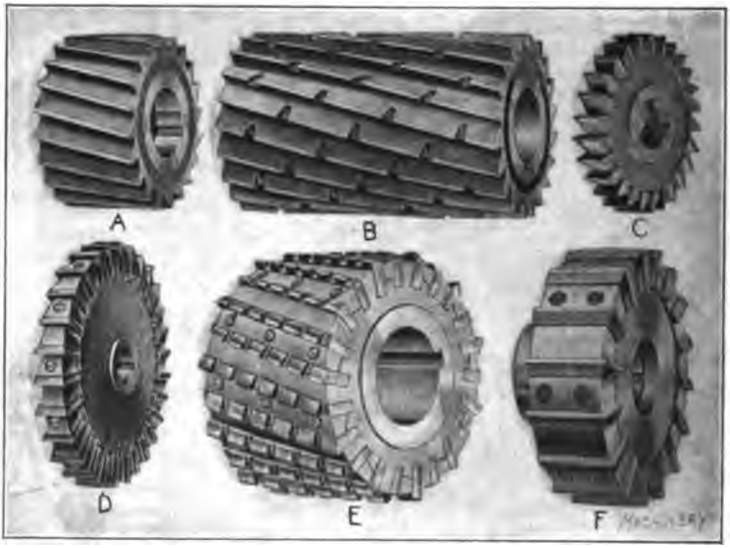

Fig. 8. Cylindrical, Side, and Face Milling Cutters

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 experienced with helical teeth which, being at an angle, begin to cut at one side and continue across the work with a smooth shaving action. Helical cutters also require less power for driving and produce smoother surfaces.

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

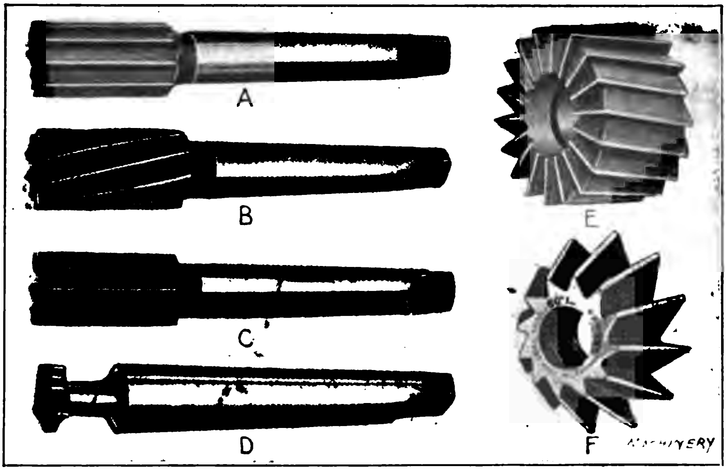

Fig. 9. End Mills, T-slot Cutter, Shell End Mill, and Angular Cutter

is shown at *E*. The cutter illustrated at *F* also has inserted teeth and is called a face milling cutter. This form is especially adapted to end or face milling operations. When in use, the cutter is mounted on a short arbor which is inserted in the milling machine spindle.

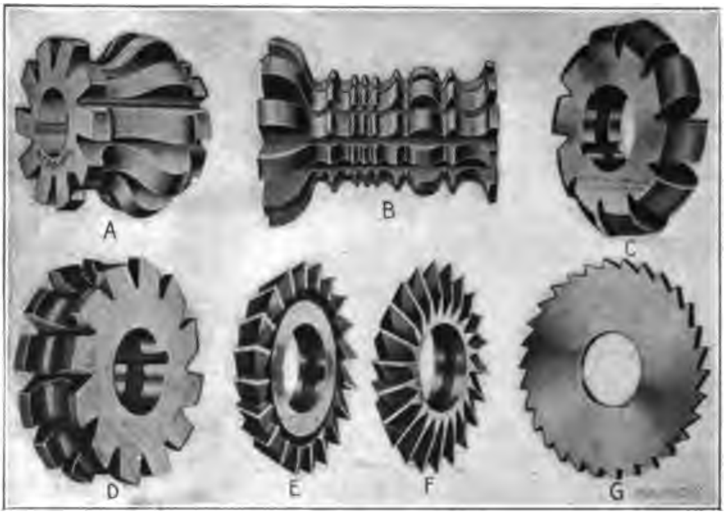

Fig. 10. Formed Cutters, Angular Cutters, and Slitting Saw

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

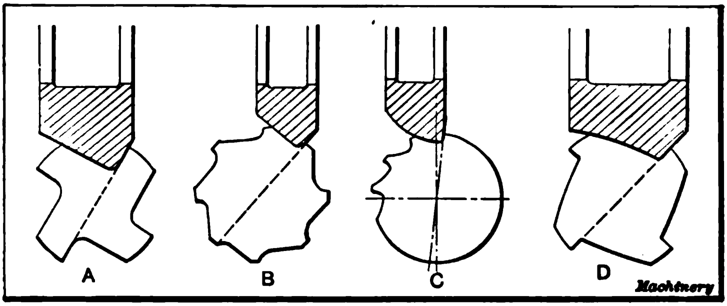

Fig. 11. Diagrams illustrating use of Formed Cutters for fluting Taps, Reamers, etc.

mill, because the inner ends of the teeth are sharp, and can more readily cut a path from the starting point.

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

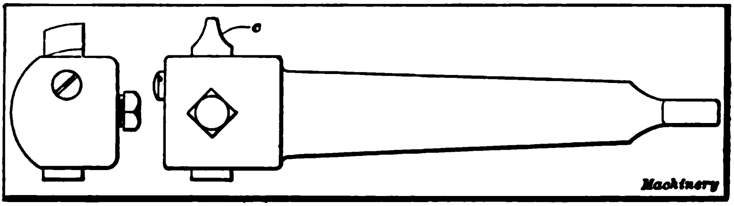

Fig. 12. Fly-cutter and Arbor

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

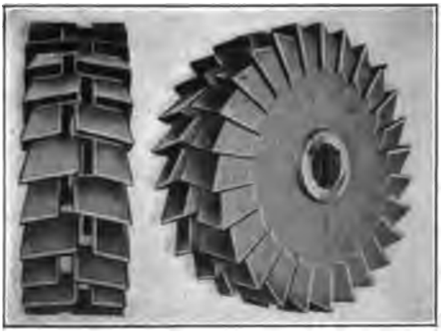

Fig. 13. Interlocking Side Milling Cutter

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

Fig. 12 shows a simple type of cutter that is often used for operations that will not warrant the expense of a regular formed cutter. This is called a fly-cutter. The milling is done by a single tool *c* which has the required outline. This tool is held in an arbor having a taper shank the same as an end mill. The advantage of the fly-cutter is that a single tool can be formed to the desired shape, at a comparatively small expense.

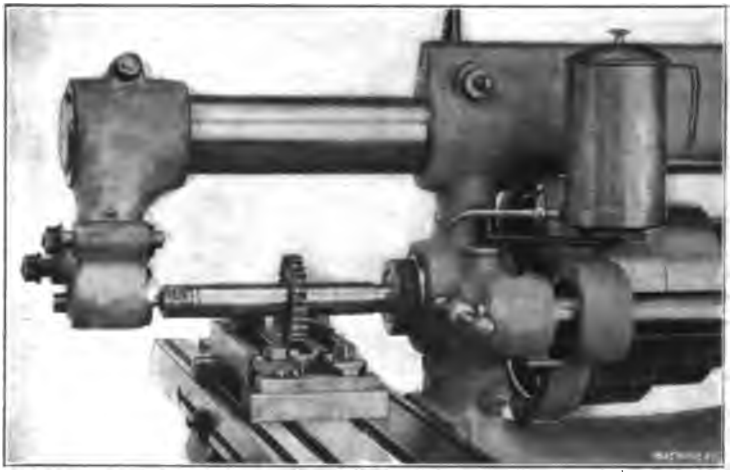

Fig. 14. Milling Groove with Interlocking Cutter

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

CHAPTER IV

FORM MILLING—STRADDLE AND GANG MILLING—END MILLING

One of the great advantages of the milling process is that duplicate parts having intricate shapes can be finished within such close limits as to be interchangeable. Because of this fact, milling machines are widely used for manufacturing a great variety of small machine parts having an irregular outline. The improved high-speed steel cutters now used, and the powerful machines which have been developed for driving these cutters, also make it possible to machine many heavy parts more rapidly by milling than in any other way.

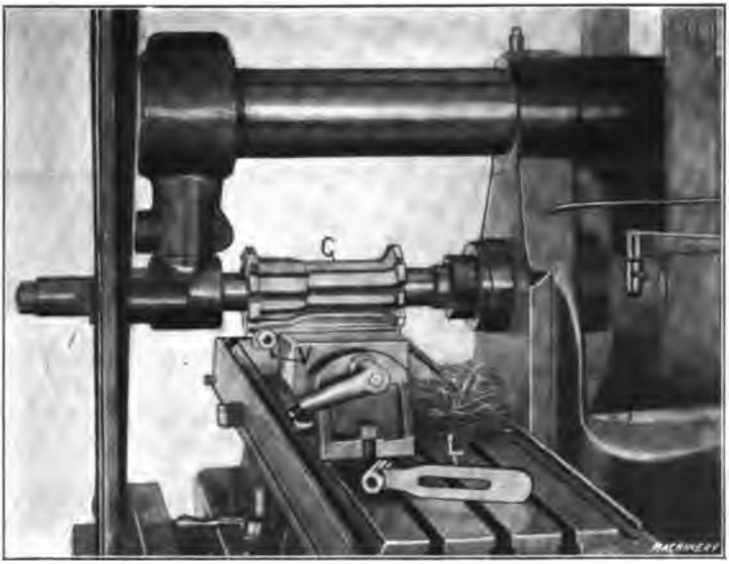

Fig. 15. Example of Form Milling

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

An example of form milling is illustrated in Fig. 16, which shows a steel piece *W* having an irregular edge which is milled by form cutter *C*. The part *W* is held in a vise which is equipped with special false jaws having the 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 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.

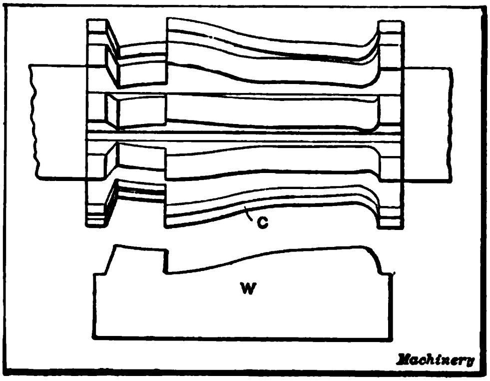

Fig. 16. Formed Cutter for Milling Part W

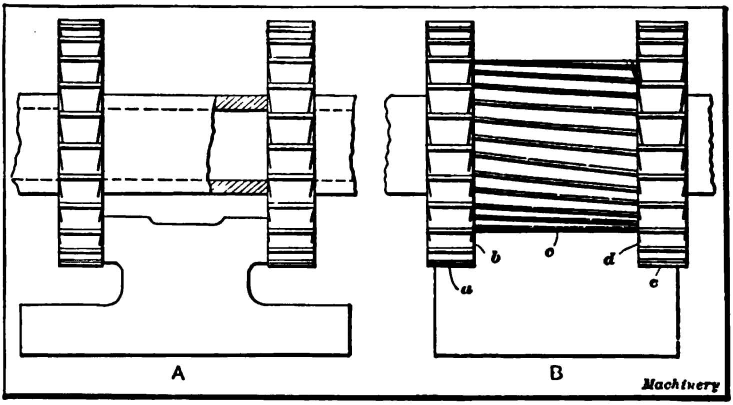

Fig. 17. (A) Straddle Milling. (B) Gang Milling

Straddle and Gang Milling

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

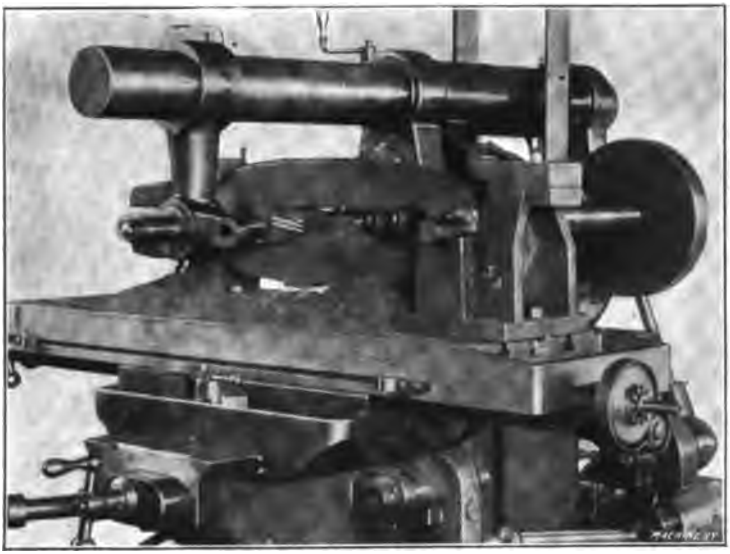

Fig. 18. Milling Slot of Crank-shaper Rocker-arm

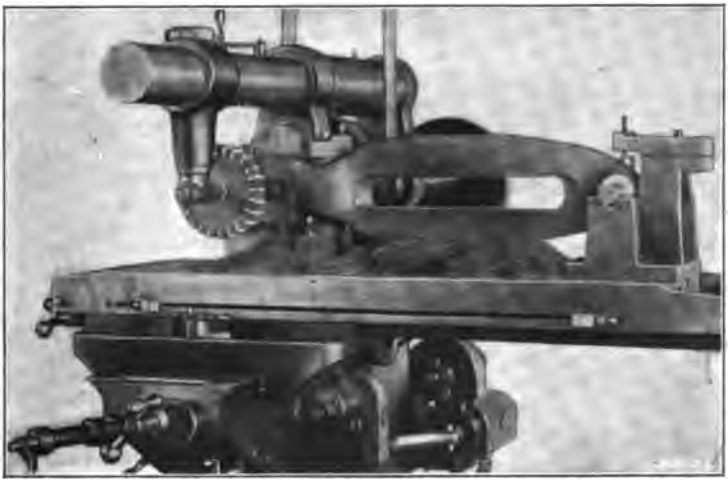

Fig. 19. Finishing End of Rocker-arm with Straddle Mill

made by taking a trial cut and measuring the finished surface. When the teeth on one side of each mill become dull, the opposite sides can be used by placing the right-hand cutter on the left-hand side and *vice versa;* that is by exchanging the positions of the mills on the arbor.

Figs. 18 and 19 show how the rocker-arm of a crank-shaper is finished by milling. This work requires two operations, one of which is a good example of straddle milling. A cylindrical cutter is used to mill both sides of the central slot, as shown in Fig. 18. The short slot at the left end of the rocker-arm is also milled by this same cutter, as well as the raised pads on the top and bottom of the arm. This cutter is 2¾ inches in diameter, and when milling the long central slot, a 1/16 inch cut is taken at the top and bottom with a feed of 3 inches per minute. The second operation consists in milling the sides of the slotted end, as shown in Fig. 19. Two 8½-inch cutters of the inserted-tooth type, are used to form a straddle mill, which machines both sides at the same time. The time required for milling each arm is 2¼ hours. The casting is held in a special two-part fixture which is bolted to the table. That section of the fixture which supports the right-hand end, has V-shaped notches which receive a trunnion as shown, thus setting the casting vertically, whereas the left-hand end is clamped between setscrews that are adjusted to locate the casting horizontally. After this fixture is once set up and adjusted, very little time is required for setting one of these rocker-arms in position for milling, but it would be rather difficult to hold a casting of this shape by the use of ordinary clamps.

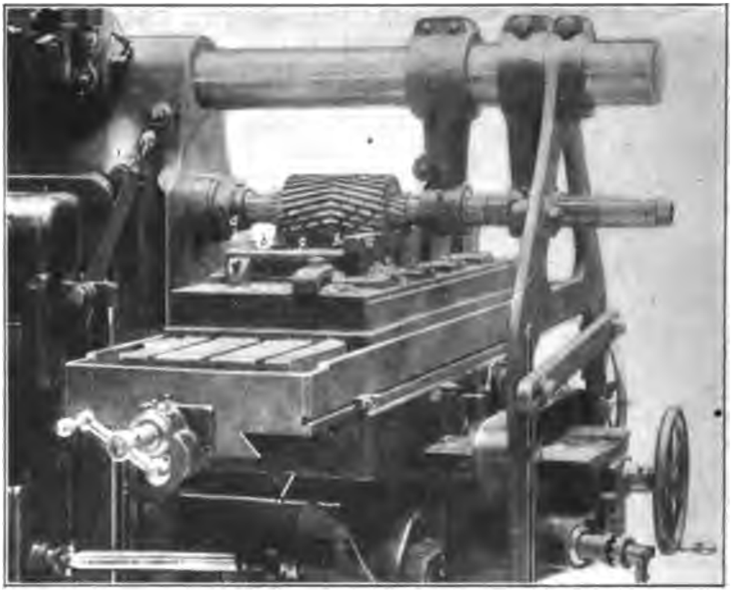

Fig. 20. Example of Gang Milling

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.

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 9⅜ inches and they are 6 inches in diameter. The speed of the cutter is 32 revolutions per minute and the greatest depth of cut about 3/16 inch.

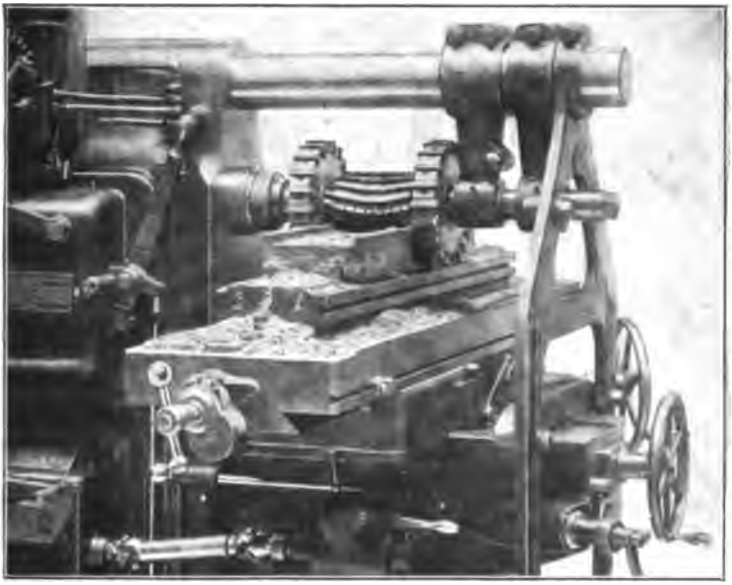

Fig. 21. Milling Top and Sides of Casting with Gang Mill

Another gang milling operation is shown in Fig. 21. The cutter, in this case, is similar to the one illustrated in Fig. 20, except that large side mills are employed for finishing the sides of the castings while the top surfaces are being milled. These side mills are 10½ inches in diameter and have inserted teeth or blades. The speed of a gang-mill which is composed of cutters that vary considerably in diameter, must be regulated to suit the largest cutters. In this instance, the cutter only makes 21 revolutions per minute, a comparatively slow speed being necessary owing to the large side mills.

Gang milling is usually employed when duplicate pieces are milled in large quantities, and the application of this method is almost unlimited. Obviously, the form of a gang-cutter and the number of cutters used, depends altogether on the shape of the part to be milled. Gang-cutters are sometimes made by combining cylindrical and formed cutters, for producing an irregular or intricate profile.

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

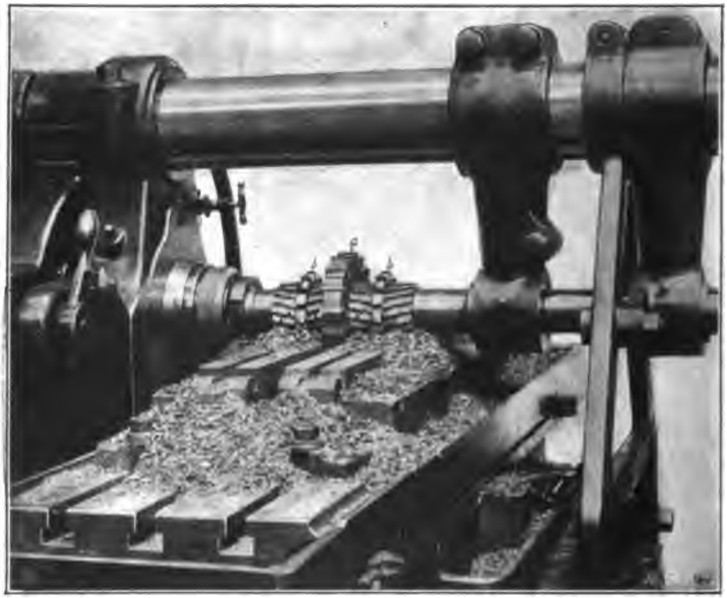

Fig. 22. Milling Two Parts Simultaneously

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 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, 6⅛ inches per minute. The feeding movement is to the left or against the rotation of the cutters, which is also true of Figs. 20, 21 and 22.

Fig. 23. Another Gang Milling Operation

End and Face Milling

All of the milling operations referred to so far have been performed with cutters mounted on an arbor, the latter being driven by the spindle and supported by an out-board bearing. For some classes of work, the cutter, instead of being placed on an arbor, is attached directly to the machine spindle. End mills, for instance, are driven in this way, as previously mentioned, and large face milling cutters are also fastened to the end of the spindle. Surfaces are frequently machined by end mills, when using a horizontal milling machine, because it would not be feasible to use a cutter mounted on an arbor.

Sketch *A*, Fig. 24, illustrates how a pad or raised part on the side of a casting would be machined by an end mill. The surface is milled by the radial teeth on the end as well as by the axial teeth, as the work is traversed at right-angles to the cutter. Occasionally, an end mill is used in this way, after the top surface of a casting has been milled with one or more cutters mounted on an arbor, in order to finish the work at one setting, which not only saves time, but insures accuracy of alignment between the finished parts.

Sketch *B* indicates how an end mill is used for cutting grooves in a vertical surface. The cutter is set to the required depth by moving the table inward, and then the longitudinal feed is engaged, which causes a groove to be milled equal in width to the diameter of the cutter. As mentioned in Chapter III, if it is necessary to start a groove by sinking the cutter in to depth, without first drilling a hole as a starting place, the form of mill shown at *C*, Fig. 9, is preferable, as the radial end-teeth have cutting edges on the inside so that they can more readily cut a path from the starting point, when the work is fed laterally. An end mill should not be used for cutting grooves or slots if a regular cutter mounted on an arbor can be employed.

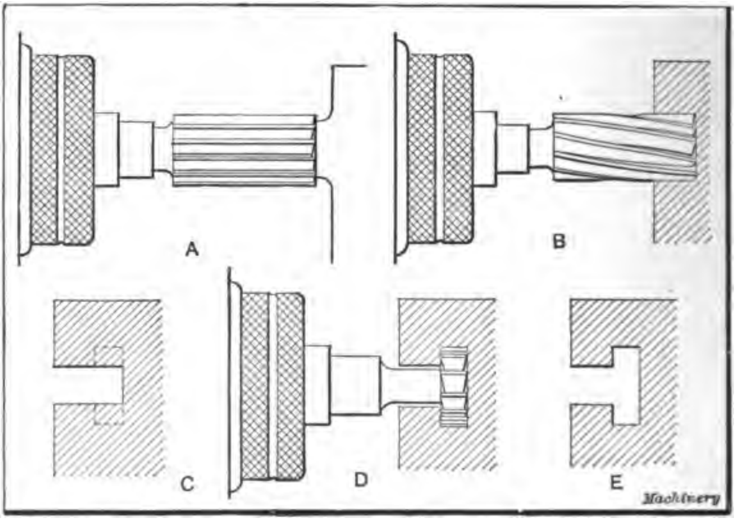

Fig. 24. End Milling—Diagrams illustrating use of T-slot Cutter

When milling T-slots such as are cut in the tables of machine tools for receiving clamping bolts, a plain slot is first milled to the depth of the T-slot as shown by sketch *C*, Fig. 24. This preliminary operation is usually done with a side mill of the proper width, while the work is clamped in a horizontal position. The enlarged or T-section is then milled as shown by sketch *D*, the casting being clamped in a vertical position, provided a horizontal milling machine is employed. The T-slot cutter enlarges the bottom of the straight groove, as indicated at *E*, which shows the finished slot.

Fig. 25 shows how an end mill is used for cutting an elongated slot in a link *L*. Prior to milling, holes are drilled at each end of the slot, one of which forms a starting place for the milling cutter. The link is held in a vise and the metal between the two holes is 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

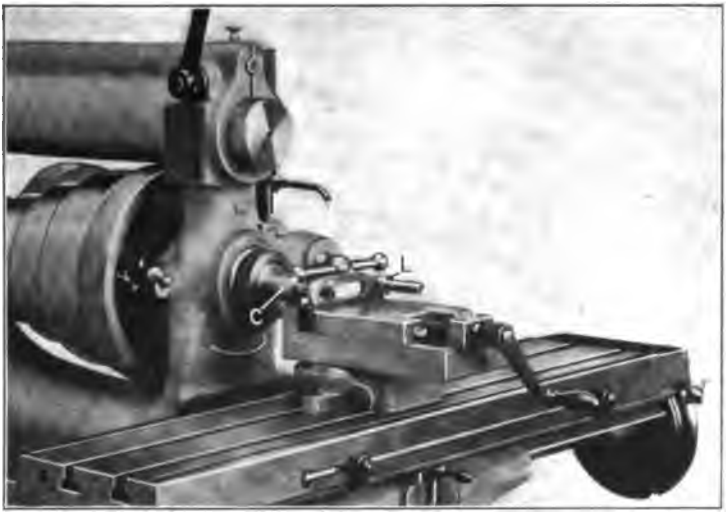

Fig. 25. Milling Slot with End Mill

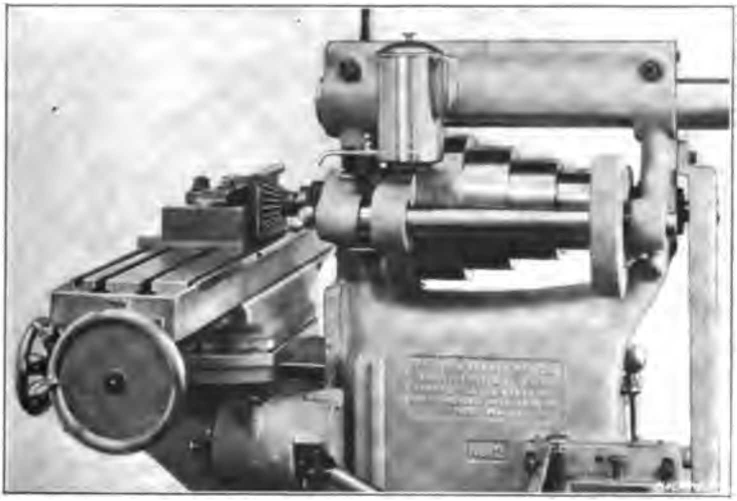

Fig. 26. Milling a Dovetail Groove

receive the end mill, the shank of which is too small to be placed directly in the spindle.

One method of machining a dovetail groove for a slide is shown in Fig. 26, which illustrates another end milling operation. The cutter used for this work has radial teeth on the end, and also angular teeth which incline 30 degrees with the axis of the cutter. The radial end teeth mill the bottom or flat surface of the groove and the angular teeth finish the sides and form the dovetail. The way the casting is clamped to the table is plainly shown by the illustration. The cutter is mounted on an arbor which is inserted in the spindle.

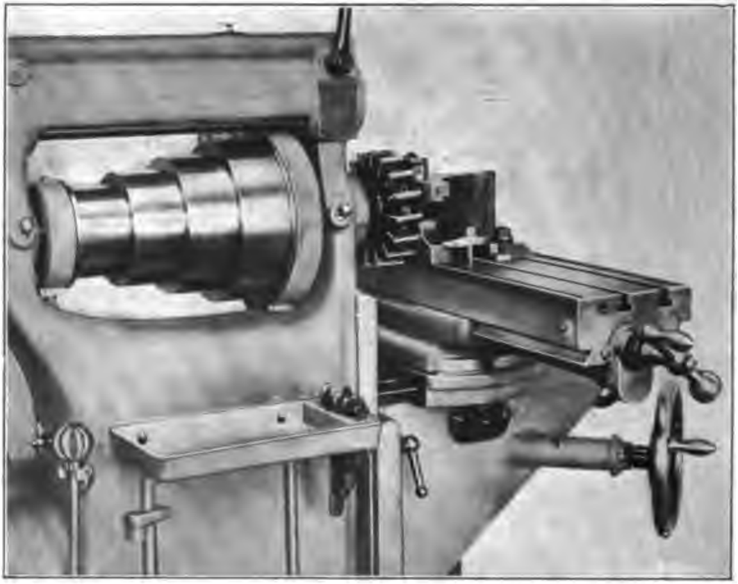

Fig. 27. Finishing Vertical Surface with Face Mill

An end milling operation is shown in Fig. 27, which differs from those previously referred to, in that a large face cutter is used, which, in this instance, is screwed onto the end of the spindle. Large face mills are employed on horizontal machines for milling flat surfaces that lie in a vertical plane. Some cutters of this type, instead of being threaded directly to the spindle, are mounted on a short arbor, whereas other designs fit over interchangeable sleeves threaded to the spindle. The casting illustrated in Fig. 27 is clamped against an angle-plate to hold it securely, and a strap at the rear prevents it from shifting backward when a cut is being taken. The surface is milled by feeding the table longitudinally, and only one cut is necessary, as the work is finished afterward by a surface grinder. The number of cuts required, when milling, is governed by the amount of metal to be removed and also by the accuracy of the work, as well as the quality of finish desired.

CHAPTER V

UNIVERSAL MILLING MACHINE

The milling machine illustrated in Fig. 28 is referred to as a universal type, because it is adapted to such a wide variety of milling operations. The general construction is similar to that of a plain milling machine, although the universal type has certain adjustments and attachments which make it possible to mill a greater variety of work. On the other hand, the plain machine is more simple, and, for a given size, more rigid in construction; hence, it is better adapted for milling large numbers of duplicate parts in connection with manufacturing operations.

The universal machine has a column *C*, a knee *K* which can be moved vertically on the column, and a table with cross and longitudinal adjustments the same as a machine of the plain type. There is a difference, however, in the method of mounting the table on the knee. As explained in Chapter I, the table of a plain machine is carried by a saddle *Z* (see Fig. 2), which is free to move in a crosswise direction, whereas, the table"s line of motion is at right angles to the spindle. The table of a universal machine also has these movements, and, in addition, it can be fed at an angle to the spindle by swiveling saddle *Z*, Fig. 28, on clamp-bed *B*, which is interposed between the saddle and knee. The circular base of the saddle has degree graduations which show the angle at which the table is set. When the zero mark of these graduations coincides with the zero mark on the clamp-bed, the table is at right angles to the spindle. The saddle is held rigidly to the clamp-bed, in whatever position it may be set, by bolts which must be loosened before making an adjustment. The utility of this angular adjustment will be explained later in connection with examples of universal milling operations.

The feed motion is derived from the main spindle, which is connected with the feed change mechanism enclosed at *F* by a chain and sprockets located inside of the column. The power is transmitted from *F* to gear-case *A* containing the reverse mechanism operated by lever *R*, which serves to start, stop, or reverse all feeds. Levers *T* and *V* control the automatic transverse and vertical feeds, respectively, and the longitudinal feed to the table is controlled or reversed by lever *L*. The longitudinal feed is automatically tripped by the adjustable dogs or tappets *D*. The vertical feed also has an automatic trip mechanism operated by dogs D_1. The table can be traversed by handles at each end and the cross movement is effected by wheel *E*. The vertical hand adjustment for the knee is controlled by handwheel *G*, which operates a telescopic elevating screw *H*. Adjustable dials, graduated to thousandths of an inch, indicate the longitudinal, traverse and vertical movements of the table. The spindle on this machine is driven by pulley *P*. Speed changes are obtained by shifting levers *O*, *Q* and *S*, and the speed obtained for any position of the levers is shown by a table or plate attached to the column. The machine is started or stopped by lever *U* which operates a clutch that engages or disengages belt pulley *P*. There is an outboard support for the arbors, having a bronzed-bush bearing and also an 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.

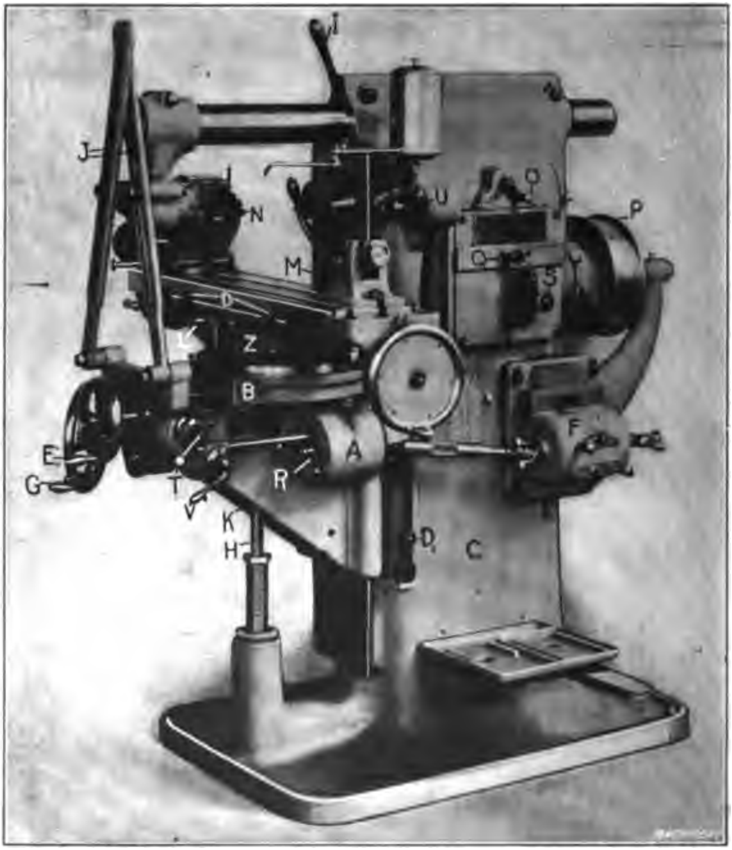

Fig. 28. Brown & Sharpe Universal Milling Machine

Indexing or Spiral Head

We have now considered, in a general way, the principal features of a universal machine, so far as the machine itself is concerned, but before referring to its practical application, the construction and use of the attachment seen at *N* should be explained. This attachment is called the spiral or indexing head and it forms a part of the equipment of all milling machines of the universal type. The spiral head, when in use, is bolted to the table of the machine. It is employed in connection with the foot-stock *M*, when milling work that must be supported between the centers. The spiral head is also used independently, that is, without the foot-stock, in which case the work is usually held in a chuck attached to the spindle. By means of the spiral head, the circumference of a cylindrical part can be divided into almost any number of equal spaces, as, for example, when it is necessary to cut a certain number of teeth in a gear. It is also used for imparting a rotary motion to work, in addition to the longitudinal feeding movement of the table, for milling helical or spiral grooves.

As a great deal of the work done in a universal milling machine requires a spiral head, its construction and operation should be thoroughly understood. The general arrangement of the design used on Brown & Sharpe machines is shown in Fig. 29. The main spindle *S* has attached to it a worm-gear *B* (see the cross-sectional view) which meshes with the worm *A* on shaft *O*, and the outer end of this shaft carries a crank *J* which is used for rotating the spindle when indexing. Worm-wheel *B* has forty teeth and a single-threaded worm *A* is used, so that forty turns of the crank are required to turn spindle *S* one complete revolution; hence, the required number of turns to index a fractional part of a revolution is found by simply dividing forty by the number of divisions desired. (As there are different methods of indexing, this subject is referred to separately to avoid confusion). In order to turn crank *J* a definite amount, a plate *I* is used, having several concentric rows of holes that are spaced equidistant in each separate row. When indexing, spring-plunger *P* is withdrawn by pulling out knob *J* and the crank is rotated as many holes as may be required. The number of holes in each circle of the index plate varies, and the plunger is set in line with any circle by adjusting the crank radially. One index plate can be replaced by another having a different series of holes, when this is necessary in order to obtain a certain division.

Sometimes it is desirable to rotate the spindle *S* independently of crank *J* and the worm gearing; then worm *A* is disengaged from worm-wheel *B*. This disengagement is effected by turning knob *E* about one-quarter of a revolution in a reverse direction to that indicated by the arrow stamped on it, thus loosening nut *G* which holds eccentric bushing *H*. Both knobs *E* and *F* are then turned at the same time, which rotates bushing *H* and throws worm *A* out of mesh. The worm is re-engaged by turning knobs *E* and *F* in the direction of the arrow; knob *E* should then be tightened with a pin wrench. The worm is disengaged in this way when it is desired to index rapidly by hand, and when the number of divisions required can be obtained by using plate *C*. This plate is attached to the spindle and contains a circle of holes which are engaged by pin *D*, operated by lever D_1, (see cross-section). This direct method of indexing can often be employed to advantage when milling flutes, reamers, taps, etc., but, as only a limited number of divisions can be obtained by this method, it is necessary to use crank *J* and index plate *I* for most of the work requiring indexing.

When the spiral head is used in connection with the milling of helical grooves (which are commonly but erroneously called spiral grooves), the main spindle *S* is rotated slowly by change gears as the work feeds past the cutter. These change gears transmit motion from the table feed-screw *L* to shaft *W*, which, in turn, drives spindle *S* through spiral gears, spur gears and the worm-gearing *A* and *B*. The method of determining what size gears to use for milling a helix of given lead is explained in Part II of this treatise.

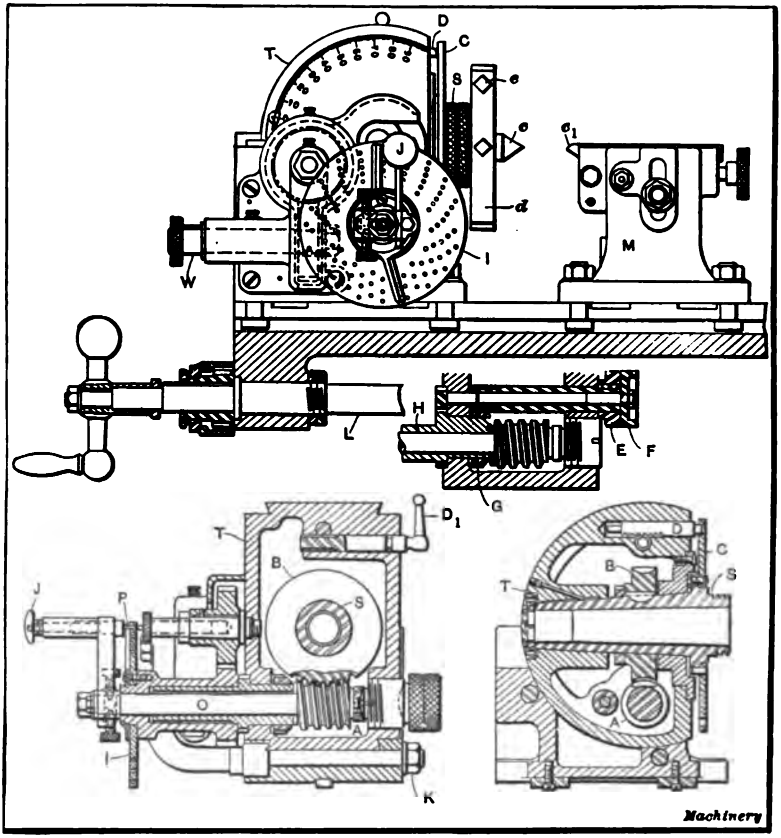

Fig. 29. Spiral Head used for Spiral Milling and Indexing

There is one other feature of the spiral head which should be referred to, and that is the angular adjustment of the main spindle. It is necessary for some classes of taper work to set the spindle at an angle with the table, and this adjustment is made by loosening bolts *K* and turning the circular body *T* in its base. The angle to which the head is set, is shown by graduations reading to ½ a degree. The spindle of this particular head can be set to any angle between 10 degrees below the horiontal and 5 degrees beyond the perpendicular. This adjustment is needed when milling taper work which must be set at an angle with the table.

The footstock *M*, which is used in connection with the spiral head when milling parts that are supported between centers, is also adjustable so that the centers c and c_1 can be aligned when milling flutes in taper reamers, etc. The foot stock center is set in line with center c, when the latter is in a horizontal position, by two taper pins on the rear side. When it is desired to set the center at an angle, these pins are removed and the nuts shown are loosened; the center can then be elevated or depressed by turning a nut at the rear, which moves the center through a rack and pinion.

Work mounted between the centers is caused to rotate with the spindle, either when indexing or when cutting helical grooves, by a dog which engages driver plate *d*. The tail of the dog should be confined by a set-screw *e*, to prevent any rocking movement of the work.

Spiral heads of different makes vary more or less in their arrangement, which is also true of milling machines, or, in fact, of any other kinds of machine tools. Machines or attachments of a given type, however, usually have the same general features, and if one or two typical designs are understood, it is comparatively easy to become familiar with other makes. Of course, the operator of any machine tool should be acquainted with its general construction, but it is even more important to have a clear understanding of its appplication to various kinds of work.

CHAPTER VI

USE OF THE SPIRAL HEAD—SIMPLE INDEXING

The spiral head is ordinarily used for such work as milling the teeth in milling cutters, fluting reamers and taps, cutting teeth in small gears, or for holding any part which must be rotated either at the time it is being milled or between successive cuts. As an example of the work that requires indexing between successive cuts, suppose we have a cylindrical milling cutter blank which requires 18 equally-spaced teeth to be cut across the circumference parallel to the axis and with the front face of each tooth on a radial line. The first step would be to press the blank on an arbor, assuming that it has previously been bored and turned to the proper diameter. The arbor and work is then placed between the centers of the spiral head and footstock, as shown in Fig. 30. After attaching a dog to the left-hand end, set-screw *e* is set against the dog to take up any play between these parts, and the footstock center is adjusted rather tightly into the center of the arbor to hold the latter securely.

The form of cutter to use is the next thing to consider. As the grooves which form the teeth are angular, the cutter must have teeth which incline to the axis a corresponding amount. A cutter of this type which is largely used for milling straight teeth, is shown at *E* in Fig. 10. The cutting edges (in this instance) have an inclination of 60 degrees with the side, and the cutter is known as a 60-degree, single-angle cutter, to distinguish it from the double-angle type, the use of which will be mentioned later. After the cutter is mounted on an arbor *b*, as indicated in Fig. 30, the straight side or vertical face is set in line with the center of the arbor as shown by the detail end-view *A*. There are several ways of doing this: A simple method is to draw a horizontal line across the end of the blank with an ordinary surface gage (the pointer of which should be set to the height of the spiral head center) and then rotate the work one-quarter of a revolution to place the line in a vertical position, after which the side of the cutter is set to coincide with this line. The side of the cutter can also be set directly by the centers. The table is first adjusted vertically and horizontally until the cutter is opposite the spiral head center. A scale or straightedge held against the side of the cutter is then aligned with the point of. the center, by shifting the table laterally.

The next step is to set the cutter to the right depth for milling the grooves. The depth is regulated according to the width which the tooth must have at the top, this width being known as the land. The usual method is to raise the knee, table and blank far enough to take a cut, which is known to be somewhat less than the required depth. The blank is then indexed or turned 1/18 of a revolution (as there are to be 18 teeth) in the direction shown by arrow *a*, and a second groove is started as at *B*. Before taking this cut, the blank is raised until the required width of land is obtained. The second groove is then milled, after which the blank is again indexed 1/18 of a revolution, thus locating it as at *C*. This operation of cutting a groove and indexing is repeated, without disturbing the position of the cutter, until all the teeth are formed as shown at *D*.

Plain or Simple Indexing

The dividing of a cylindrical part into an equal number of divisions by using the spiral head, is called indexing. The work is rotated whatever part of a revolution is required, by turning crank *J*. As previously explained, the shaft carrying this crank has a worm which meshes with a worm-wheel on the spiral-head spindle. As the worm is single-threaded, and as there are 40 teeth in the worm-wheel, 40 turns of the crank are necessary to rotate the spindle one complete revolution. If only a half revolution were wanted, the number of turns would equal 40 ÷ 2, or 20, and for 1/12 of a revolution, the turns would equal 40 ÷ 12, or 3-1/3, and so on. In each case, the number of turns the index crank must make, is obtained by dividing the number of turns required for one revolution of the index-head

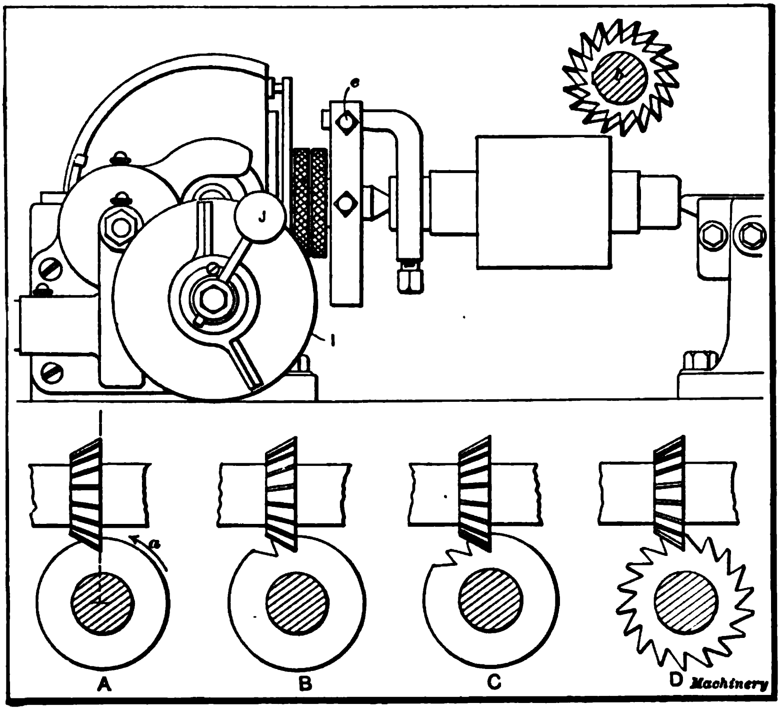

Fig. 30. Views illustrating use of Spiral Head for Indexing

spindle, by the number of divisions wanted. As the number of turns for one revolution is always 40, the rule then is as follows: Divide 40 by the number of divisions into which the periphery of the work is to be divided, to obtain the number of turns for the index crank.

By applying this rule to the job illustrated in Fig. 30, we find that the crank *J* must be turned 2-2/9 times to index the cutter from one tooth to the next, because there are 18 teeth, or divisions, and 40 ÷ 18 = 2-2/9. The next question that naturally arises is, how is the crank to be rotated exactly 2/9 of a turn? This is done by means of the index plate *I*, which has six concentric circles of holes. These holes have been omitted in this illustration owing to its reduced scale, but are shown in the detail view, Fig. 31. The number of holes in the different circles of this particular plate are 33, 31, 29, 27, 23, and 21. Now, in order to turn crank *J* 2/9 of a revolution, it is first necessary to adjust the crank radially until the latch-pin is opposite a circle having a number of holes exactly divisible by the denominator of the fraction (when reduced to its lowest terms) representing the part of a turn required. As the denominator of the fraction in this case is 9, there is only one circle on this plate that can be used, namely, the 27-hole circle. In case none of the circles have a number which is exactly divisible by the denominator of the fractional turn required, the index plate is replaced by another having a different series of holes. The number of holes that the latch-pin would have to move for 2/9 of a turn equals 27 × 2/9, or 6 holes. After the latch-pin is adjusted to the 27-hole circle, the indexing of the cutter 1/18 of a revolution is accomplished by pulling out the latch-pin and turning the crank 2 complete turns, and then 2/9 of a turn, or what is the same thing, 6 holes in a 27-hole circle. After each tooth groove is milled in the cutter, this indexing operation is repeated, the latch-pin being moved each time 2-2/9 of a turn from the position it last occupied, until the work has been indexed one complete revolution and all the teeth are milled.

Use of the Sector

After withdrawing the latch-pin, one might easily forget which hole it occupied, or become confused when counting the number of holes for the fractional turn, and to avoid mistakes of this kind, as well as to make it unnecessary to count, a device called a sector is used. The sector has two radial arms *A* and *B* (Fig. 31), which have an independent angular adjustment for varying the distance between them. The sector is used by so adjusting these arms that when the latch-pin is moved from one to the other, it will traverse the required number of holes for whatever fractional turn is necessary. Arm *A* is first set against the left side of the latch-pin, and then arm *B* is shifted to the right until there are 6 holes between it and the latch-pin, as shown in the illustration. When indexing, the latch-pin is withdrawn from hole *a* and the crank is first given two complete turns and then 2/9 of a turn by moving the crank until the latch-pin enters hole *b* adjacent to the arm *B* of the sector. The sector is then revolved until arm *A* again rests against the pin, as shown by the dotted lines. After the next groove is milled, the crank is turned two complete revolutions as before, with hole *b* as a starting point, and then 2/9 of a revolution, by swinging the latch-pin around to arm *B* and into engagement with hole *c*. This operation of indexing and then moving the sector is repeated after each tooth is milled, until the work has made one complete revolution.

When setting the sector arms, the hole occupied by the latch-pin should not be counted or, in other words, the arms should span one 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."

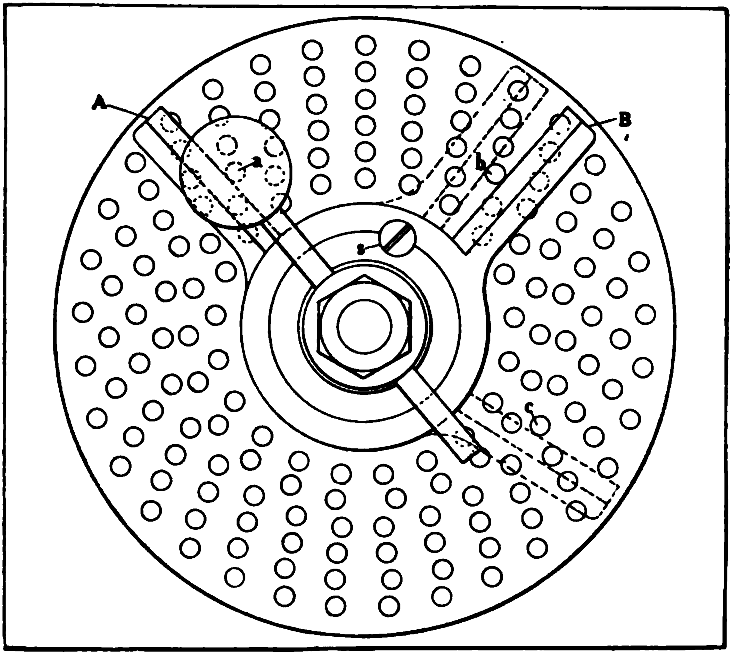

Fig. 31. Diagram showing how Sector is used when Indexing

In actual practice, the number of turns of the index crank for obtaining different divisions, is determined by referring to index tables. These tables give the numbers of divisions and show what circle of holes in the index plate should be used, and also the turns or fractional part of a turn (when less than one revolution is necessary) for the index crank. The fractional part of a turn is usually given as a fraction having a denominator which equals the number of holes in the index circle to be used, whereas the numerator denotes the number of holes the latch-pin should be moved, in addition to the complete revolutions, if one or more whole turns are required. For example: the movement for indexing 24 divisions would be given as 1-26/39 of a turn, instead of 1-2/3, the denominator 39 representing the number of holes in the index circle, and 26 the number of holes that the crank must be moved for obtaining 2/3 of a revolution, after making one complete turn.

Indexing for Angles

Sometimes it is desirable to index a certain number of degrees instead of a fractional part of a revolution. As there are 360 degrees in a circle and 40 turns of the index crank are required for one revolution of the spiral-head spindle, one turn of the crank must equal $\frac{360}{40} = 9$ degrees. Therefore, two holes in an 18-hole circle, or three holes in a 27-hole circle, is equivalent to a one-degree movement, as this is 1/9 of a turn. If we want to index 35 degrees, the number of turns the crank must make equals 35 ÷ 9 = 3-8/9, or three complete turns and 8 degrees. As a movement of two holes in an 18-hole circle equals one degree, a movement of 16 holes is required for 8 degrees. If we want to index 11½ degrees, the one-half degree movement is obtained by turning the crank one hole in the 18-hole circle, after the 11 degrees have been indexed by making one complete revolution (9 degrees), and four holes (2 degrees). Similarly, one and one-third degree can be indexed by using the 27-hole circle, three holes being required to index one degree, and one hole, one-third degree.

When it is necessary to index to minutes, the required movement can be determined by dividing the total number of minutes represented by one turn of the index crank or 540 (9 × 60 = 540), by the number of minutes to be indexed. For example, to index 16 minutes requires approximately 1/34 turn (540 ÷ 16 = 34, nearly), or a movement of one hole in a 34-hole circle. As the 33-hole circle is the one nearest to 34, this could be used and the error would be very small.

The following is a general rule for the approximate indexing of angles, assuming that forty revolutions of the index crank are required for one turn of the spiral-head spindle:

Divide 540 by the number of minutes to be indexed. If the quotient is nearly equal to the number of holes in any index circle available, the angular movement is obtained by turning the crank one hole in this circle; but, if the quotient is not approximately equal, multiply it by any trial number which will give a product equal to the number of holes in one of the index circles, and move the crank in the circle as many holes as are represented by the trial number.

If the quotient of 540 divided by the number of minutes to be indexed, is greater than the largest indexing circle, it is not possible to obtain the movement by the ordinary method of simple indexing.

Use of Chuck on the Spiral Head

It is often necessary to use a spiral head in connection with milling of parts which cannot be held between centers and must be attached directly to the spiral head spindle. A common method of holding work of this kind is to place it in a chuck which is screwed onto the spiral head spindle. An example of chuck work is shown in Fig. 32. The operation is that of milling a square head on bolt *B*. As the illustration shows, the spiral head spindle is set in a vertical position. This is done by loosening the clamp bolts *C* and turning the head 90 degrees, as shown by the graduations on the front side.

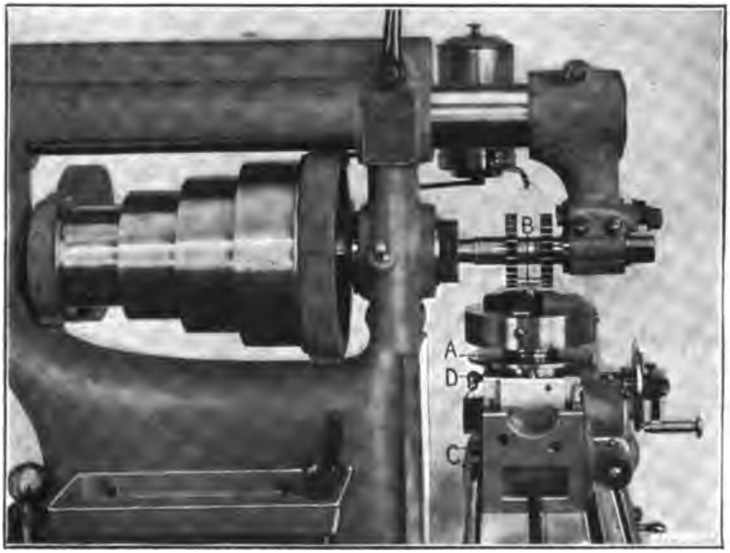

Fig. 32. Straddle Milling a Square Bolt-head

These clamp bolts should be tightened after the adjustment is made. The bolt is held in a three-jawed chuck and the body of the bolt extends into the hollow spindle of the spiral head. The square bolt head is machined to the required width by a straddle mill. One passage of this mill finishes two sides and then the spiral head spindle is indexed ¼ of a turn for milling the remaining sides. This indexing is done by using plate *A* which is attached directly to the spindle. The latch-pin engaging this plate is withdrawn by lever *D* and then the spindle and chuck are turned ¼ of a revolution, after which the latch-pin is again moved into engagement. This direct method of indexing requires little time and is used for simple operations of this kind, whenever the required movement can be obtained.

There is quite a variety of work which is milled either while held in a chuck or on some form of arbor inserted in the spiral head spindle. Whether a chuck or arbor is used, depends on the shape of the work, and, in some instances, on the nature of the milling operation. Chucks are frequently employed for holding cylindrical parts that are too long to go between the centers, but are small enough to pass through the hole in the spiral head spindle. The foot-stock 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.

Fig. 33. Vertical Attachment applied to a Horizontal Milling Machine

CHAPTER VII

ATTACHMENTS FOR THE MILLING MACHINE

The range of a milling machine or the variety of work it is capable of doing, can be greatly extended by the use of special attachments. Many of these are designed to enable a certain type of milling machine to perform operations that ordinarily would be done on a different machine; in other words, the attachment temporarily converts one type of machine into another. There are quite a number 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.

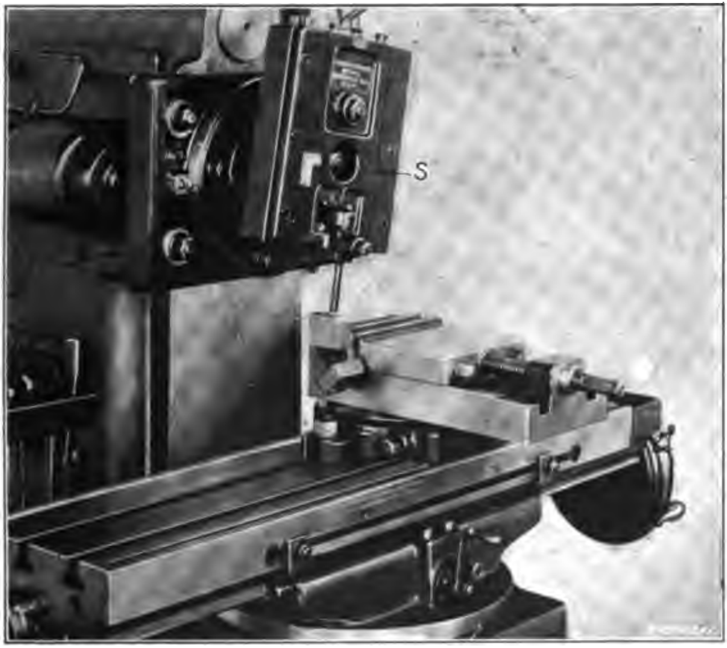

Fig. 34. Slotting Attachment applied to a Milling Machine

Vertical Milling Attachment

The way a vertical spindle milling attachment is applied to a horizontal milling machine is shown in Fig. 33. The base of the attachment is securely clamped to the column of the machine by four bolts and the outer end is inserted in the regular arbor support. The spindle is driven through bevel gears connecting with a horizontal shaft inserted in the main spindle of the machine. The spindle of this particular attachment can be set at any angle in a vertical or horizontal plane, and its position is shown by graduations reading to degrees. For the operation illustrated, which is that of milling the edge of the steel block shown, the spindle is set at an angle of 45 degrees from the vertical. The block is held in an ordinary vise and it is fed past the cutter by using the cross feed. The opposite edge 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.

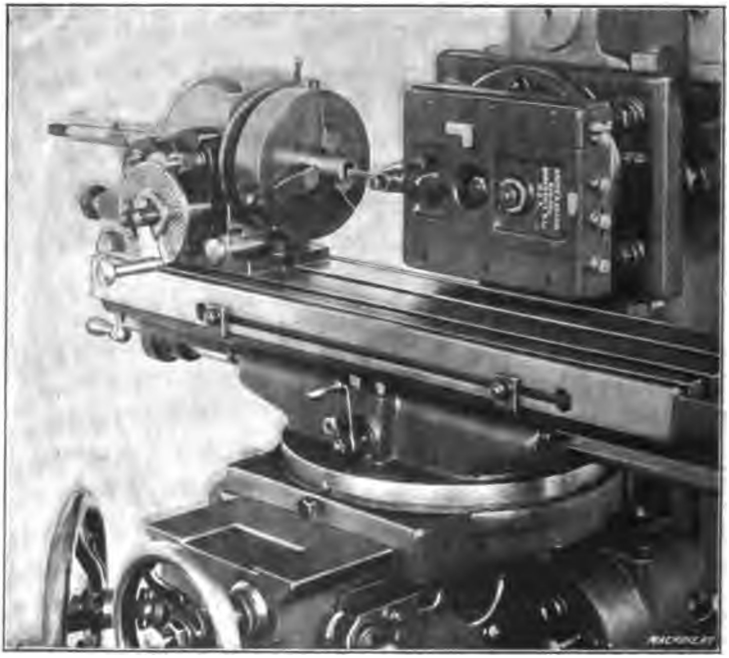

Fig. 35. Slotting Attachment finishing Square Hole in Long Rod held in Spiral Head

Slotting Attachment

The slotting attachment, as its name implies, is used for converting a milling machine into a slotter. The base *B* is clamped to the column of the machine as shown in Fig. 34. The tool slide *S*, which has a reciprocating movement like the ram of a slotter, is driven from the main spindle of the machine by an adjustable crank which enables the stroke to be varied. The tool slide can be set in any position from the vertical to the horizontal, in either direction, the angle being indicated by graduations on the base. When the attachment is in use, a slotting tool of the required shape is clamped to the end of the slide by the bolt shown, and it is prevented from being pushed upward by a stop that is swung over the top of the tool shank. Fig. 34 shows the attachment slotting a rectangular opening in a screw machine tool which is held in the vise. As this opening must be at an angle, the tool slide is inclined to the vertical, as shown. A previously drilled hole forms a starting place for the slotting tool.

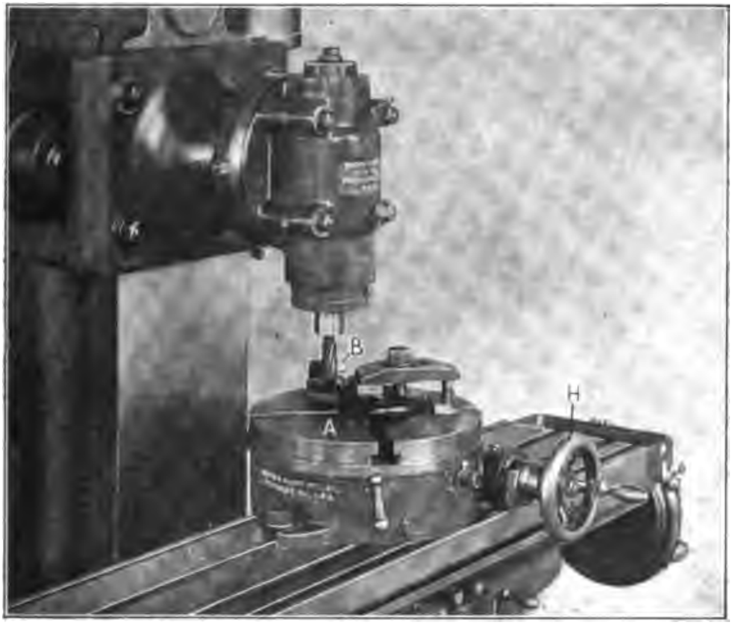

Fig. 36. Combined use of Vertical and Circular Milling Attachments

Fig. 35 shows another application of the slotting attachment. The operation in this case is that of cutting a square hole in the end of a rod. As this rod is too long to be placed in a vertical position, it is inserted through the hollow spindle of the spiral head and is held in a three-jaw chuck as shown. The slotting attachment is swung around to the horizontal position, and after one side of the opening is finished, the rod is indexed ¼ of a turn by using the direct indexing plate attached to the spindle back of the chuck.

Circular Milling Attachment

A circular milling attachment is shown in Fig. 36. It is bolted to the machine and has a round table *A* which can be rotated for milling circular parts. This attachment is generally used in connection with the vertical spindle attachment, as shown in this illustration. The operation is that of milling a segment-shaped end on a small casting *B*. The bored hub of this casting is placed over a bushing in the center of the table, and is held by a clamp. The top or flat surface of the outer end is first milled, and then the table is raised for finishing the circular part as shown. The table of the attachment is given a circular feeding movement by turning handwheel *H*. Incidentally this view shows another type of vertical attachment which differs from the one illustrated in Fig. 33 in that it can only be adjusted at right-angles to the axis of the spindle. This type is designed for comparatively heavy vertical milling operations.

CHAPTER VIII

GASHING AND HOBBING A WORM-WHEEL IN A MILLING MACHINE

The universal milling machine is sometimes used for cutting the teeth in worm-wheels, although when there is much of this work to be done, regular gear-cutting machines are generally used. The worm itself should be finished first, as it can be used advantageously for testing the center distance when hobbing the worm-wheel. We shall assume that the worm has been made, and that the wheel blank has been turned to the required size.

The teeth of the worm-wheel are formed by two operations, which are illustrated in Figs. 37 and 38. First it is necessary to gash the blank and then the teeth are finished by hobbing. Gashing consists in cutting teeth around the periphery of the blank, which are approximately the shape of the finished teeth. This is done, preferably, by the use of an involute gear cutter of a number and pitch corresponding to the number and pitch of the teeth in the wheel. If a gear cutter is not available, a plain milling cutter, the thickness of which should not exceed three-tenths of the circular pitch, may be used. The corners of the teeth of the cutter should be rounded, as otherwise the fillets of the finished teeth will be partly removed.

As the worm which meshes with and drives the worm-wheel is simply a short screw, it will be apparent that if the axes of the worm-wheel and worm are to be at right angles to each other, the teeth of the wheel must be cut at an angle to its axis, in order to mesh with the threads of the worm. The method of setting the work and obtaining this angle will first be considered.

After the dividing head and tailstock have been clamped to the table and the cutter has been fastened on its arbor, the table is adjusted until the centers of the dividing head and the center of the cutter lie in the same vertical plane. If the cutter used has a center-line around its periphery, the table can be set by raising it high enough to bring the index head center in line with the cutter; the table can then be adjusted laterally until the center coincides with the center-line on the cutter. When the table is set, it should be clamped to the knee slide.

The blank to be gashed is pressed on a true-running arbor which is mounted between the centers of the dividing head and tailstock as illustrated in Fig. 37, and the driving dog is secured, to prevent any vibration of the work. The table is next moved longitudinally until a point midway between the sides of the blank is directly beneath the center of the cutter arbor. To set the blank in this position, place a square blade or straightedge against it first on one side and then on the other and adjust the table longitudinally until the distances between the blade and arbor are the same on both sides.

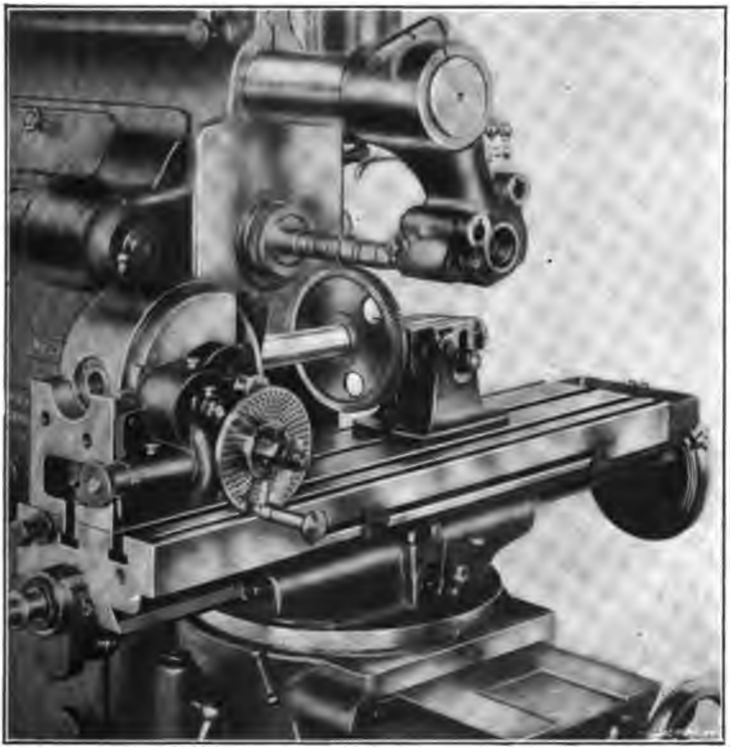

Fig. 37. Gashing a Worm-wheel in a Universal Milling Machine

Angular Position of Table for Gashing

The table should now be set to the proper angle for gashing the teeth. This angle, if not given on the drawing, may be determined either graphically or by calculation. The first method is illustrated in

Fig. 39. Some smooth surface should be selected, having a straight edge as at *A*. A line having a length *B* equal to the lead of the worm thread, is drawn at right angles to the edge *A*. and a distance *C* is laid off equal to the circumference of the pitch circle of the worm. If the diameter of the pitch circle is not given on the drawing, it may be found by subtracting twice the addendum of the teeth from the outside diameter of the worm. The addendum equals the linear pitch × 0.3183. The angle x is next measured with a protractor, as shown in the illustration. The table of the machine is then swiveled to a corresponding angle, as shown by the graduations provided on all universal milling machines. If the front of the table is represented by the edge *A*. and the worm has a right-hand thread, the table should be swiveled as indicated by the line *ab*; whereas if the worm has a left-hand thread, the table should be turned in an opposite direction.

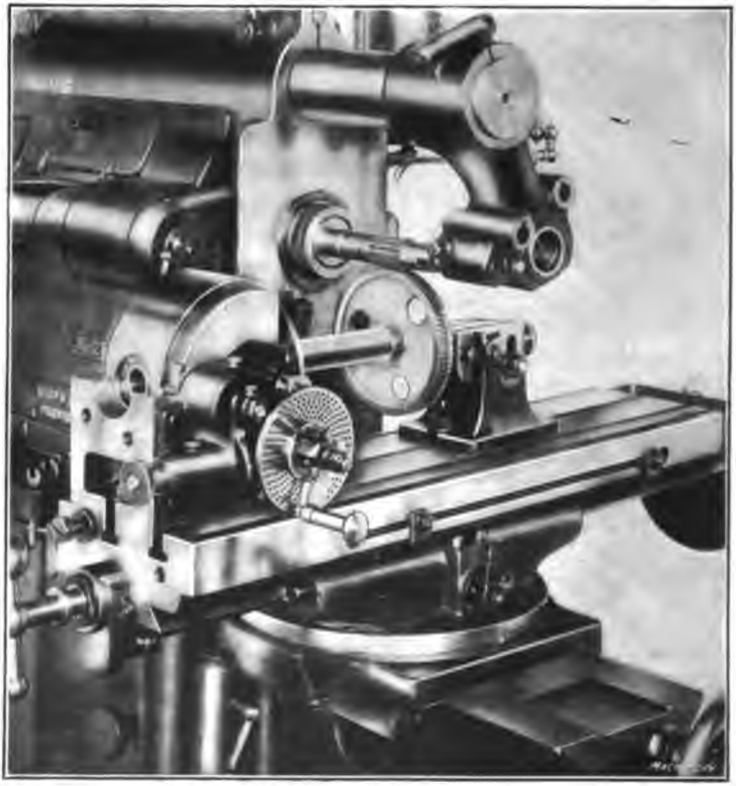

Fig. 38. Hobbing the Teeth of a Worm-wheel

The angle that the teeth of the worm-wheel make with its axis, or the angle to which the table is to be swiveled, may also be found by dividing the lead of the worm thread by the circumference of the pitch circle; the quotient will equal the tangent of the desired angle. This angle is then found by referring to a table of natural tangents.

Milling the Gashes in a Worm-wheel

When the table is set and clamped in place, as many gashes are cut in the periphery of the wheel as there are to be teeth. If the diameter of the cutter is no larger than the diameter of the hob to be used, the depth of the gashes should be slightly less than the whole depth of the tooth. This whole depth may be found by multiplying the linear pitch by 0.6866. Before starting a cut, bring the cutter into contact with the wheel blank, set the dial on the elevating screw at zero, and sink the cutter to the proper depth as indicated by the dial. The blank is then lowered to clear the cutter and indexed for gashing the next tooth.

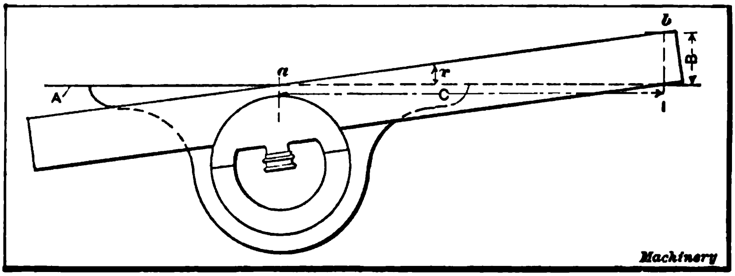

Fig. 39. Method of obtaining Helix Angle of Worm

When the cutter is larger than the hob, the whole depth of tooth should be laid off on the side of the blank, and a gash cut in to this line. The depth as indicated on the dial should then be noted and all the gashes cut to a corresponding depth.

Hobbing the Teeth of a Worm-wheel

When the gashing is finished, the table is set at right angles with the spindle of the machine, and the cutter is replaced with a hob, as shown in Fig. 38. The latter is practically a milling cutter shaped like the worm with which the wheel is to mesh, except that the thread on the hob has several lengthwise flutes or gashes to form cutting edges. The outside diameter of the hob and the diameter at the bottom of the teeth, are slightly greater than the corresponding dimensions of the worm, to provide clearance between the worm and worm-wheel. Before hobbing, the dog is removed from the arbor to permit the latter to turn freely on its centers. The hob is then placed in mesh with the gashed blank, and the teeth of the worm-wheel are finished by revolving the blank and hob together. As the two rotate, the blank is gradually raised until the body of the hob between the teeth just grazes the throat of the blank. The latter is then allowed to make a few revolutions to insure well-formed teeth.

If the center-to-center distance between the worm and worm-wheel must be accurate, this dimension can be tested by placing the finished worm in mesh with the wheel (after the latter has been hobbed), and measuring the center distance directly. The worm is placed on top of the wheel, after removing the chips from the teeth, and it is turned along until its axis is parallel with the top of the table. It can be set in this position by testing the threads at each end with a surface gage. The distance from the top of the worm to the top of the arbor is then measured, and the *difference* between the radii of the arbor and worm is either added to or subtracted from this dimension, to obtain the center-to-center distance.

If the worm is accurately made and the worm-wheel blank of the correct size, this center distance should be very close to the dimension required. If necessary, the hob may be again engaged with the wheel and another light cut taken. When testing the center distance, as explained in the foregoing, it is better to lower the knee sufficiently to make room for the worm beneath the hob, and not disturb the longitudinal setting of the table. The relation between the wheel and hob will then be maintained, which is desirable in case it is necessary to re-hob the wheel to reduce the center distance.

The center-to-center distance can also be measured with a fair degree of accuracy (when using the machine in Figs. 37 and 38) at the time the wheel is being hobbed. This is done by elevating the knee and blank until the distance from the top of the column knee-slide to the line on the column marked *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 betweeen the centers of the arbor on which the worm-wheel is mounted, and the hob.

When worm-wheels are cut in machines especially designed for this purpose, the wheel blanks, instead of being mounted on a free-running arbor, are driven by gearing at the proper speed. This makes gashing the blank previous to hobbing unnecessary, as the change gears insure a correct spacing of the worm-wheel teeth.

No. 45. Drop Forging.—Lay-out of Plant; Methods of Drop Forging; Dies.

No. 46. Hardening and Tempering.—Hardening Plants; Treating High-Speed Steel; Hardening Gages.

No. 47. Electric Overhead Cranes.—Design and Calculation.

No. 48. Files and Filing.—Types of Files; Using and Making Files.

No. 49. Girders for Electric Overhead Cranes.

No. 50. Principles and Practice of Assembling Machine Tools, Part I.

No. 51. Principles and Practice of Assembling Machine Tools, Part II.

No. 52. Advanced Shop Arithmetic for the Machinist.

No. 53. Use of Logarithms and Logarithmic Tables.

No. 54. Solution of Triangles, Part I.—Methods, Rules and Examples.

No. 55. Solution of Triangles, Part II.—Tables of Natural Functions.

No. 56. Ball Bearings.—Principles of Design and Construction.

No. 57. Metal Spinning.—Machines, Tools and Methods Used.

No. 58. Helical and Elliptic Springs.—Calculation and Design.

No. 59. Machines, Tools and Methods of Automobile Manufacture.

No. 60. Construction and Manufacture of Automobiles.

No. 61. Blacksmith Shop Practice.—Model Blacksmith Shop; Welding; Forging of Hooks and Chains; Miscellaneous.

No. 62. Hardness and Durability Testing of Metals.

No. 63. Heat Treatment of Steel.—Hardening, Tempering, Case-Hardening.

No. 64. Gage Making and Lapping.

No. 65. Formulas and Constants for Gas Engine Design.

No. 66. Heating and Ventilation of Shops and Offices.

No. 67. Boilers.

No. 68. Boiler Furnaces and Chimneys.

No. 69. Feed Water Appliances.

No. 70. Steam Engines.

No. 71. Steam Turbines.

No. 72. Pumps, Condensers, Steam and Water Piping.

No. 73. Principles and Applications of Electricity.—Static Electricity; Electrical Measurements; Batteries.

No. 74 Principles and Applications of Electricity.—Magnetism; Electro-Magnetism; Electro-Plating.

No. 75. Principles and Applications of Electricity.—Dynamos; Motors; Electric Railways.

No. 76. Principles and Applications of Electricity.—Electric Lighting.

No. 77. Principles and Applications of Electricity.—Telegraph and Telephone.

No. 78. Principles and Applications of Electricity.—Transmission of Power.

No. 79. Locomotive Building.—Main and Side Rods.

No. 80. Locomotive Building.—Wheels; Axles; Driving Boxes.

No. 81. Locomotive Building.—Cylinders and Frames.

No. 82. Locomotive Building.—Valve Motion.

No. 83. Locomotive Building.—Boiler Shop Practice.

No. 84. Locomotive Building.—Erecting.

No. 85. Mechanical Drawing. — Instruments; Materials; Geometrical Problems.

No. 86. Mechanical Drawing.—Projection.

No. 87. Mechanical Drawing.—Machine Details.

No. 88. Mechanical Drawing.—Machine Details.

No. 89. The Theory of Shrinkage and Forced Fits.

No. 90. Railway Repair Shop Practice.

No. 91. Operation of Machine Tools.—The Lathe, Part I.

No. 92. Operation of Machine Tools.—The Lathe, Part II.

No. 93. Operation of Machine Tools.—Planer, Shaper, Slotter.

No. 94. Operation of Machine Tools.—Drilling Machines.

No. 95. Operation of Machine Tools.—Boring Machines.

No. 96. Operation of Machine Tools.—Milling Machines, Part I.

No. 97. Operation of Machine Tools.—Milling Machines, Part II.

No. 98. Operation of Machine Tools.—Grinding Machines.

No. 99. Automatic Screw Machine Practice.—Operation of the Brown & Sharpe Automatic Screw Machine.

No. 100. Automatic Screw Machine Practice.—Designing and Cutting Cams for the Automatic Screw Machine.

No. 101. Automatic Screw Machine Practice.—Circular Forming and Cut-off Tools.

No. 102. Automatic Screw Machine Practice.—External Cutting Tools.

No. 103. Automatic Screw Machine Practice.—Internal Cutting Tools.

No. 104. Automatic Screw Machine Practice.—Threading Operations.

No. 105. Automatic Screw Machine Practice.—Knurling Operations.

No. 106. Automatic Screw Machine Practice.—Cross Drilling, Burring and Slotting Operations.

No. 107. Drop Forging Dies and Die-Sinking.—A Complete Treatise on Die-sinking Methods.

No. 108. Die Casting Machines.

No. 109. Die Casting.—Methods and Machines Used; the Making of Dies for Die Casting.

No. 110. The Extrusion of Metals.—Machines and Methods Used in a Little-known Field of Metal Working.

No. 111. Lathe Bed Design.

No. 112. Machine Stops, Trips and Locking Devices.—Also includes Reversing Mechanisms and Clamping Devices.

ADDITIONAL TITLES WILL BE ANNOUNCED IN *MACHINERY* FROM TIME TO TIME

MACHINERY'S REFERENCE BOOKS

This treatise is one unit in a comprehensive Series of Reference books originated by Machinery, and including an indefinite number of compact units, each covering one subject thoroughly. The whole series comprises a complete working library of mechanical literature. The price of each book is 25 cents (one shilling) delivered anywhere in the world.

LIST OF REFERENCE BOOKS

No. 1. Worm Gearing.—Calculating Dimensions; Hobs; Location of Pitch Circle; Self-Locking Worm Gearing, etc.

No. 2. Drafting-Room Practice.—Systems; Tracing, Lettering and Mounting.

No. 3. Drill Jigs.—Principles of Drill Jigs; Jig Plates; Examples of Jigs.

No. 4. Milling Fixtures.—Principles of Fixtures; Examples of Design.

No. 5. First Principles of Theoretical Mechanics.

No. 6. Punch and Die Work.—Principles of Punch and Die Work; Making and Using Dies; Die and Punch Design.

No. 7. Lathe and Planer Tools.—Cutting Tools; Boring Tools; Shape of Standard Shop Tools; Forming Tools.

No. 8. Working Drawings and Drafting-Room Kinks.

No. 9. Designing and Cutting Cams.—Drafting of Cams; Cam Curves; Cam Design and Cam Cutting.

No. 10. Examples of Machine Shop Practice.—Cutting Bevel Gears; Making a Worm-Gear; Spindle Construction.

No. 11. Bearings.—Design of Bearings; Causes of Hot Bearings; Alloys for Bearings; Friction and Lubrication.

No. 12. Out of print.

No. 13. Blanking Dies.—Making Blanking Dies; Blanking and Piercing Dies; Split Dies; Novel Ideas in Die Making.

No. 14. Details of Machine Tool Design.—Cone Pulleys and Belts; Strength of Countershafts; Tumbler Gear Design; Faults of Iron Castings.

No. 15. Spur Gearing.—Dimensions; Design; Strength; Durability.

No. 16. Machine Tool Drives.—Speeds and Feeds; Single Pulley Drives; Drives for High Speed Cutting Tools.

No. 17. Strength of Cylinders.—Formulas, Charts, and Diagrams.

No. 18. Shop Arithmetic for the Machinist.—Tapers; Change Gears; Cutting Speeds; Feeds; Indexing; Gearing for Cutting Spirals; Angles.

No. 19. Use of Formulas in Mechanics.—With numerous applications.

No. 20. Spiral Gearing.—Rules, Formulas, and Diagrams, etc.

No. 21. Measuring Tools.—History of Standard Measurements; Calipers; Compasses; Micrometer Tools; Protractors.

No. 22. Calculation of Elements of Machine Design.—Factor of Safety; Strength of Bolts; Riveted Joints; Keys and Keyways; Toggle-joints.

No. 23. Theory of Crane Design.—Jib Cranes; Shafts, Gears, and Bearings; Force to Move Crane Trolleys; Pillar Cranes.

No. 24. Examples of Calculating Designs.—Charts in Designing; Punch and Riveter Frames; Shear Frames; Billet and Bar Passes, etc.

No. 25. Deep Hole Drilling.—Methods of Drilling; Construction of Drills.

No. 26. Modern Punch and Die Construction.—Construction and Use of Subpress Dies; Modern Blanking Die Construction; Drawing and Forming Dies.

No. 27. Locomotive Design, Part I.—Boilers, Cylinders, Pipes and Pistons.

No. 28. Locomotive Design, Part II.—Stephenson and Walschaerts Valve Motions; Theory, Calculation and Design.

No. 29. Locomotive Design, Part III.—Smokebox; Exhaust Pipe; Frames; Cross-heads; Guide Bars; Connecting-rods; Crank-pins; Axles; Driving wheels.

No. 30. Locomotive Design, Part IV.—Springs, Trucks, Cab and Tender.

No. 31. Screw Thread Tools and Gages.

No. 32. Screw Thread Cutting.—Lathe Change Gears; Thread Tools; Kinks.

No. 33. Systems and Practice of the Drafting-Room.

No. 34. Care and Repair of Dynamos and Motors.

No. 35. Tables and Formulas for Shop and Drafting-Room.—The Use of Formulas; Solution of Triangles; Strength of Materials; Gearing; Screw Threads; Tap Drills; Drill Sizes; Tapers; Keys, etc.

No. 36. Iron and Steel.—Principles of Manufacture and Treatment.

No. 37. Bevel Gearing.—Rules and Formulas; Examples of Calculation; Tooth Outlines; Strength and Durability; Design; Methods of Cutting Teeth.

No. 38. Out of print. See No. 98.

No. 39. Fans, Ventilation and Heating.—Fans; Heaters; Shop Heating.

No. 40. Fly-Wheels.—Their Purpose, Calculation and Design.

No. 41. Jigs and Fixtures, Part I.—Principles of Design; Drill Jig Bushings; Locating Points; Clamping Devices.

No. 42. Jigs and Fixtures, Part II.—Open and Closed Drill Jigs.

No. 43. Jigs and Fixtures, Part III.—Boring and Milling Fixtures.

No. 44. Machine Blacksmithing.—Systems, Tools and Machines used.

(See inside back cover for additional titles)