MACHINE TOOLS AND THEIR OPERATION

MACHINE TOOLS
AND
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PART II

PLANERS, SHAPERS, SLOTTERS, BROACHING, MILLING, GEAR CUTTING AND GRINDING

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PREFACE

THE machine tools in this volume divide themselves into two groups, one in which the tools (or work) travel in a straight line, the other group in which they (or it) rotate. The planer and the vertical boring mill have stationary tools and the work moves, the others move the tools and hold the work. There are, however, certain principles involved which are common to them all. Cutting, speed, clearance, angles, chip clearance and support for the cutting edge are all problems which must be considered in all cutting tools. The solution is not the same in all cases, but an understanding of the principles involved will help in all cases, no matter what the special details.

It has been our aim to show enough examples of the uses of various machines to give a thorough understanding of the principles involved so that adaptations can be readily made to other uses. This requires both experience and imagination, but the real mechanic enjoys solving problems which are out of the ordinary.

THE AUTHORS.

NEW YORK, N. Y.
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INCLUDING

PLANER WORK, SHAPERS AND SLOTTERS, BORING, MILLING AND GEARS

SECTION I

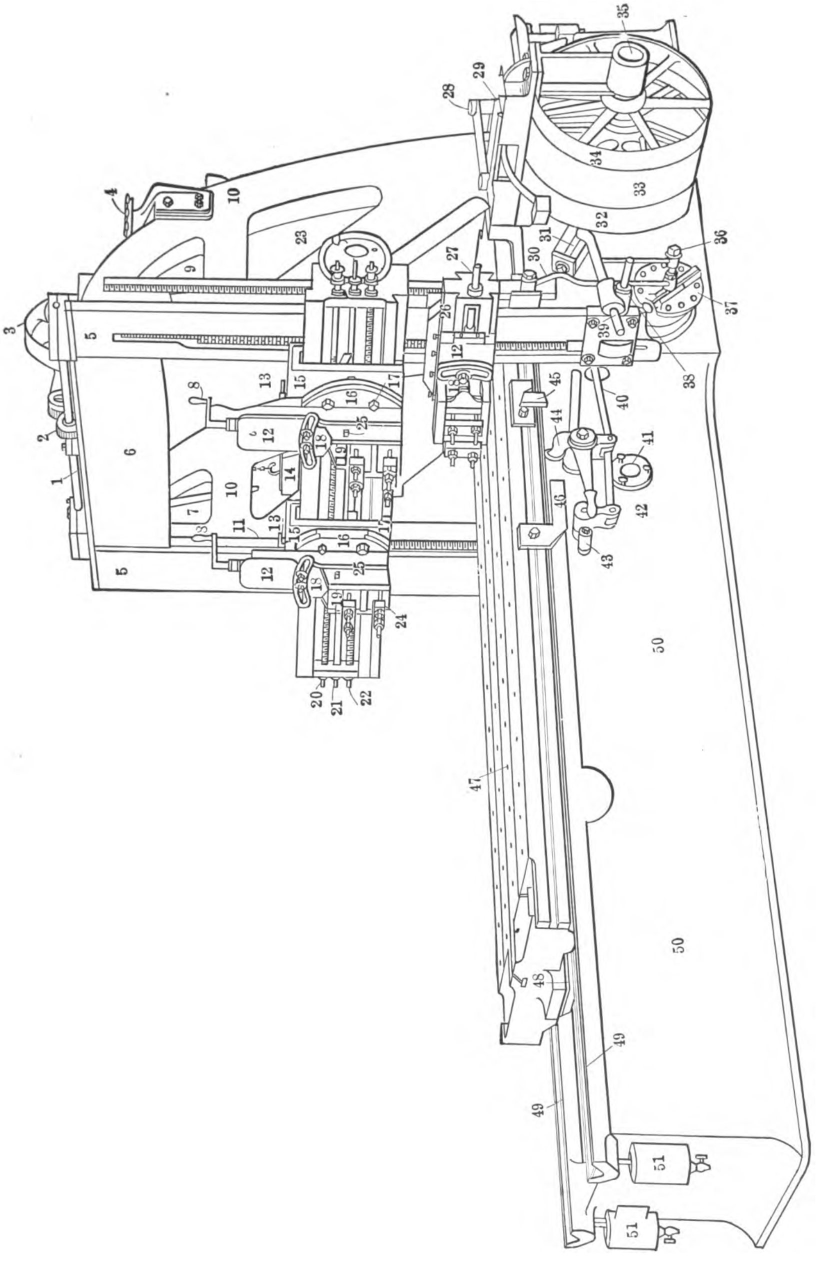
PLANERS

CHAPTER I

PLANERS AND THEIR CARE

The first requirements of a planer are that the bed shall be true, that it be set level and square on the foundation, that it bears evenly on it, and has sufficient bearing surface and that the cross-rail be square with the bed. The table has not been mentioned because with the bed level and well supported and the cross-rail square, the table can be trued up at any time and it is usually done after a planer is put into place.

The modern way of supporting a planer or other heavy tool is to use foundation plates on the order of wedges under each bearing, between the planer and the foundation. These give a good support and also allow accurate adjustment in case the foundations settle and the planer gets out of line. With some such arrangement as this it is possible to correct quite an error in the planer bed itself, and to bring it back to level after being worn out of true. No tool will show the effect of a settling of the foundation more than a planer, and we know of one instance where the slight giving way of a heavy floor beam was detected through its effect on the work of a planer that was supported by it.



A Typical Planer.

Planer—Parts of

1. Shaft for raising cross-rail.
2. Gears for raising cross-rail.
3. Pulley drive for raising cross-rail.
4. Chain for counterweighting the cross-rail.
5. Face of uprights.
6. Tie piece between uprights.
7. Handle controlling cross-rail.
8. Crank handle for raising tool block.
9. Rack for moving feed screw in cross-rail.
10. Upright or housing.
11. Screw for elevating cross-rail.
12. Tool slide.
13. Screw to clamp saddle to cross-rail.
14. Counterweight for left side of cross-rail.
15. Saddle.
16. Swivel.
17. Clamping bolt.
18. Clapper box.
19. Clapper block.
20. Feed screw for left-hand head.
21. Vertical feed rod.
22. Feed screw for right-hand head.
23. Feed mechanism on end of cross-rail.
24. Tool-holding straps.
25. Clapper block pin.
26. Side head.
27. Side head for feed screw.
28. Belt shifter.
29. Drive-pulley support.
30. Connection to feed rack.
31. Regulator for vertical feed.
32. Forward driving pulley.
33. Loose pulley.
34. Return driving pulley.
35. Driving shaft.
36. Regulator cross-feed.
37. Cross-feed drive.
38. Vertical feed pinion.
39. Vertical feed rod.
40. Rod to belt shifter for reversing.
41. Bull or driving-wheel shaft.
42. Connections to safety lock.
43. Lock to prevent table being moved.
44. Reversing latch or trip.
45. Forward stop dog.
46. Backward stop dog.
47. Platen or table.
48. Rack under platen.
49. Ways or V's.
50. Bed.
51. Oil reservoirs.

The planer ways should be level both across and lengthwise of the bed and the adjusting blocks allow this to be accomplished with the aid of a good level. This should be fairly long or be used on top of a straight-edge long enough to reach across the ways. To be sure this measurement is made from the V's themselves and not from the

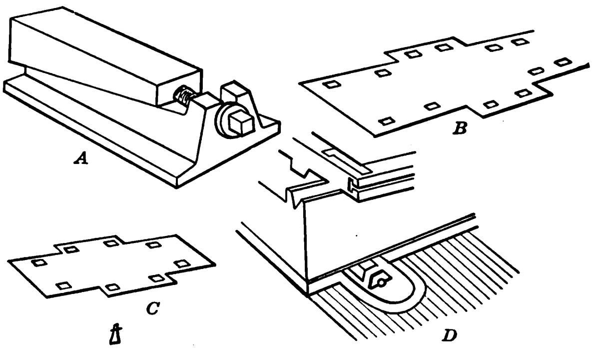


FIG. 1.—Leveling blocks.

top of their sides which may not be uniform, take two round bars or gages of equal diameter and lay one in each V, then lay the level across these and you can get the level of the V's themselves. Figs. 2 to 4 show how it can be leveled in both directions.

A good foundation can be made from a proper concrete mixture but wedge-blocks or foundation plates should be provided. The type

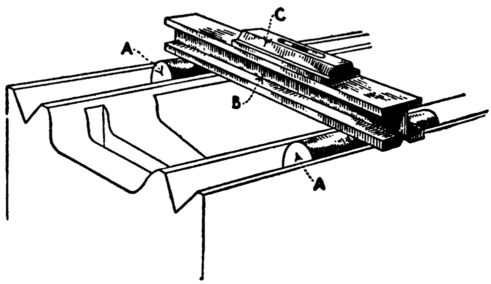


FIG. 2.—Testing ways crosswise.

shown at *A*, Fig. 1. These can be spaced as shown in *B* and *C* while *D* shows the block in place under one corner. It will be noted that pockets are provided in the concrete to admit the easy use of a wrench for adjusting the block. This plan enables the planer bed to be leveled in an hour or two and kept in shape for first class work.

With a good foundation and adjusting wedges, all that is needed are two accurately sized cylindrical plugs or bars as at *A*, Figs. 2 and

3, a good test bar *B* and a precision level *C*. Planers large enough to have a bed without legs, are leveled by the blocks with the aid of the tools mentioned, in the order indicated in Fig. 4. As this shows, the first step is to level across the bed between the housings, then lengthwise, beside each housing, the crosswise as at 4, following with the portions of the bed marked 5, 6, 7 and so on, in the order given.

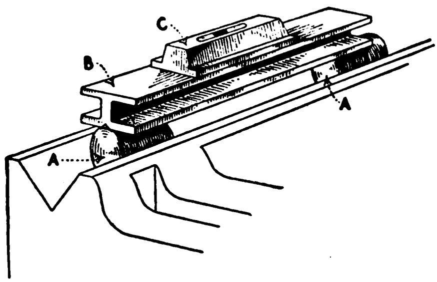


FIG. 3.—Testing ways lengthwise.

Another method, especially where a precision level is not available, is to use a few gallons of kerosene as shown in Fig. 5. Here the two V's are connected by the piping shown so that the level will be the same in both V's. A surface gage is mounted on a block which fits the V's as shown at *A*. This is moved along each V and the height of the kerosene tested with the bent end of the scribe.

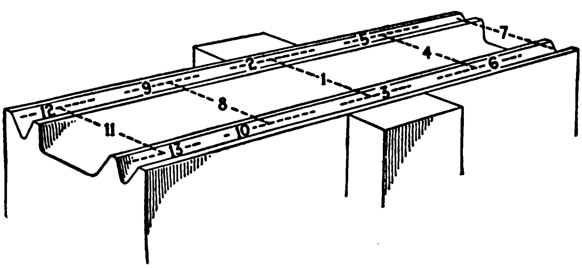


FIG. 4.—Testing large planer.

The magnifying glass, Fig. 5, shows how capillary attraction causes the kerosene to rise to meet the needle, but this is a help rather than a hindrance. For it has been found that this rising occurs when the needle point is about two-thousandths of an inch above the surface, which gives a very good guide for leveling.

PROTECTING THE PLANER WAYS

The ways of a planer must be true if good work is to be done and yet they are the most exposed of any bearing in any machine we use. On short work you often see a careful planer hand cover the end of the ways not being used, with narrow boards or with canvas.

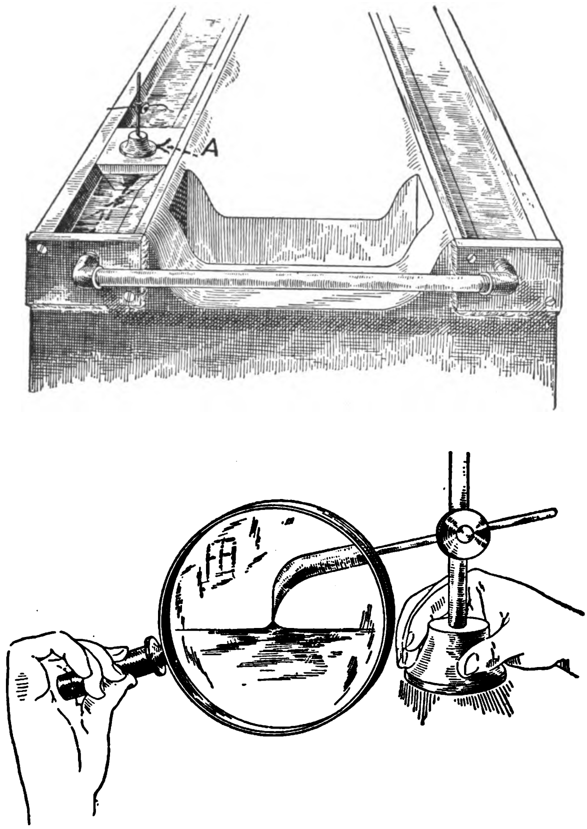


FIG. 5.—Testing with kerosene.

Some shops stretch a canvas or cotton-cloth canopy over the whole planer to keep dirt and chips from sifting down on the ways from the ceiling, from the cranes carrying castings with core sand in them or from the floor above when there is one.

A good method of protecting planer ways is shown in Fig 6. This, as will be seen from Fig. 6 consists of two strips of heavy duck wound upon spools located at the end of the bed, the outer ends of the strips (which are of course somewhat wider than the V's) being attached to the end of the platen at points directly over the ways. The spools are mounted, as upon a spring-actuated shaft which, upon the platen moving forward, permits the protecting strips to be unwound; the tension of the springs, which are wound up by the forward movement of the platen, acting precisely like a window-shade roller spring to keep the strips taut at all times and rewind them on the spools as the platen returns.

To keep the canvas strips clear of the corners of the bed a pair of rollers carried by swinging arms pivoted in suitable brackets are interposed between the bed and the spools. The pivoted members are weighted and normally the position of the rollers is that indicated at the left, the weights swinging the arms upward until a stop screw contacts with the end of the bed. In this position the rollers lift the

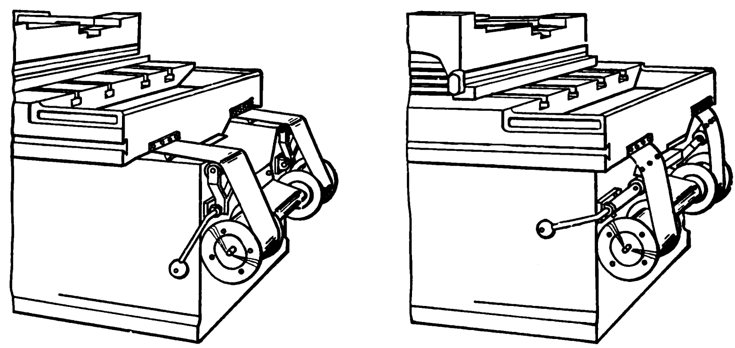


FIG. 6.—Protecting the planer ways.

strips above the ways and prevent their dragging on the edge of the bed during the travel of the platen. As the platen returns and the protecting strips are wound up tight on their spools by the action of the springs, the two blocks secured to the under side of the strips come in contact with the rollers carried by the pivoted arms and swing them into the position shown at the right, out of the reach of the V's under the platen. Upon the reversal of the machine and the forward movement of the platen the rollers again swing up into normal position to lift the strips clear of the edge of the bed.

TESTING THE CROSS-RAIL

Having leveled the bed the next thing is to find if the cross-rail is true or square with the ways. This can be measured from the cross-rail to the V's with the table run back, and after seeing that it is square the table should be planed off square and level with the bed and rail. After the bed is planed level and true with the ways the truth of the cross-rail in any positions on the uprights can be tested, as shown in Fig. 7, and this should be done if there is an important job on hand as the cross-rail can very easily get out of level by one screw raising a little faster than the other. There are other ways of testing this, but it is very easy to clamp the micrometer to a tool and run the thimble down until it holds a piece of tissue paper. Note the reading, run the thimble up a little and move the tool saddle across to the other end of the cross-rail. Run the thimble of the micrometer down again, and if the rail is exactly level the reading will be the same as before; if it is not it shows the amount it is out of level.

Special, large, steel squares are used in squaring up the guiding surfaces on the uprights or housings, some of these being provided with

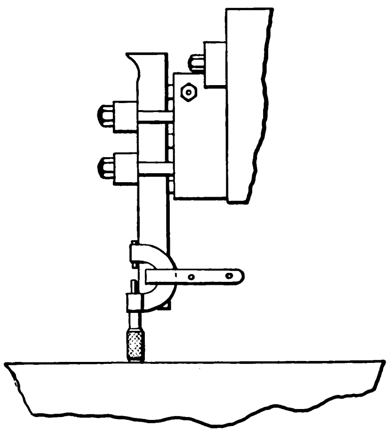


FIG. 7.—Testing cross-rail.

accurate levels in the lower arm. But with the table leveled it is easy to square the uprights.

It is always well to bear in mind that a level table may not mean that the V's are level. They may be low in the center and produce hollow work. The center of the planer bed should be set from one to two-thousandths higher than the ends.

Another method is to use a dial indicator as in Fig. 8, testing the rail for being level, by moving the head to different positions. Before doing this it is well to be sure that the planer table is level which can be done by taking a very light cut over it after the planer is installed or after the bed has been leveled up for any reason. This can sometimes be avoided by careful testing at various points of the bed.

When we consider the back lash of the elevating screws and gears, the short bearing the cross-rail has on the housing, and the weight of the rail and its heads, it is something of a marvel that any planer

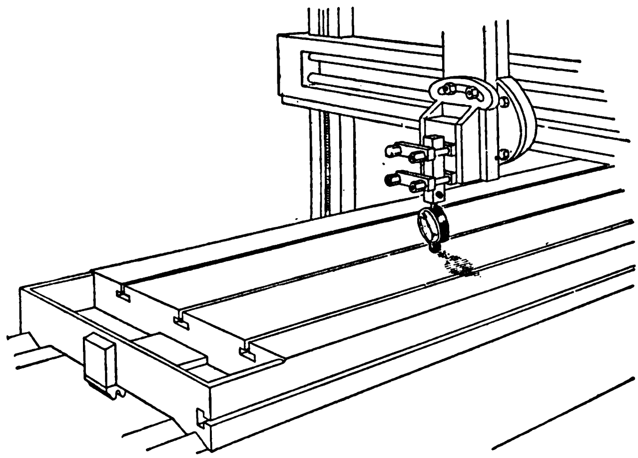


FIG. 8.—Testing with dial indicator.

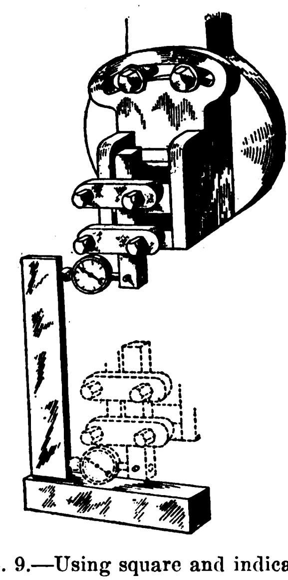


FIG. 9.—Using square and indicator.

can plane square when the rail is moved into various positions. The back lash of the screws can be taken out by running the rail down further than necessary and then raising it to the desired point. On very accurate work it is well to test the rail for squareness after setting it in a new position.

It frequently happens that the slide of the saddle is not square when the swivel scale is set to zero. This should be tested for accurate work. This can easily be done by the method shown in Fig. 9. Here a dial indicator is fastened in the tool block so as to touch a large, accurate square which rests on the table. By taking readings at different positions along the blade of the square it is easy to see whether the slide is square or not. If it is not square, loosen the swivel bolts, shift the swivel until the slide is vertical as shown by the indicator, and make a new zero mark.

PROTECT THE TABLE

The table should be protected better than is done in many cases as it is not a good plan to use it for an anvil or a straightening plate, nor to let castings fall on it any more than necessary as it not only mars the table, but has a slight peening action that may in time change its shape. Some of the careful planer hands always lay boards or strips of old belting on the table when putting on heavy work in order to protect it from heavy blows should the work slip. These are then taken out by raising one side at a time and the work lowered onto the table itself.

CHAPTER II

HOLDING THE WORK

When a casting is cooling in the mold the outside cools first, and strains are set up which sometimes warp the casting or even break it. But even if it comes out straight some strains are there waiting to show themselves when the surface or skin of the casting is removed. This is also true to a less extent with rolled or drawn-steel stock and must be watched by the planer hand who wants to turn out a good job. For this reason you will see what may seem like unnecessary work as the man who knows will first rough plane one side of a piece, then turn it over and rough plane the other before finishing the first side. This is often done even where there is no need for finish, such as the underside of lathe beds, and is quite necessary even where the work is thick, if it is to be accurate when finished.

SPRINGING WORK

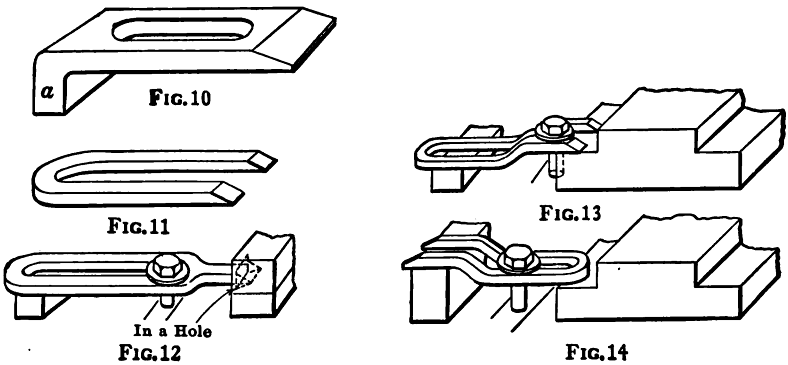
Although it seems strange to think of a heavy block of cast iron springing enough to notice from the pressure of the clamping bolts, it is too often the case unless care is taken to avoid it. It can be taken as a good rule not to clamp or bolt a piece of work any tighter than is necessary to prevent the tool from lifting it. It is best to take the end thrust of the tool by blocks or stops at the end of the piece. Blocks should also be used to take as much of the side thrust or tendency of the tool to crowd the work across the table in the same way, and bolt down as little as can be done with safety. This is only a general suggestion and will have to be modified to suit conditions.

Springing can also be avoided by making sure that the work is supported directly under the strap or clamp, if at no other place, as if this is not done it is impossible to avoid springing the work and it will not be true when it comes off the planer.

It is quite common practice to use thin steel wedges or shims to get an even bearing between the casting to be planed and the planer bed, using a wedge under four, six, or as many points as required to give a good support. Then when the work has been rough planed on the back side, it is turned over and again supported, but on strips of paper instead of steel wedges. Paper is very handy in this respect, as it comes quite uniform in thickness.

HOLDING WORK FOR PLANING

One of the important features in all planer work is the proper clamping of the work to the table, and it pays to have plenty of clamps and straps and to have them made so as to suit a large variety of work. In many places the only strap is a plain flat bar with a hole in the center for the bolt, or perhaps two or three holes to allow it to be placed in different positions. This kind of a strap always requires blocking up at the end away from the work to an amount



Figs. 10–14.—Straps for holding work.

equal to the thickness of the piece being clamped. Some of this can be avoided by the use of angle clamps as shown in Fig. 10 and, of course, the bent end *a* will have to vary in length according to the work in hand. But a few of these with the end *a* of varying lengths will be found extremely useful in any planing job. Fig. 11 shows a very popular form of strap, as it can be taken on or off by simply slacking the nut and does not require the nut to be taken off. Fig. 12 is often used for holding work which has openings on the side into which the point of the clamp goes and leaves the top of the work perfectly clear. Sometimes holes are drilled in the side of the work for this strap to bite into. This can be made of a variety of shapes and sizes and the clamping point is often bent up or down as the case may demand, somewhat similar to the bent open strap shown in Figs. 13 and 14. These show strap 11 bent so as to accommodate different cases and how it can be used on the main piece by using different parallel strips or blocking.

One of the main things to remember is that in all cases the strap should be as nearly level as possible and the bolt should be as near the work as circumstances will allow. Fig. 15 gives some good and bad ways of using straps.

It is comparatively easy to clamp heavy work to the planer, and the most difficulty is experienced when it becomes necessary to plane thin pieces of work as shown in Fig. 16. There are a number of ways

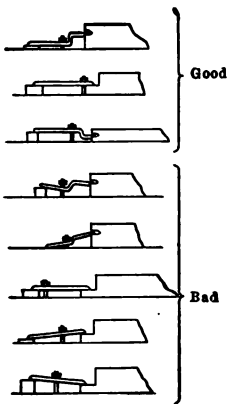


FIG. 15

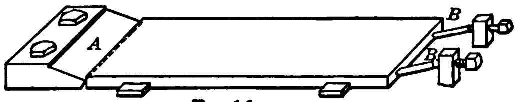


FIG. 16

FIG. 15.—Methods of clamping.

FIG. 16.—Holding thin work.

in which this can be done, this being only a suggestion which can probably be modified to advantage in many cases. As in all other work it should be the aim to take the thrust of the tool by stop block and only use the clamping device for holding the piece level on the planer table. In this case the piece *A* has a sharp or serrated edge and

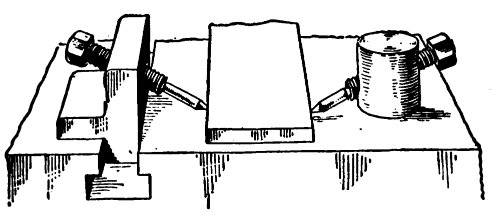


FIG. 17.—Another application to thin work.

the pieces *BB* are sharp-pointed tool steel so that the point will be forced into the work by the set-screws in the block at the end. If the set-screws have cupped points the pieces *BB* should be sharp at both ends, but if cone-pointed set-screws are used it is, of course, necessary to have one end of the pieces cupped to receive it.

A somewhat similar method is shown in Fig. 17.

STOPS AND OTHER FURNITURE

Three clamps or step blocks are shown in Figs. 18, 19 and 20, the first two being the more common and easier to make. These are made of square-machine steel with the end turned down to fit the round holes in the planer table and the square portion above is tapped for one or two set-screws according to the work it is designed for. If arranged for two screws as at *A* in Fig. 18, it is particularly useful in a corner as one set-screw can go against each side of the piece. It also gives practically two blocks as in some cases it is much more convenient to have the screws high or low as the case may be. Block B is very similar to the other except that the set-screw is at an angle which will be found very useful in many cases. Fig. 19

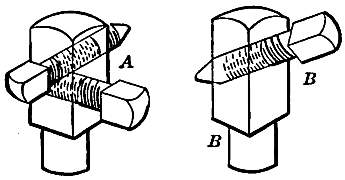


FIG. 18

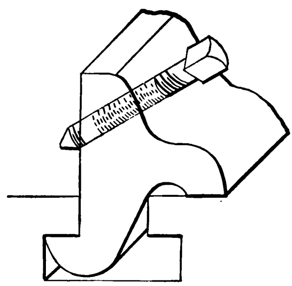


FIG. 19

FIG. 18.—Two simple screw clamps.

FIG. 19.—Another type of clamp.

makes a very rigid clamp and when work is held between a number of these and a substantial angle plate on the other side, it is very similar to a planer chuck. The angle of the screw is perhaps excessive in the sketch, but it will naturally vary with the work in hand. Figure 20 shows what might be called a self-contained clamp which is useful at times. The arm *A* and the clamping bolt *B* are both hinged in the base *C* which is held to the table by a T-headed bolt.

Parallel strips are a necessity among planer furnishings, but instead of making them of cast iron and having them carefully planed up as formerly, a number of shops are using die-drawn steel bars for this purpose. By using a little care in the selection of these and measuring them so as to secure uniformity, it is generally possible to buy this material practically as accurate as the average parallel strip is planed up, and as all that is necessary is to saw them to any desired length from the bar, they are decidedly cheaper to make.

In order to avoid having an extremely large number of parallels, it is quite customary to plane some of these in steps as shown in Fig. 21, so that they will accommodate a number of different heights. The best proportion for these must be determined by each shop accord-

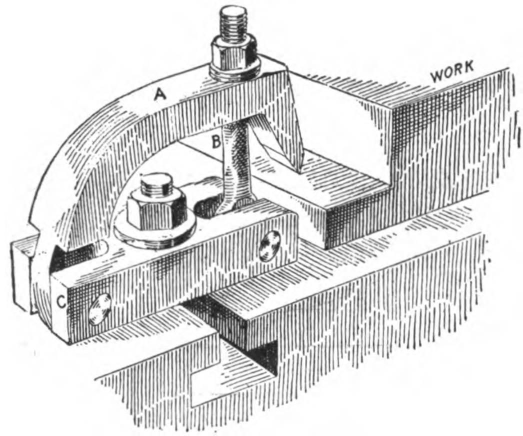


FIG. 20.—A self-contained clamp.

ing to its own particular work, but a suggestion may possibly be had from Fig. 22, which shows a small parallel block which will give five different heights varying by quarter inches from one to two inches, inclusive, according to the way in which it is used.

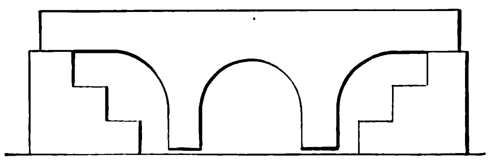


FIG. 21

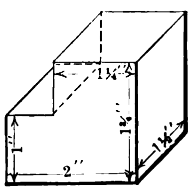


FIG. 22

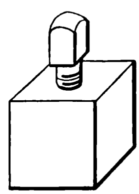


FIG. 23

FIGS. 21–22.—Stepped blocking.

FIG. 23.—Simple planer jack.

By laying out the steps of parallels in this way they can be made to give a large variety of graduations and will be found extremely useful. Figure 23 is a cheap form of planer jack which consists simply of a cast-iron cube or other shaped block having a hole tapped in it for the set-screw shown. Every planer should be supplied with all the furniture that it needs, and a goodly stock of these small blocks shown in Fig. 22, and the jack in Fig. 23 will be well repaid. They cost very little to make and a man can very easily spend more time hunting around for the right block than a number of these would cost, and these save time on practically every job that comes to the planer.

OTHER WAYS OF HOLDING FLAT WORK

Figures 24, 25 and 26 show other ways of holding work that is comparatively thin. The first is very common, but not especially desirable.

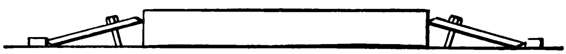


FIG. 24

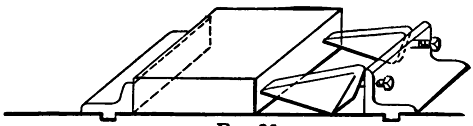


FIG. 25

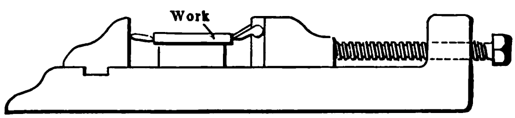


FIG. 26

FIGS. 24–26.—Forcing work downward.

If, however, the straps bear as near the top of the piece as possible, it answers very well.

Figure 25 shows a plan used to take the place of a chuck. The angle plates have tongues fitting the planer-table slots, and are, of course, bolted down. Set-screws are provided in either or both of these, and in this case a three-cornered clamping block is used for the holding down. The set-screw bears against the upper corner, the corner next to this rests on the table and makes a fulcrum, while the long end grips the work and has a downward movement which tends to hold the work in place. Figure 26 is another and somewhat similar plan for holding thin work; the jaw at the right has sort of hinged gripping jaws which always tend to hold the work down. The plan of mounting thin work on a block as in this case has advantages at times, but unless the support comes very close to the edge there is apt to be a bending tendency to the piece and it will be planed thin in the middle.

THE PLAN OF MARKING HARD CASTINGS

As planing is usually the first operation, some shops depend on the planer hand to act as a guide for the following operations, so far as the hardness of the metal is concerned: If he strikes a casting which is harder than usual, he marks the word "hard" with chalk in a conspicuous place where it will not be rubbed off, and this is a guide to all future operations. On seeing this the milling-machine man will adjust the speed of the milling cutters accordingly so as not to dull them, as would be the case if run at the usual speed, and as milling cutters represent quite a large investment, many dollars can be saved

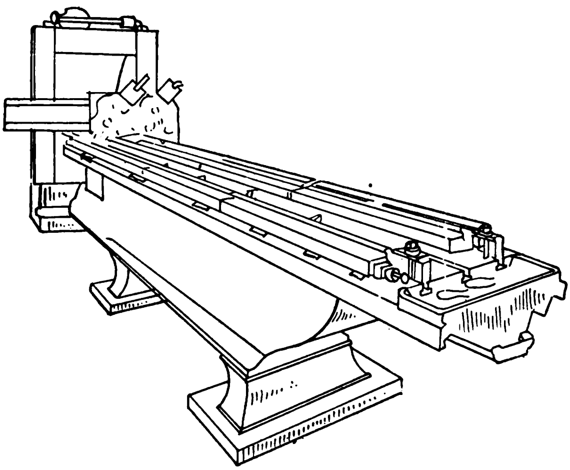


FIG. 27.—Planing milling machine beds.

in this way during a year. It is simply an example of coöperation between departments which should be very much more common than it is, and all those in the shop should feel that they are working for the best interests of the shop as a whole instead of trying to make a show for their department at the expense of all the rest.

The work shown in Fig. 27 rests on paper at six points, three on each side, and two thicknesses are used at each point in this case. This insures a good, even bearing, and the work is held down by straps at the end, the thrust being taken by the end blocks or stops, two varieties of straps being shown on this job. This also shows how work is grouped or strung along the table, so that a long cut can be taken and the cost per piece materially reduced. The ends which join each other are clamped by a plain strap and only room enough for the bolt allowed between.

CHAPTER III

FIXTURES, GAGES AND TOOLS

The use of jigs or fixtures for planing, as in other kinds of machining, depends on the quantity to be planed and the expense which is justified. If there are only a few pieces to plane we must devise some cheap, temporary fixture, usually blocking of some kind to hold it, and this often means considerable work if the piece is irregular in shape, as in the case of a knee for a milling-machine. But when a quantity is to be made it is economy to make some sort of jigs or fixtures for holding them so they can be readily put in place or taken down. Only in this way can the cost of planing be reduced as it should. It often happens that it takes almost as long to put a piece on the planer properly as it does to plane it after it is in place. This handling time cannot be reduced by increased cutting speeds so that the importance of reducing the time for chucking or clamping becomes apparent.

Figure 28 shows a string of milling-machine knees held in fixtures that support the front end. These fixtures have a tongue which fits the T-slot of the table and clamps the front end of the knee between the side set-screws, while the lower ones at the angle adjust the height so as to make the piece level. The side straps hold the work down by clamping the screw projection against the block underneath. At the sides of the knee toward the back are the double-screw stop blocks. These fit into the table and have set-screws running both ways through the square upright. When the lot is large enough, two strings of these are used at once, one on each of the outer T-slots and both planer heads can then be put to work. In this way a long cut can be taken without reversal and the cost of planing can be considerably reduced.

LARGE PLANING FIXTURES

Another example of this kind is shown in Fig. 29, and is one of the best cases of large jig planing we know of. Here six large milling-machine knees are hung on the planer bed at one setting and both of the heads brought into operation. These are large pieces, each of the jigs shown being about 30 inches high.

The top faces of these knees are first planed with their proper dovetail, and these surfaces are used for locating and clamping them in the fixture. These fixtures are first carefully lined up with the bed so as to be perfectly square in both directions. After this it is an easy matter to swing the castings into place and slide them down into the jigs with an overhead crane or hoist of some kind. By substituting different widths of shoes at the sides these jigs can be used for several sizes.

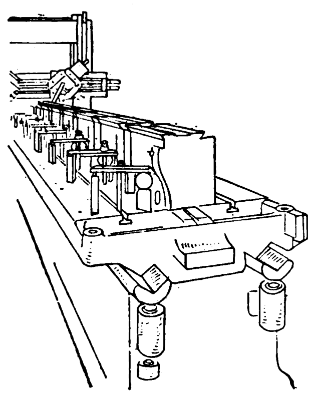


FIG. 28.—A string of knees.

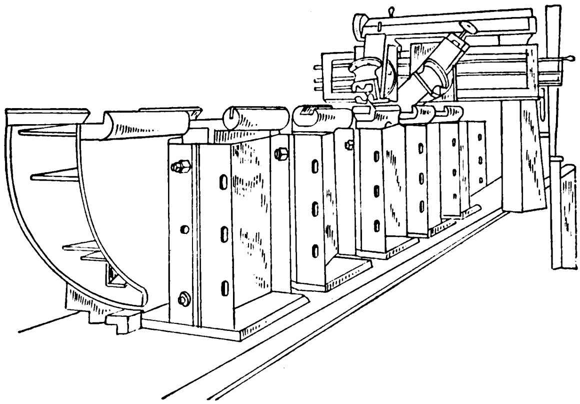


FIG. 29.—Good planing fixtures.

USING PLANING GAGES

The use of planing gages is very clearly shown in Fig. 30. This method of planing to the correct size is interesting, instructive and economical and should be carefully studied and considered. It does away with all but the preliminary laying out, on the first surface planed in order to have the casting clean up along its entire length. After this has been done and the first surface has been correctly planed, these gages enable a careful man to get very accurate results and practically cut out all chance of making mistakes.

In this case the inside or column dovetails have been planed first. and the knee is simply slipped down over a form or angle plate, which represents the column of the milling machine itself. In setting this angle plate care must be taken to have it square with the planer table in both directions, but after this is done no further attention need be paid to this end of the work, and the knees to be planed are clamped to this plate and supported at the outer end in any way that will prevent springing under the cut.

The gage shown in place has a dovetail projection at the back which just fits inside the planed surfaces of this bearing of the knee, and has been carefully laid out so that the angular sides shown in front are in exact relation to the dovetail projection which are slid into the fixture. This gage is put in place after the top surface of the knee has been planed, and all that is necessary is to set the planer head at the desired angle, 45 degrees in this case, and plane the angular sides until these sides are a continuation of the angular sides of the gage. When this is accomplished on both sides of the knee the planer hand knows without measuring that they are correct and will fit the table which is to be mounted on them.

The other gage shown lying on the planer table is used in a somewhat similar way, being located in front of one or more carriage slides,

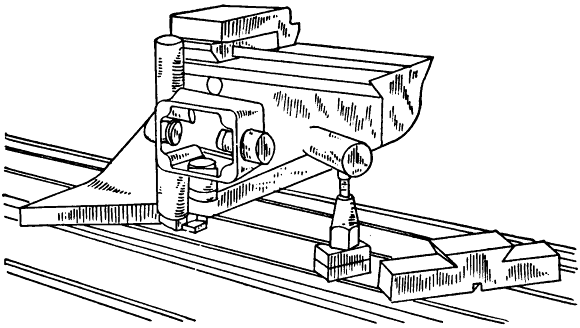


FIG. 30.—Planer gages.

and the dovetails planed until they match the dovetails of the gage. Both the work and the gage are located by a steel strip which fits the planer-table slot and also the slot in the work and in the gage.

SUPPORTING OVERHANGING TOOLS

It is one of the first principles of planing, or, in fact, of almost any machine work, that the cutting tool should be supported as rigidly as possible, and the overhang reduced to the lowest point. There are many cases, however, where on account of projections on the piece to be planed it is absolutely necessary to have the cross-rail of the planer at a considerable height above the surface to be planed, in order to clear this projection. This means overhang in spite of anything we can do, and to offset this we make planer tools with long, heavy shanks so as to be stiff as possible. Even with this, however, it usually prevents the taking of a good cut on account of the spring of the tool, and as a cure for this disease we recommend the treatment shown in Fig. 31. This is a strongly ribbed arm which projects from the side rail and carries an adjusting screw in the end so as to make a positive support for the shank of the tool, or the tool holder in this case, as close to the cutting point as is possible. While this is not as good as though the entire overhang could be avoided, it is a decided improvement over the usual method of support and allows a fairly good cut to be taken, and also makes it possible to secure a more accurate job. This is a large piece of work, as can be seen from the size of the tool shank and the use of ribs under the base, and while it may not be possible to adopt this particular form of tool support in all cases, it gives an idea which can be adapted to suit

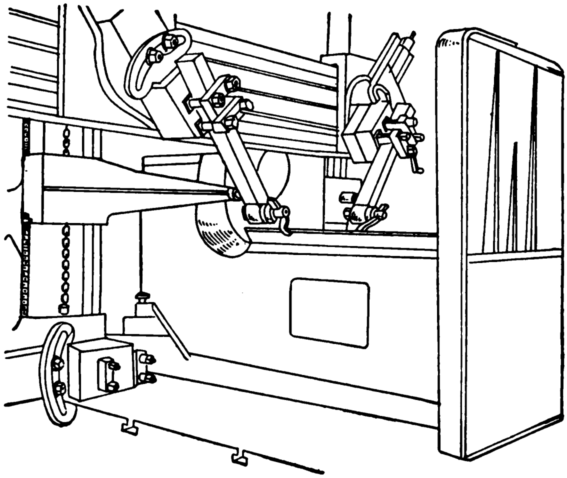


FIG. 31.—Supporting overhanging tools.

many conditions. In this case it is connected to the elevating screw of the cross-rail so that it can be easily moved into any desired position. One of these on each side makes it possible to use two cutting tools and get good results from them both.

PLANER TOOLS

In addition to the round-nose roughing tool, which is very popular for roughing cuts on almost any material except brass, and which very closely resembles the regular round-nose roughing tool used in the lathe, some prefer a tool very closely resembling the old diamond point, as shown in Fig. 32. In place of forging this in the usual way, as shown by the dotted line *A*, a much different tool is produced by omitting this depression and having the diamond-pointed nose project straight up from the body. In order to support the cutting edge there should be very little clearance, so that the point of the tool will be nearly straight.

For a finishing tool on cast iron some prefer a shape similar to

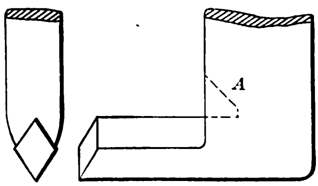


FIG. 32

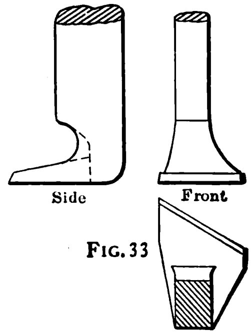


FIG. 33

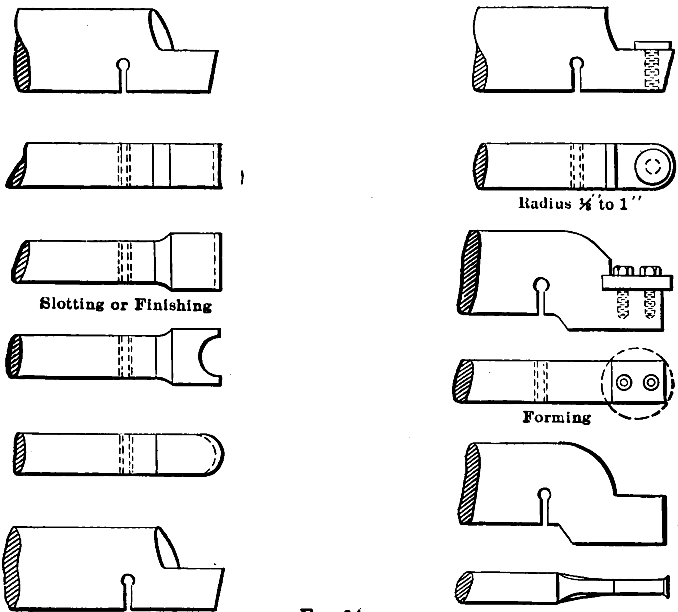
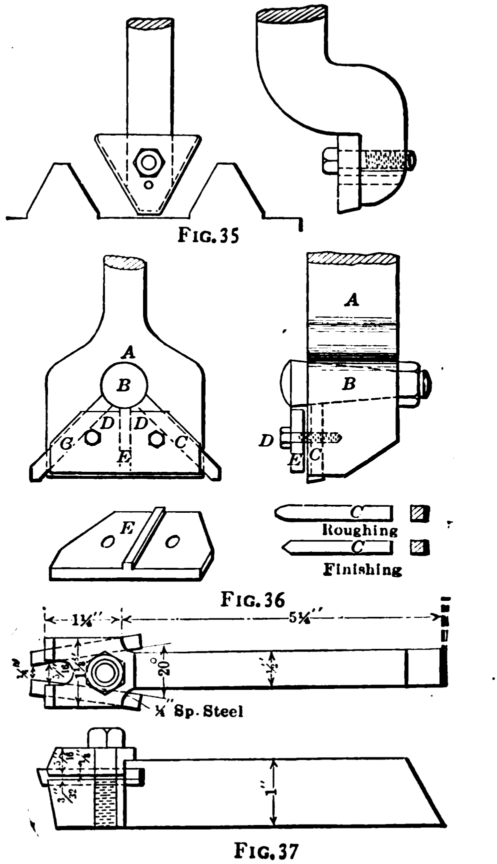


FIG. 34

FIGS. 32–34.—Plain and spring tools.

Fig. 33, in which the cutting edge is at an angle of about 40 degrees so as to produce a shearing cut. Many, however, use a tool with a broad face of this kind, but have the cutting edge square across. For finishing steel some use a tool somewhat similar to this, and having an edge on the angle; but the cutting edge of the tool is rounded so as to cut only in the center, and in this way curls up the chip somewhat similar to that coming from the lip of a twist drill, and the cut is also directly under the body of the tool.

Figure 34 shows a variety of spring tools, which, instead of being forged with the regular goose necks, secure their spring by having a hole drilled through the shank and a saw-cut being let into this

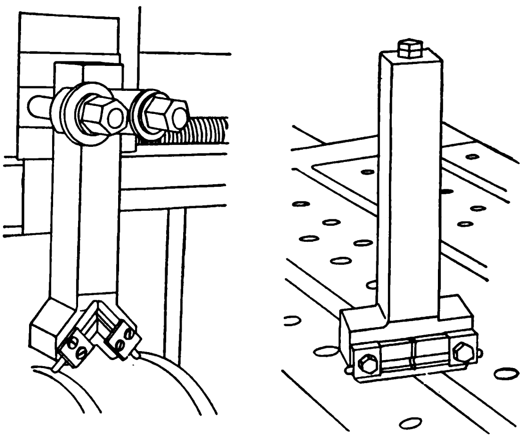


FIGS. 35–37.—Special planer tools.

hole. Their various uses can be easily seen and need no explanation. For radius tools there is nothing better than the one shown at the right, in which the cutting edge is simply a round disk held on the tool body either by a central stud or by two cap-screws is shown on larger sizes.

The tool shown in Fig. 35 is made especially for planing the V's on lathe beds, but various modifications of this can easily be made to suit other work. This is one of the tools in which the cutting edge is brought back behind the back edge of the shank, in order to avoid all digging in, which occasionally happens when this is not done. With the cutting edge behind the bottom of the tool shank it is easy to see that any springing of the tool must throw the cutting edge away from the work instead of digging into it.

Figures 36 and 37 show two forms of adjustable tools. In this case the tools are fastened rigidly in the holder and the clapper box is depended on to raise them out of the cut on the return stroke. The taper pin *D* coming down against the back of the cutters *C* forces them out and, of course, increases the distance between the cutting points. The details make the construction of the tool very plain.



FIGS. 38 and 39.—Two double tool holders.

In Fig. 37 this is reversed in order to bring the cutting edges closer together as the blades are extended from the shank. This is for use in planing tongues or any other raised portion which is to be a certain width, and in this case it is only necessary to center the tools so that the tongue or rib will come in the correct position and bring the tool down over the work, as it cuts both sides at once and sizes it.

Figures 38 and 39 show two double tool holders in which each tool is held in an independent clapper box of its own so that the tool, as a whole, can be clamped rigidly in the tool block. In Fig. 38 the tools and their clapper boxes are at an angle, in Fig. 39 they are both horizontal.

Goose-necked tools of the old style have little use on the modern rigid planer. In some cases however it may be desirable to bring the cutting edge back and the tool shown in Fig. 40 has some good points.

This tool does not have to be reforged and only a small piece of tool steel is required, as against the large piece in the solid tool. Any desired shape tool can be inserted making what is practically a new tool at only the cost of the cutter.

Figure 41 shows a very broad face finishing tool which gives good results where the surface warrants its use. Only a hand feed can be used to get the most out of such a cutter. A 4-inch feed can be used. The whole thing must be very rigid and the illustration gives

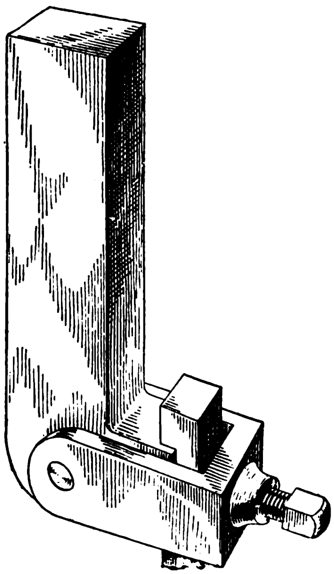


FIG. 40.—Inserted planer tool.

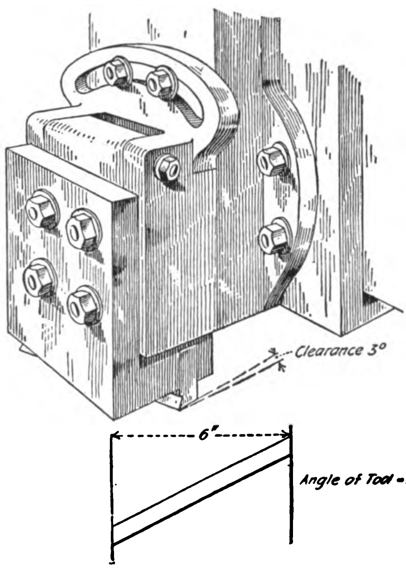


FIG. 41.—Broad finishing tool.

all necessary dimensions. It must be set dead level with the planer table.

TWO HANDY PLANER TOOLS

In some shops where a variety of planer work is handled, the machinist is not always provided with a sufficient supply of tools.

The universal tool holder shown in Fig. 42 takes the place of single-sided tools and tool holders, as it can be used to advantage anywhere they can be used. It can be made cheaply, three forgings only being necessary. The shank of the tool should be rather long, and it need only be finished at the bottom, faced on both sides and bored for the swivel-box spindle.

The swivel box and the tool block are machined as shown. The taper-pin hole is drilled with the two parts together. Any kind of spring can be used, but the one shown has proved satisfactory and is of a form quite easy to make.

In use, the clapper box or apron on the head is blocked to keep it from swinging. The beauty of the lower clapper box is that it cannot be set wrong, as when a tool is set to cut one way, the apron must be right.

Cutting out a circle to gage, with a common round-nose tool, is

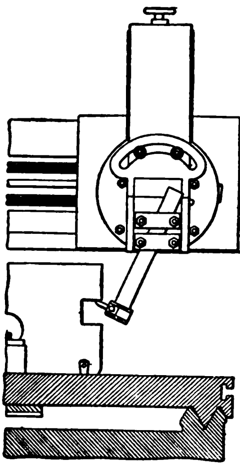


FIG. 42.

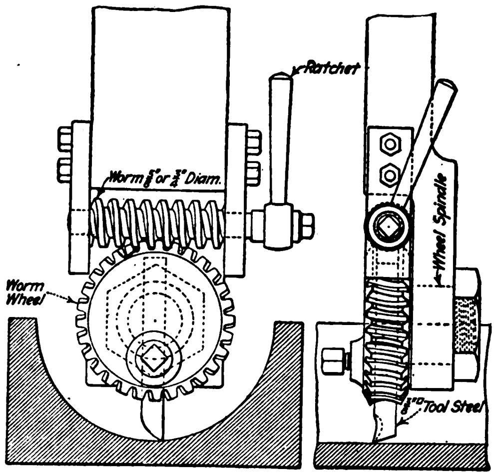


FIG. 43.

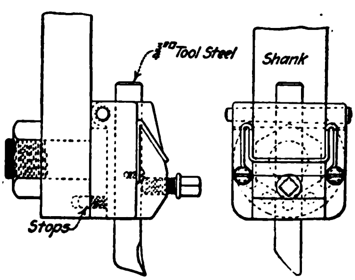


FIG. 42.—Tool bar and head.
FIG. 43.—Rotating head planer tool.

about the most tedious job a planer hand can get. The tool shown in Fig. 43 not only makes the work more agreeable, but does a better job in much less time.

The tool block and its spindle are solid and consist of a wormwheel with a tool slot, a setscrew and a setscrew boss, and a spindle with a nut which should tighten against a shoulder. Meshing in the wormwheel is the worm shown, held by two plates, cap-screwed to the bar. One end of the worm shaft is squared and fitted with a ratchet handle.

In operation the head is clamped to the rail and the apron set central. The ratchet can be mechanically operated, if so desired, by clamping a stop to the table, high enough to clear the job and move the handle the necessary amount, but owing to the variation in stroke, the hand-operation of this ratchet feed is best and safest in most cases.

SPRING TOOL FOR CUTTING BAR STOCK

While spring tools are not recommended for regular work, there are special cases where they have been found very useful. Such a case occurred during the war where a lot of bar stock for shrapnel had to be cut off with no machine but a planer available in a French

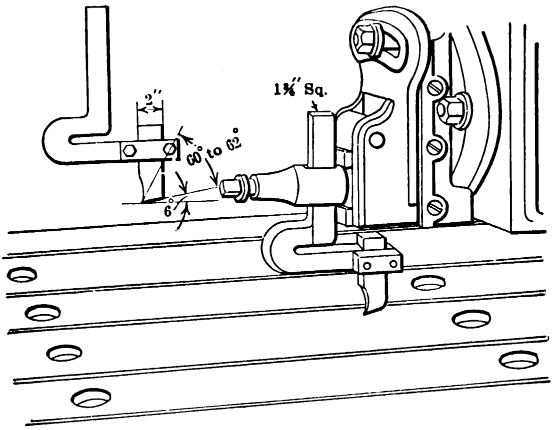


FIG. 44.—Tool for cutting off bar stock.

shop. The regular type of rigid tool would not stand up but the spring tool shown in Fig. 44 proved very satisfactory. The width of the cutting blade however must not be too thin—3/8 inch being about the minimum for cutting 3½-inch bars.

PNEUMATIC TOOL LIFTER FOR PLANER

A large contract required much planing on long bedplates and other similar pieces. Judging by the quantity of metal removed, the planer tools were wearing out fast. A little study showed that the abuse of the tool on the return stroke was responsible for this wear, especially when planing the bottom of bedplates, where the tool would rap severely against the webbing. The pneumatic tool lifter shown in Fig. 45 solved the trouble. The apparatus consists of a cylinder and piston *A* supplied with compressed air at about 75 lb. pressure through the opening *B* by means of an air hose from the controller valve. The piston rod is connected to the lever *C,* which is fulcrumed at one end. As the air is applied to the piston, the lever lifts the tool jack by means of the rod *D* and lifter bracket *E.* It will be noticed that the end of the lifter bracket on which the rod lifts is spherical. This was done in order that the tool jack might be used at an angle. In operation it was found possible to use the lifter successfully when the tool jack was at an angle of 20 deg. with the vertical.

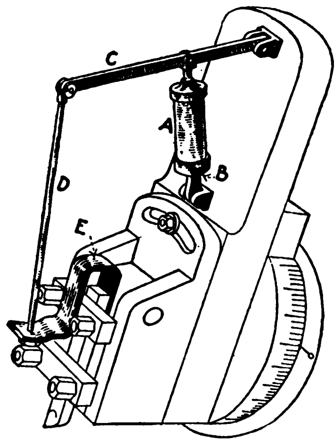


FIG. 45.—Pneumatic tool lifter.

A three-way air valve was connected to the belt shifter at the side of the planer and timed so as to admit air to the cylinder at the beginning of the return stroke and exhaust it at its completion, thus lifting the tool from the work during the return stroke and dropping it back in place just before the cutting stroke.

In case of short work, where it was not desired to use the lifter, the rod was unhooked and swung up out of the way.

CHAPTER IV

DIFFERENT KINDS OF WORK

GENERAL SUGGESTIONS ON PLANER WORK

The kink shown in Fig. 46 is overlooked in too many shops. When you work with a planer, shaper or miller chuck, you must always figure on the solid or "dead" jaw for the alignment of a piece which has to be squared up. The movable jaw of the average chuck is not to be relied upon. Placing a round bar *A* between the live jaw and the work *W* forces the latter against the true surface of the dead jaw and helps produce square results.

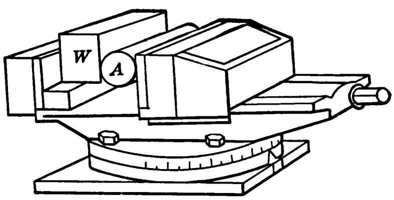


FIG. 46.—Squaring work in vise.

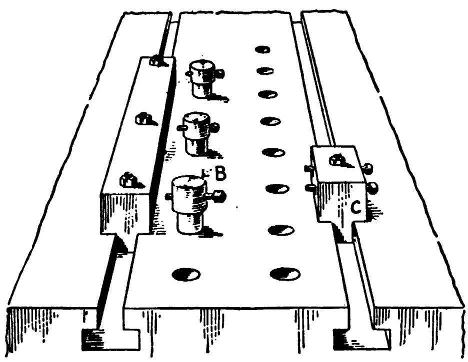


FIG. 47.—Stop block and side screw clamps.

JUDGMENT IN USING CLAMPS

A great deal of time is lost on planers in putting on too many clamps with too little judgment. A properly ground planer tool will not tend to lift the work; the thrust will be down and against the motion of the platen. A piece of work properly stopped endwise does not need much clamping and can be held sidewise by means of such stops as are shown in Fig. 47, any one of which may be applied in much less time than the customary U-clamps. The square side-bar, in connection with the smaller screw-stops *B* and *C*, in reality takes the place of a planer chuck and will earn dividends on a large class of work.

EMERGENCY JOB

There are many emergency jobs of planing that have to be done and that tax a man's ingenuity to the utmost. This is especially true

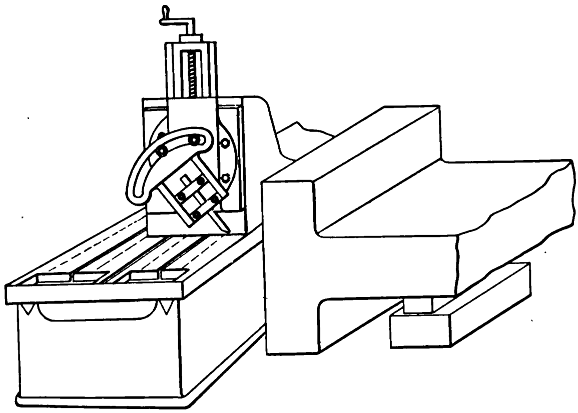


FIG. 48.—Planer tool mounted on table.

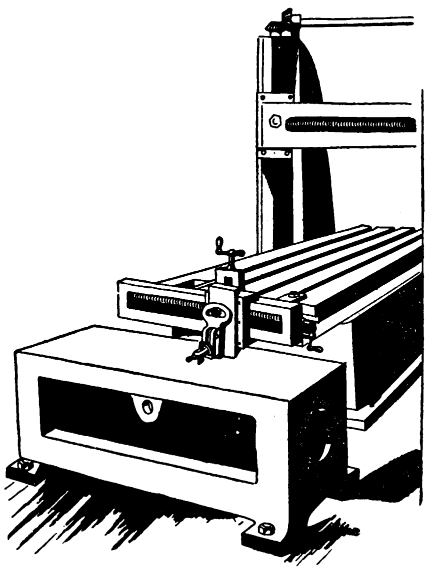


FIG. 49.—Planing at end of table.

of a job shop that gets the reputation of never letting a job go by. One of these cases is shown in Fig. 48, where a large casting is being planed by a machine too small to carry the piece. A heavy angle plate is fastened to the table, the tool saddle mounted on this and the machine becomes a traveling-head planer, which is first cousin to a shaper. Many modifications of this can be made to suit conditions, and it often helps out of a bad hole.

A somewhat similar emergency job was handled as shown in Fig. 49.

HOLDING ROUND BARS

Two ways of holding round bars are shown in Figs. 50 and 51. Both require a little special furniture but none that is expensive to make. Both illustrations explain themselves.

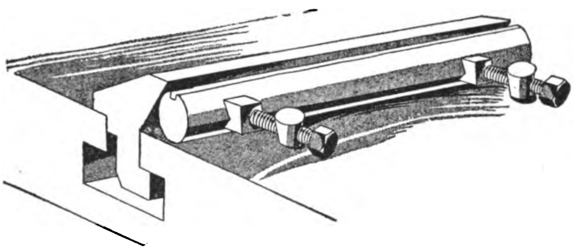


FIG. 50.—Holding round bars.

Although slitting sheet metal is hardly a job for the planer in the average shop, the emergency sometimes arises when the planer is the only machine available for handling long sheets. Figure 52 shows a method that worked very satisfactorily in one instance.

The sheet of metal *A*, was fastened to the planer table and the tool *B*, carrying a wheel cutter such as are used in steam pipe cutters,

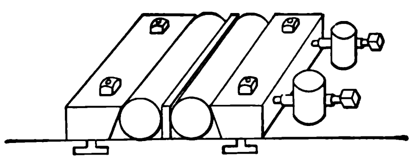


FIG. 51.—A double round bar holder.

was fastened in the tool block. The wheel was set so that the cutting edge came at the edge of one of the T-slots as shown. Sheets of considerable thickness can be cut in this way without difficulty.

MAKING A PLANER PLANE ITS OWN WAYS

As a consequence of long use, occasionally by careless machinists, the ways of an old planer were scored and cut so badly that little bearing surface remained. When it became necessary to refinish them there was no planer large enough to take in the entire bed of the old planer, so it became necessary to find some other way of doing the work. The design of the ways made possible the following method as shown in Fig. 53.

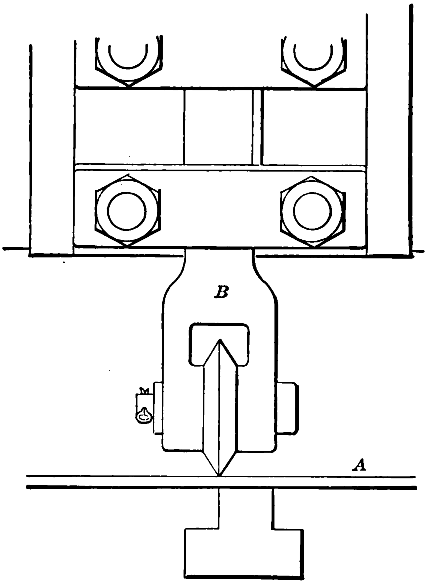


FIG. 52.—Cutting sheet metal on planer.

The finished surfaces *A* and *B* on the top of the bed had been accurately finished when the original machine work was done on the ways, and were paralleled with them. Pieces of iron were planed to fit the surfaces *A* and *B* and were attached to the bottom of the

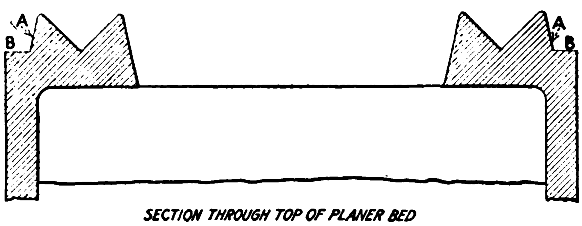


FIG. 53.—Making planer true its own ways.

table, raising it about $^1/_{16}$ in. from the original bearings. Then the head was taken off the cross-rail and bolted to an angle plate at one end of the table. A tool was used which just cleared the end of table, and the travel of the table was adjusted so that the rack was nearly out of mesh with the large driving gear at the end of travel. It was then an easy matter to plane the ways for practically half the length of the bed.

After this work was completed the angle plate and head were moved to the opposite end of the table and the other half of the ways finished, the tool cutting on the return stroke of the table. A space about two inches long, which could not be reached because the ends of rack were flush with ends of table, was afterward finished by hand.

UNUSUAL PLANER JOBS

Just to give an idea of the variety of work which is handled on planers in different shops, the following illustrations will suggest ways

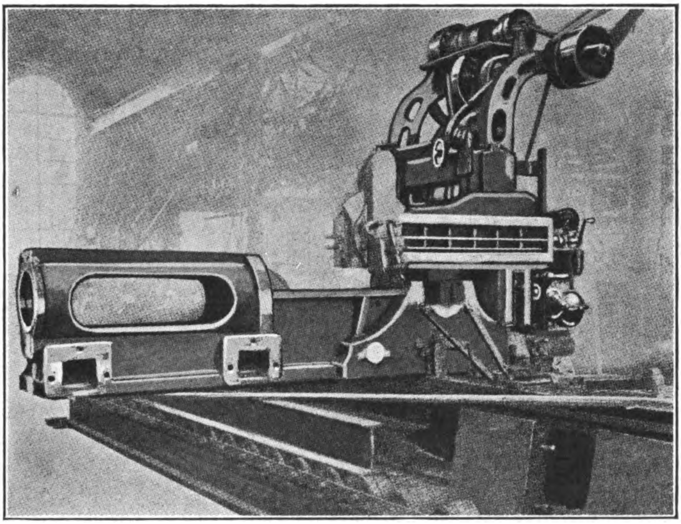


FIG. 54.—Open side planer work.

and means of handling almost any kind of a job which may come along. Figure 54 shows how a big open side planer is being used to plane the bearing end of a large stationary engine frame. This end is fastened to the planer table while the outer end is supported on the I beam which rests on rollers, these in turn rolling on a suitable track. The outer end of the bed is also held in position by the angular bar which ties it to the table of the planer.

Another unusual job is shown in Fig. 55 where ten large castings, weighing about 7 tons each, are being planed at one setting on a ten-foot planer. This makes a load of 70 tons on the planer foundations in addition to the weight of the planer itself.

Locomotive shop planers are often rigged up to plane the radius on the link used in their valve motions although this is not the best nor the most economical method of machining them. Figure 56 shows a somewhat similar job and the way in which it was done on a job shop planer. No boring mill was available so the pin or stud *E* was fastened into the planer table *A* and the plate *B* made to carry the link which was to be planed. The plate *B* was slotted cross-wise as shown, the slot being a fairly good fit on the pin. The casting *C* was

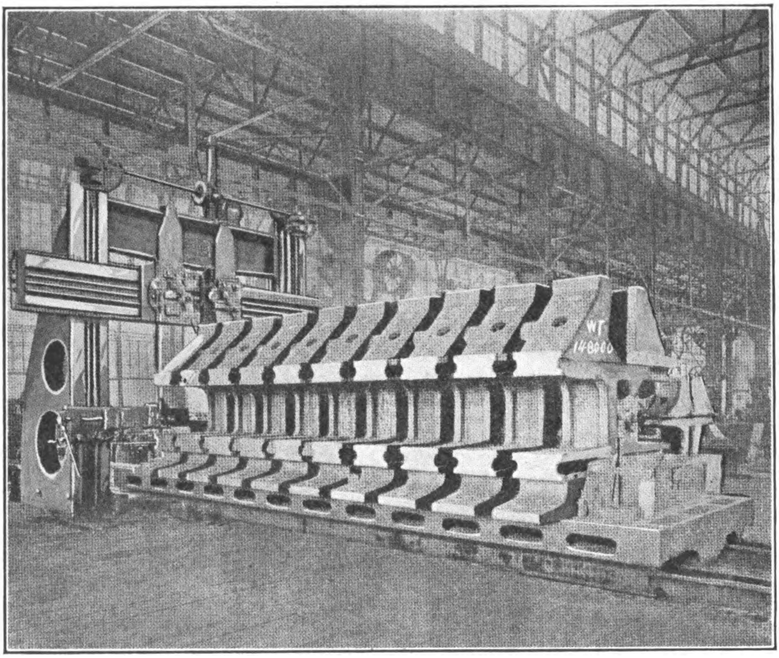


FIG. 55.—A big planer job.

then bolted to the side of the plate *B* its outer end being fulcrumed at *F* in the support *D* which bolted to the floor. The link to be planed is fastened to the plate *B* and the work is ready. The planer tool is set to the desired radius from *F*, 72 inches in this case, and the planer started. As the table moves back and forth the plate *B* is free to move on it with the fulcrum *F* as a center, the pin *E* preventing end movement but allowing perfect freedom sideways. This proved very satisfactory in a number of similar cases.

CUTTING SPIRALS

Cutting spirals is usually a job for the milling machine with its indexing head which can be power driven. They can however be

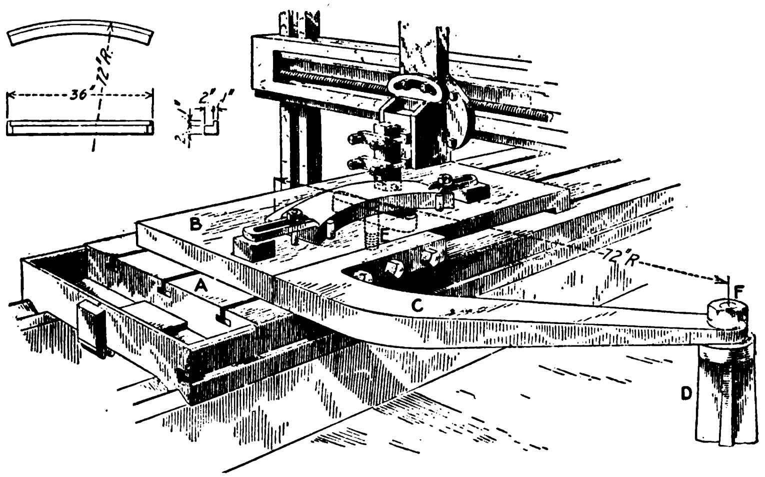


FIG. 56.—Planing a large link radius.

cut on the planer where necessary and in the case of large work, this is frequently the better way. A very old method is shown in Fig. 57. The roll to be planed is mounted on bearings in which it

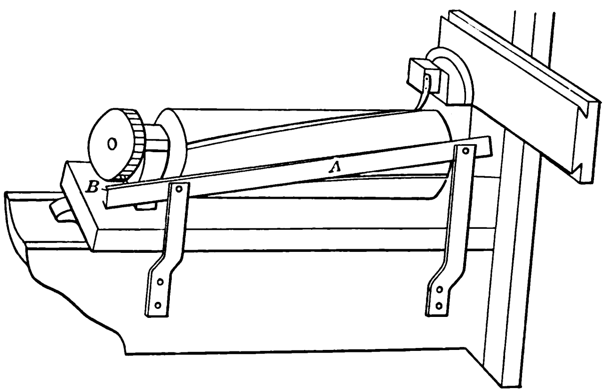


FIG. 57.—Old method of planing a spiral.

can revolve. An inclined bar is rigged up beside the roll and set to the desired angle as shown. This bar usually has a channel at *A* on the side next the roll in which a pin, attached to the index wheel

B, slides as the planer table carries the roll under the tool. This inclined bar must be fastened to the bed or some stationary portion of the machine. As the planer table moves forward the pin moves along the slot in the bar and turns the roll under the cutting tool. After one groove is cut, the roll is indexed, the pin shifted to a new hole and the next spiral groove is cut. This method is necessarily limited to comparatively small angles.

Another method is shown in Fig. 58 and this can be used for as sharp angles as it is policy to cut in this way. For it must be remembered that work of this kind requires careful attention to the shape of the cutting tool and to the clearance provided on the sides to avoid

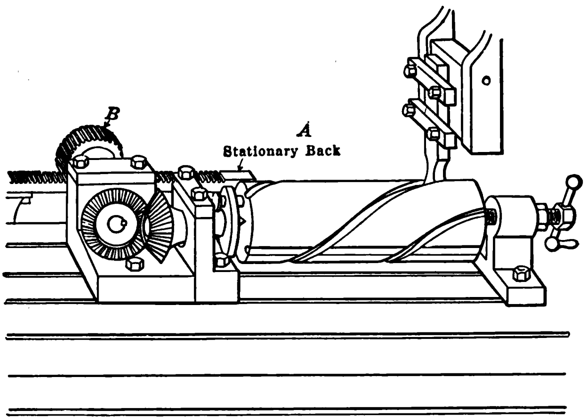


FIG. 58.—A geared spiral fixture.

binding along the sides of the cut. Here the work is also mounted in bearings but the stationary member is a rack *A* instead of the inclined bar, this being fastened to the planer bed in a similar manner as the inclined bar of the first method. The gear *B* meshes into the rack and as the table moves, it turns the work through the medium of the bevel gears shown. The angle of the spiral is determined by the ratio of the bevel gears although this can be still further controlled by the introduction of reducing gears either between the spur gear and the bevels or between the bevels and the work, whichever may be most convenient.

RADIUS AND FORM PLANING

Where a fairly large radius is wanted the swivel of the planer tool head can be utilized as in Fig. 59. Here the swivel is simply loosened sufficiently to allow it to be moved with sufficient ease, the saddle locked in the correct position on the cross rail, and some means provided to swing the swivel. In the case shown the movement is obtained by means of the long screw and handle *A*, the nut in which the screw works being swiveled to allow for the turning of the tool

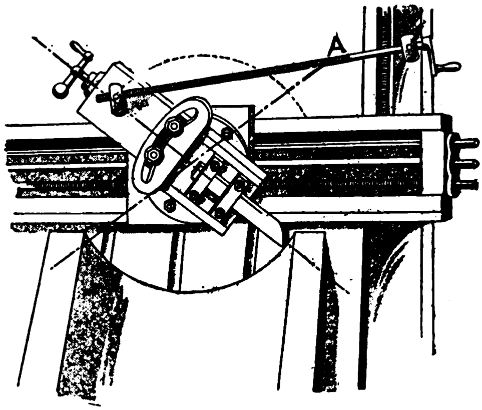


FIG. 59.—Planing an arc.

swivel itself. Should the curved surface desired be on the side of a large piece, the side head of the planer could be rigged up in the same way. Where a small radius is necessary, special tools having a revolving head are made for this purpose.

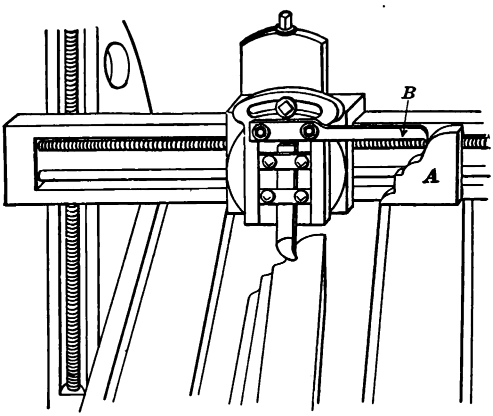


FIG. 60.—Planing with a former.

One way of using a templet on the planer is shown in Fig. 60. Here the pattern or templet *A* is fastened to the cross rail as shown. The guide *B* is fastened to the tool block and by keeping the end of this guide in contact with the templet, the tool must follow this outline and reproduce it on the work being planed. Other applications of this method can be readily worked out.

Another method of form planing, where the form is not too large, is to utilize formed tools or formed cutters in the planer head. An application of this is shown in Fig. 61 where the planer is being used to cut a rack. The tool is a standard milling cutter for gear teeth, these being made of the correct size and shape for different sized teeth. By using one of these cutters in the tool head as shown, the correct shape of the rack tooth is assured, the spacing will depend

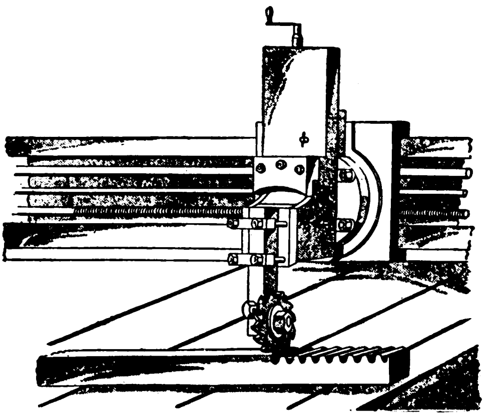


FIG. 61.—Cutting rack with a circular cutter.

on the accuracy or the feed screw in the cross rail and the method of indexing it. Milling cutters of different forms can be used to secure any shape wanted and they provide a long life cutting tool for any work of this kind. Flat tools can also be made and utilized in the same way. Care must be taken however not to attempt too wide cuts. In fact it is better to rough out the work with a form as shown in Fig. 60 and finish with the specially formed cutter, if the surface to be cut is at all large.

CHAPTER V

PLANER BELTING, SPEEDS AND POWER

Of all the machine tools the planer perhaps gives the belting the best opportunity for developing power on account of the high belt speed which is possible. On the other hand, the sudden reversals impose a heavy load on the belting and frequently burns the belting. This was formerly supposed to be due to the work of reversing the heavy weight of the planer table and its load but this is incorrect. What makes the planer so hard to reverse is the inertia of the driving and overhead pulleys, which must be reversed in such a short space of time.

It has been figured out that the reversal of the pulleys takes from eight to twelve times as much power as the reversal of the table and its load. This is why nearly all modern, high-speed planers have aluminum driving pulleys. Tests on a large 72 inch planer show a saving of 25 per cent in power and a gain of 15 per cent in the number of cutting strokes per hour, due to the use of aluminum driving pulleys. These pulleys usually have a cast iron bushing to secure the advantages of this metal for the bearing surfaces.

It has also been figured out that on an average planer on a busy day, the pair of planer belts slip a total of five miles. This is why fast running planers sometimes burn their belting, and it is not uncommon to smell scorched leather near a high-speeded planer.

Planer belts should be endless and double belting is best as it will not stretch as quickly as single belting and consequently requires less attention.

CUTTING SPEEDS FOR PLANERS

It is of course impossible to give any rule for the best planer speed as this will necessarily vary with the special work in hand. On long, continuous cuts, the planer tool will not stand the speed of a lathe tool, presumably because there is usually no lubricant to keep it cool. This is why we sometimes find that when a string of short work is planed on a long table that a higher speed can be used than when the cut is continuous, as in a lathe bed. And this in spite of the fact that the tool gets a distinct shock on entering each separate piece.

A well known planer builder suggests the following speeds for general work:

Cast iron, roughing	40 to 50 feet per minute
Cast iron, finishing	20 to 25 " " "
Steel castings, roughing	30 to 35 " " "
Wrought iron, roughing	30 to 45 " " "
Steel castings, finishing	20 " " "
Wrought iron, finishing	20 " " "
Bronze and brass	50 to 60 " " "
Machinery steel	30 to 35 " " "

Quick return speed on a planer saves time, but not as much as we might suppose. The way to really save time is to increase the cutting speed as much as possible and use from 75 to 100 feet per minute as the return speed. This is a decided increase over the practice of 30 years ago but is not as fast as was tried during the spasm which followed the awakening that planer speeds were too slow. Too fast return speed means a sudden reversal which not only consumes power but racks the machine badly and requires frequent repairs. The following tables show the effect of different cutting and return speeds on the actual output of the machine.

The first table shows the feet of table travel per hour, and must be divided by the length of the stroke in feet, to get the number of strokes per hour. Dividing these figures by 60 gives the travel in feet per minute. Assuming a cutting speed of 30 feet and a return of 60 feet per minute, we see that the actual cutting speed per hour is 1200 feet, or 20 feet per minute, allowing for the time of the return stroke. This also shows that it is very much better to increase the cutting speed to 35 feet than to increase the return speed to even 80 feet.

Another way of stating this information is shown in Table 2. The first column shows the travel in feet per minute and the next column the time it takes to travel one foot at this speed. Thus if the cutting speed is 30 feet as before and the return 60 feet we see that the time of the cutting stroke is 2 seconds and the return stroke one second, a total of 3 seconds for the complete stroke. Dividing the 60 seconds in every minute by 3 we have 20 feet as before. Or we can use it in another way. The added time of the cutting and return strokes is 3 and this is opposite the actual cutting speed in the table, or 20 feet per minute. If the cutting speed had been 35 feet and the return 70 feet we would have added 1.72 and 0.857, making 2.577. As this comes between the values 2.4 and 3 in the second column, we know that the actual cutting speed is between 20 and 25 feet per minute, and we can estimate it at about 23 feet per minute, which is near enough for all practical purposes.

POWER REQUIRED FOR PLANERS

The power required to drive planers on average work is given in the following table. This assumes that the normal length of table

TABLE I.—NUMBER OF CUTTING FEET PER HOUR—DEDUCTING TIME LOST IN RETURNING TABLE

Speed of Cut, Feet per Min.	Return Speed, Feet per Minute							
	50	60	70	80	90	100	120	150
20	857	900	933	960	981	1000	1028	1059
25	1000	1058	1105	1143	1174	1200	1241	1286
30	1125	1200	1260	1309	1350	1384	1440	1500
35	1235	1321	1400	1461	1512	1555	1626	1703
40	1333	1440	1527	1600	1661	1714	1800	1895
45	1421	1543	1643	1728	1800	1862	1864	2077
50	1500	1636	1750	1846	1928	2000	2118	2250

Dividing by 60 gives actual cutting feet per minute.
Dividing by length of stroke gives the number of strokes per hour.
The figures are given to the nearest even number.

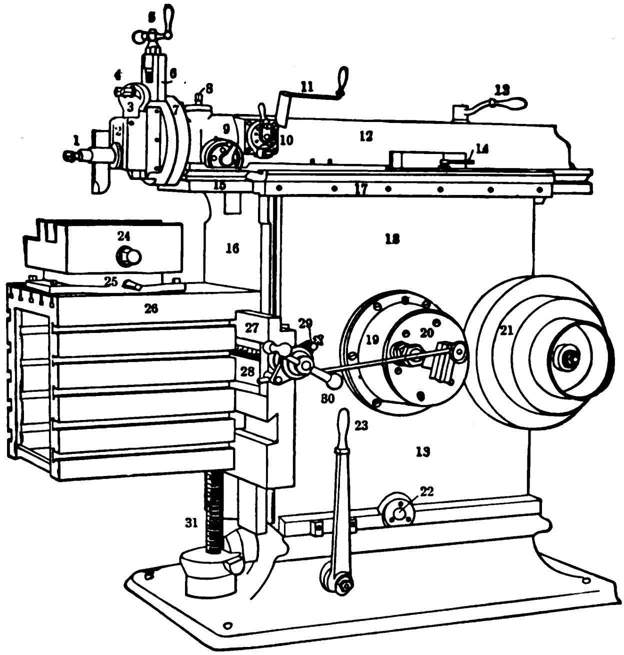
TABLE II.—TIME PER FOOT OF PLANER TRAVEL—IN SECONDS

Table Travel in Feet per Min.	Time per Foot of Travel.	Table Travel in Feet per Min.	Time per Foot of Travel.	Table Travel in Feet per Min.	Time per Foot of Travel.
	Sec.		Sec.		Sec.
10	6.	70	0.857	150	0.4
15	4.	75	0.8	160	0.375
20	3.	80	0.75	170	0.35
25	2.4	85	0.70	180	0.33
30	2.	90	0.66	190	0.32
35	1.72	95	0.63	200	0.3
40	1.5	100	0.60	220	0.27
45	1.33	105	0.57	230	0.26
50	1.2	110	0.545	240	0.25
55	1.09	120	0.5	250	0.24
60	1.	130	0.46	275	0.21
65	0.92	140	0.43	300	0.2

Figures are given to two decimal places only—near enough for all practical purposes.

in feet is about 1/4 of the width in inches. That would give a 24 inch planer a 6 foot table and a 100 inch planer a 25 foot bed.

Size of Planer	Horse Power Required
24×24	3 to 5
30×30	5 " 7½
36×36	10 " 15
48×48	15 " 20
60×60	20 " 25
72×72	25 " 30
84×84	30
100×100	40



A standard shaper.

Shaper — Parts of

1. Tool post.
2. Clapper block.
3. Clapper box.
4. Clamping bolts.
5. Down-feed screw.
6. Tool slide.
7. Tool head.
8. Binder for head.
9. Stop for down feed.
10. Down-feed adjustment.
11. Ram adjuster.
12. Ram.
13. Position lever.
14. Clamp for down feed.
15 Ram slide.
16. Face of column.
17. Ram guide.
18. Frame or body.
19. Feed box.
20. Feed regulator.
21. Cone-driving pulley.
22. Lever bearing
23. Power elevation of table.
24. Vise.
25. Swiveling base.
26. Table.
27. Saddle.
28. Cross-feed screw.
29. Cross-feed dog.
30. Cross-feed handle.
31. Elevating screw.

SECTION II

SHAPERS

CHAPTER I

THE SHAPER AND SOME OF ITS USES

Although the shaper is closely related to the planer inasmuch as both produce flat surfaces by the use of a single pointed tool, there are differences which require attention and study. In the planer the work is supported uniformly under the cut by the moving table while in the shaper the tool leaves the supporting guides as it advances on its stroke. A standard shaper is illustrated on preceding page.

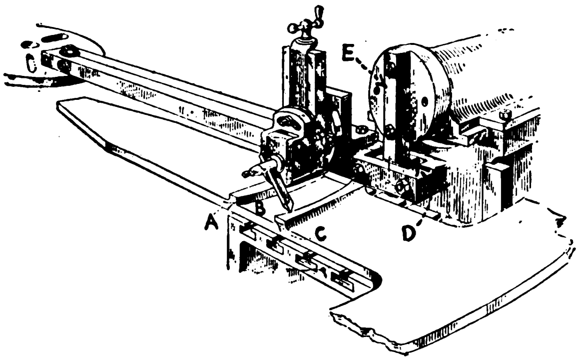


FIG. 1.—Cutting a large radius on the shaper.

The tools and work fixtures, however, bear a very close resemblance but require different adaptations according to the work to be done. The examples which follow will give suggestions for handling a variety of work.

There are also draw-cut shapers, which cut on the back or drawing, instead of pushing stroke. The shaper ram is actuated by cranks, by friction clutches and by vibrating arms.

A marine repair shop was called upon to repair a broken paddle wheel, three arms being damaged. New arms were forged with a considerable excess of metal on the faces *A, B* and *C*, Fig. 1, the channel formed by the raised faces being fitted with a snug fitting ring which tied the parts together.

The first plan was to chip the surfaces to fit the ring but a 20 inch shaper was used instead, as shown in Fig. 1. The radius bar was made of two 2 inch square bars bolted together, a recess *D* being first formed at one end to make a slot in which a block could slide. The bar *E* was bolted to the shaper ram, the end being shaped to form the block which moved in the slot. A large washer on the end supports the radius bar. The bar was pivoted at the other end, the drilling machine table being used for this purpose. The tool slide was fastened to the radius bar by means of the angle plate shown. The table slide moved the forged arm to the correct position and the tool was fed down to the work in the usual manner. Reversing the tool made it easy to shape the inner arc of the forging. This method proved very satisfactory and saved considerable time in getting the steamer into commission again.

CUTTING A RADIUS ON A SHAPER

Two other applications of the shaper to the cutting of a radius are shown in Figs. 2, 3 and 4. The first, Fig. 2, is quite similar to

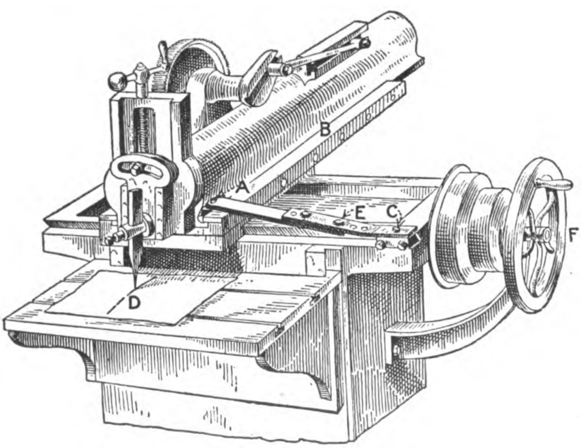


FIG. 2.—Another method of cutting a radius.

the one first described, the main difference being that the work was smaller and also that the whole ram was moved sideways by the radius bar. This method of course only applies to a shaper of the traveling head type.

The pin *A* guides one end of the radius rod, connecting it to the shaper ram *B*. The pivot *C* is fastened to the bed of the shaper. The

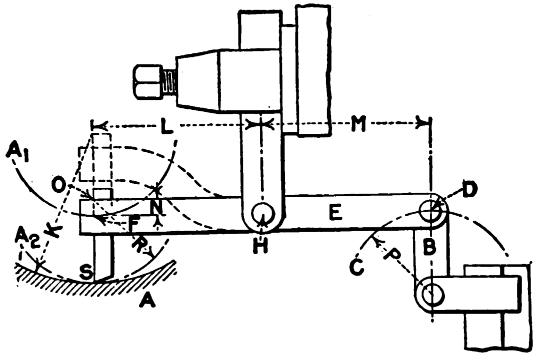


FIG. 3.—A linkage combination for cutting arcs.

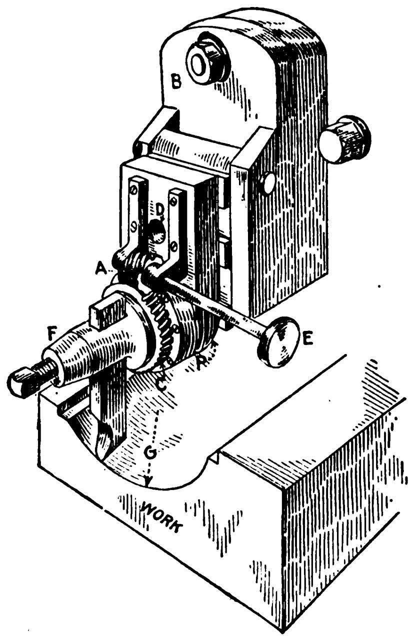


FIG. 4.—A worm and gear tool head.

work at *D* is planed with the arc as shown. The bolts *E* allow for the adjustment of the length of the radius rod. *F* is for hard work.

Another and very different method of cutting a radius, is shown in Fig. 3.

The curve *A* is drawn with its radius equal to *P* the radius of action of the link *B*. It would seem that the work curve *A* will have the same radius as the effective length of link *B*. A moment's consideration will show that this is a fallacy. The only point, other than *D* in the center line of the rod *E*, which can have a motion in an arc of the same radius as *C* is *F*, when *L* is equal to *M*. Hence the tool's point must be situated at *F* and the bar *E* bent upward, as is shown by the dotted lines. Then curve *A* will have the desired radius, that is, will be equal to *P*.

The correct curve could be generated by modifying the link length, or radius of action *P*. But at times this would lead to an impracticable construction. For instance, in the case being considered, if the tool's point were located at *S* and this must travel along the arc A_2, the center of which is at *O*, the effective length of the link would be *OF*, that is, *N*, obviously too small, having regard to constructional considerations.

At first thought one might conclude that a tool projection below the line *FD* would have a correct motion and give the desired curve radius if it were placed closer to the pivot *H*. But this can readily be shown to be a fallacious view. The point *F* has a circular locus; the point *H* moves in a straight line. Hence every point between *F* and *H* must have loci combining a circle and a straight line; that is, elliptical. And just as every point below *F* moves on a circular path, so every point below corresponding points in *OH* except the extremities will move in an elliptical path.

The only practicable general solution is to set the cutting point at *F*, bend the rod *E* as is shown by the dotted lines, and make the link length *P* to correspond to the radius of the desired curve.

An entirely different method, similar to that used in planer work. This device utilizes an attachment to the head of the shaper as shown in Fig. 4.

The accompanying illustration is of an attachment for machining concave surfaces that cannot be done practically and cheaply in a lathe. It can be easily attached and taken off, as it is only necessary to remove the tool holder from the clapper block of the shaper and bolt this attachment to the clapper block in place of the regular tool post.

The several parts are lettered as shown in the diagram, *A* being the worm, which is fastened on a shaft having a knurled handwheel *E* for the purpose of feeding the tool into the work. The worm *A* meshes into the wheel *C*, which has a tool post *F* fastened to it, in which the cutting tool is attached. The tool post and wormwheel move in the block *P*, clamping the attachment to the clapper block *B* by means of a special nut. The thickness of the block *P* should not be such as to bind the wormwheel.

By moving the cutting tool in or out rather a large number of radii can be machined. When the tool overhang is too great, the attachment can be fastened by an ordinary bolt, using the hole *D* and also the special nut as shown in the illustration.

CHAPTER II

TOOLS AND FIXTURES FOR SPECIAL WORK

In Figs. 5 and 6 is shown a die-shaping outfit at the Smith Premier Works, Syracuse, N. Y. The special clapper block *A* interchanges with the regular clapper block used on the machine. When the ordinary clapper block is used for die shaping or any other work where an extension tool is necessary, there is greater tendency for the tool to either lift as it enters the cut or to dig in after the cut

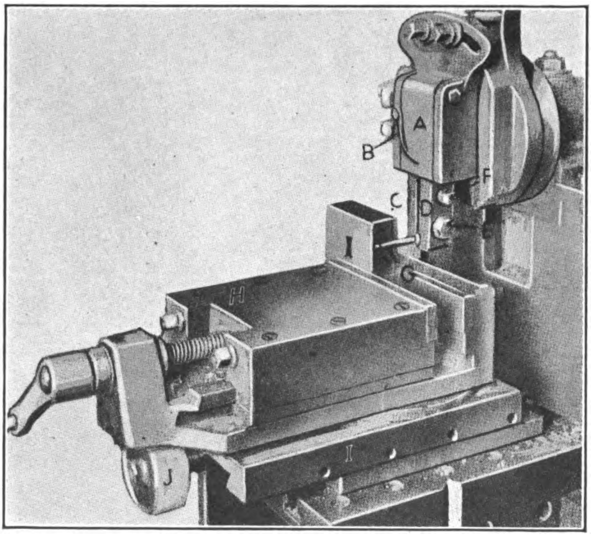


FIG. 5.—Tool head and vise for die work.

is started. Often both these conditions are met with during a single stroke of the machine.

A glance at Fig. 6 will perhaps make the reason for this more apparent. This illustration shows the difference of the entering angles with tools of the same extension length in the ordinary post and this type of tool post.

A small flat spring *B* bears on the face of *A*. This spring is swung to the side when changing clapper blocks. The lower part of the clapper block *A* is extended at *C* and has a horizontal V-groove in it. A cover or clamp plate *D* is held to *C* by a capscrew *E*. It is also provided with a "heel" screw *F* for clamping the tool *G* in the V-grooves in *C* and *D*. The tools *G* have cylindrical shanks of uniform

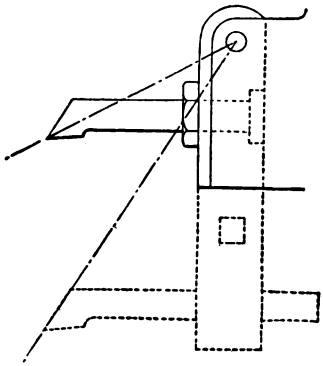
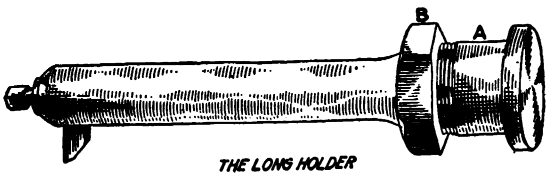


FIG. 6.—Diagram of tool action.

diameter and the cutting ends are forged or ground to various shapes to suit the work. The vise *H* is a particularly handy tool for die work. The upper part is just an ordinary vise with graduated base. This is provided with an auxiliary slide that works on the base plate *I*

FIG. 7.



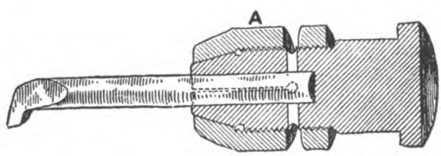


FIG. 8.

FIGS. 7–8.—Long and short tool holders.

secured to the shaper table. This extra slide is provided with an adjusting screw with a knurled knob *J* that permits the work and vise to be moved in either direction in line with the ram. The ability to move the work endwise with relation to the cutting tool is of great value in forming and drop-forging dies, and in work of a similar character. The adjustment can be made while the ram is in motion and in any event is more easily accomplished than by adjusting the ram.

TOOL POSTS AND TOOL HOLDERS

There are many designs for special tool posts and tools, a few being shown herewith. Two types of rigid tool posts are shown in Figs. 7 and 8. The first shows a holder which takes regular tool bits, and can be set at any desired angle for side and corner cutting. The shank *A* fits in the hole of the tool block in place of the tool post

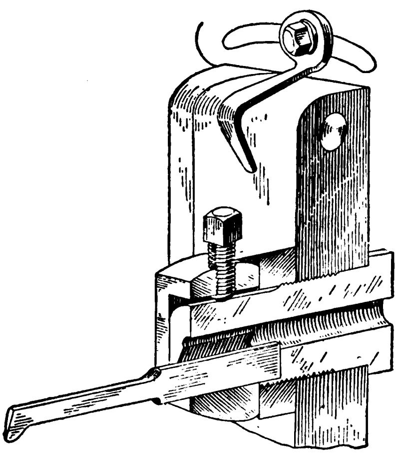


FIG. 9.—Another form of tool holder.

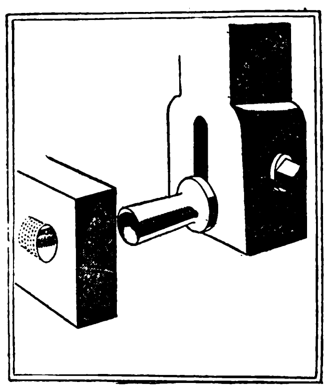


FIG. 10.—Round slotting tool.

and the holder is securely clamped to the tool block by means of the nut *B*.

In Fig. 8 is shown a small tool holder which was found useful for shaping out holes in dies. The tool is forged to the desired shape from drill rod and clamped to the holder by means of the spring collet on the end of the holder and the nut *A*. The collet end of the holder should be hardened and drawn to a spring temper. A piece of ½-in. steel should be inserted in the collet hole when it is hardened so that the collet will admit the tool freely after hardening.

Another is shown in Fig. 9. This has been found very useful in shaping irregular outlines such as dies and strippers. Such a tool holder handles a wide range of sizes and shapes, including round, square and hexagon shapes. The tool is held at three points by the set screw. The spring at the top holds the tool down and prevents it from riding over the work. It is held in place by one of the screws that clamp the swivel.

Figure 10 shows a special form of tool for slotting. It starts in a round hole and leaves a round-ended slot.

USING SHAPER FOR KNURLING AND STAMPING

Knurling is often done in the lathe, but a shaper can be used for this purpose as shown in Fig. 11.

The holder, shown at *A*, is used in place of the swivel block on the shaper, but is held fast while in use. The holder has a dovetail slot *B* for the die, this being fastened by means of the screw *C*. The

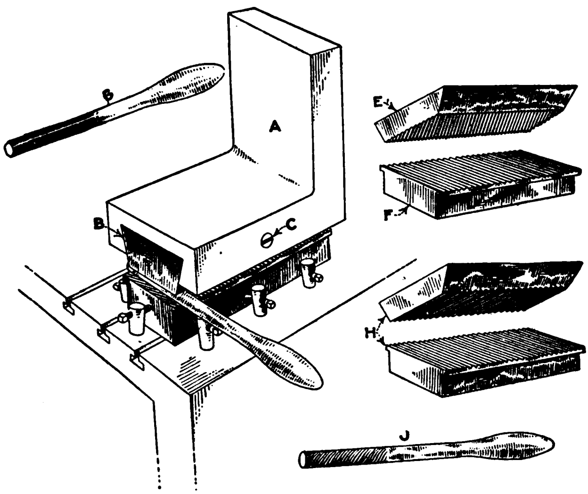


FIG. 11.—Knurling in a shaper.

upper and lower dies are shown at *E* and *F*. These have teeth milled according to the knurl desired, the lower die being milled at an angle opposite to the upper one to produce the knurl effect shown at *G*. At *H* are dies for spiral work, such as the specimen shown at *J*.

This type of tool has also been used for roughing the ends of aluminum and brass pieces $^1/_{16}$ to $\frac{1}{4}$ in. in diameter.

A somewhat different application of the same method was used to work round work. The illustration Fig. 12 shows the working of gaine bodies on fuse work which proved very rapid and satisfactory.

A holder *A* is made to fit into the tool post of a shaper. In this holder stamps are inserted, as shown, and the holder fastened into the shaper. A special platen with a stop and a recess, as indicated, is made to go in the table. The forward stroke of the shaper rolls the markings in nicely, and incidentally no time is lost in withdrawing the gaine.

A steady, heavy shaper should be used to insure satisfaction, as there is considerable upward thrust when the markings are rolled in. The capacity of this machine equals the stroke of the shaper, which should be 1 per second.

SPECIAL ANGULAR PLATEN FOR SHAPER

It often happens that a few fixtures for standard machines will save the cost of making special tools and fixtures for each job. Such

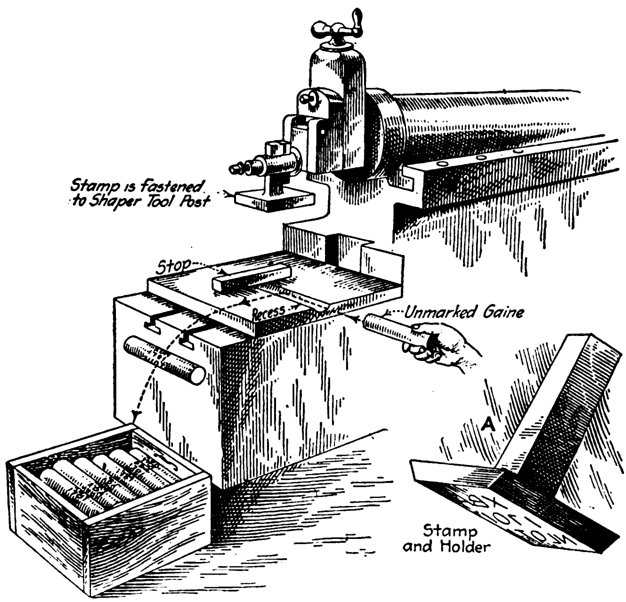


FIG. 12.—Rolling marks on round work.

a fixture is chosen in Fig. 13 which is an adjustable false platen for the shaper, made from a three-sided angle iron, as shown in the illustration. This allows the work to be held at any desired angle in the reverse way from that which is possible on the main table or apron.

A piece is frequently designed which is quite awkward to machine by any ordinary convenient holding method. The sleeve shown is a case in hand. There are two double-angular splines in the hole, and the depth, angles and center positions must all be fairly accurate. The

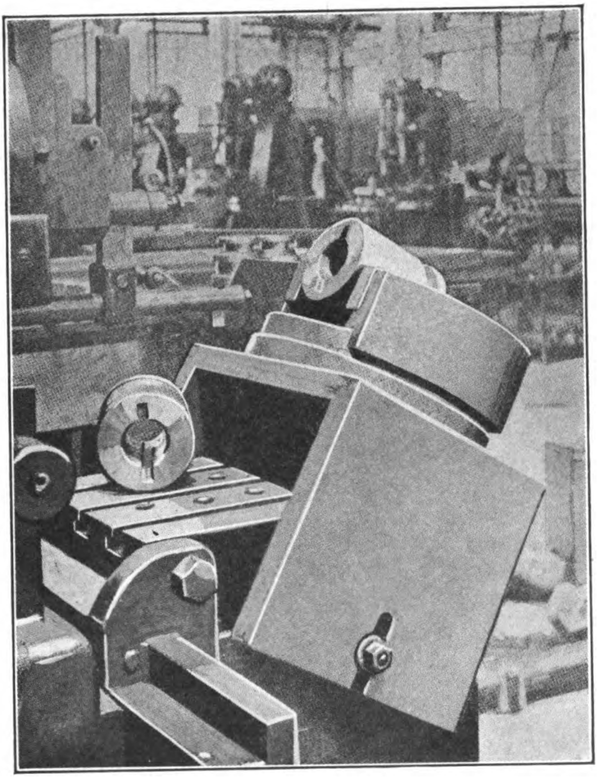


FIG. 13.—Angular attachment for shaper table.

splines could not be cut the other end to. The convenience of the false platen is obvious in this case.

When not in use the false platen can be let down in contact with

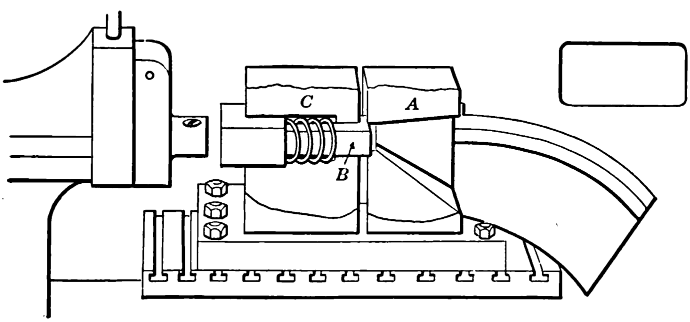


FIG. 14.—Punching sheet metal on a shaper.

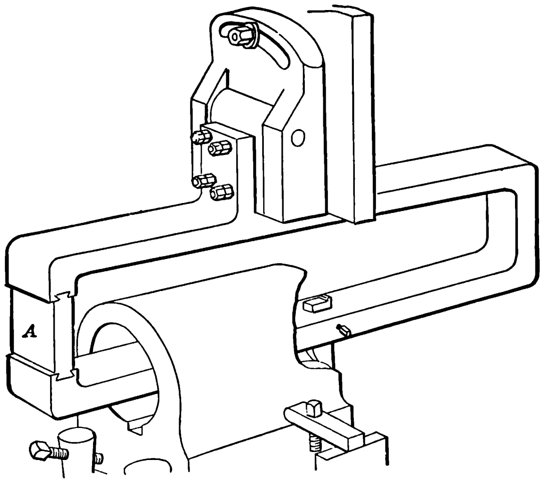


FIG. 15.—An unusual key-way cutter.

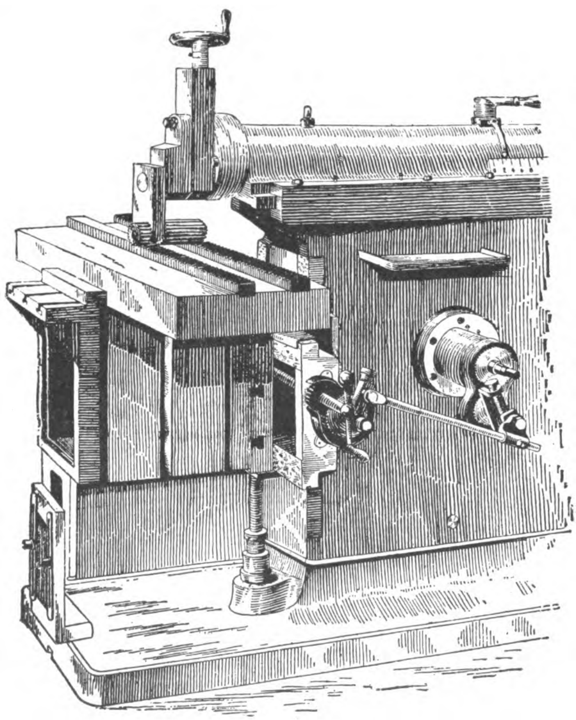


FIG. 16.—Improvised rack generator.

the apron and the regular vise clamped on as though the angular plate was off. At the same time it is always available when needed.

A very unusual adaptation of the shaper is shown in Fig. 14. A special punching die *A* and the punch *B* enable the shaper ram to make a fair job of punching. The punch is guided by the block *C* and returned by the coil spring shown. The punchings fall out of the die and down the chute shown. On thin stock such a fixture is found quite satisfactory where a punch press is not available.

A RIGID KEYWAY CUTTER

An unusual form of tool holder is shown in Fig. 15. While this is used for cutting keyways, a similar tool holder could be used for

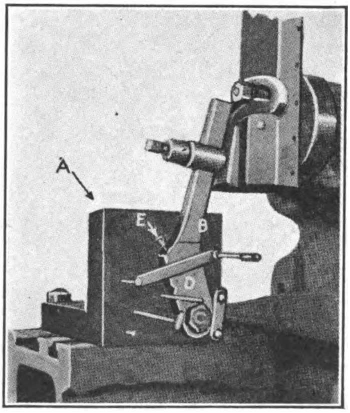


FIG. 17.—Cutting off rods in a shaper.

other work as well. The tool holder is in the form of an open link with the end *A* removable to allow it to be put through the work. This end piece is dovetailed at each end to resist any tendency to open the link.

With the tool holder in the position shown the cutting tool is rigidly held and there is no necessity to use a tool with a long nosed extension and which always has more or less spring—usually more.

Figure 16 shows a method of generating teeth in a rack. The back end of the tool is a long pinion of same size and pitch as the cutter in front. The long pinion is constantly in mesh with the rack and the cutter generates the teeth in the work as the ram travels back and forth and the table feeds sideways.

A CUTTING-OFF FIXTURE

This is a fixture for cutting off a large number of rods quickly and to uniform length. The block or angle plate *A*, Fig. 17, is bolted to the shaper table. The arm *B* fastens in the tool post and is pivoted at *C*. The broad portion *D* carries the cutting blade at the front edge, and is held close against the other cutting edge by the strap across the front. The rods are pushed through the block against a stop and a piece is cut off at each stroke of the shaper ram.

TABLE 1.—POWER REQUIRED FOR SHAPERS

Stroke of Shaper	Horse Power Required
12 to 16 inch	2
18 " " "	2 to 3
20 " 24 "	3 " 5
30	5 " 7½
20 inch Traverse Head	7½
24 " " "	10

SECTION III

THE SLOTTING MACHINE

The slotting machine, or "slotter" as it is most commonly called, is practically a shaper in which the ram and the cutting tool move vertically. In fact one make of small slotter for such tool room

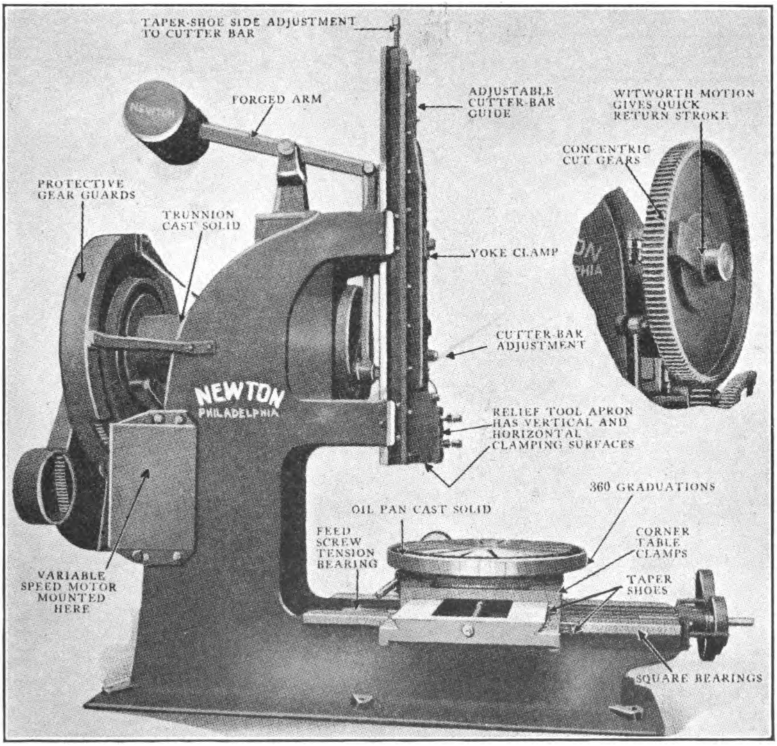


FIG. 1.—Slotter with main parts named.

work as cutting out dies, is called a "vertical shaper." The work however is held directly under the ram by tables which move both in and out from the column and also across it. In addition to this, some slotters have a rotary table mounted on the slide, which enables almost any outline to be formed on a piece of work. Figure 1 shows the Newton shaper, while Fig. 2 is the Pratt and Whitney vertical shaper for tool room work.

The slotter ram has a quick return the same as the shaper, this

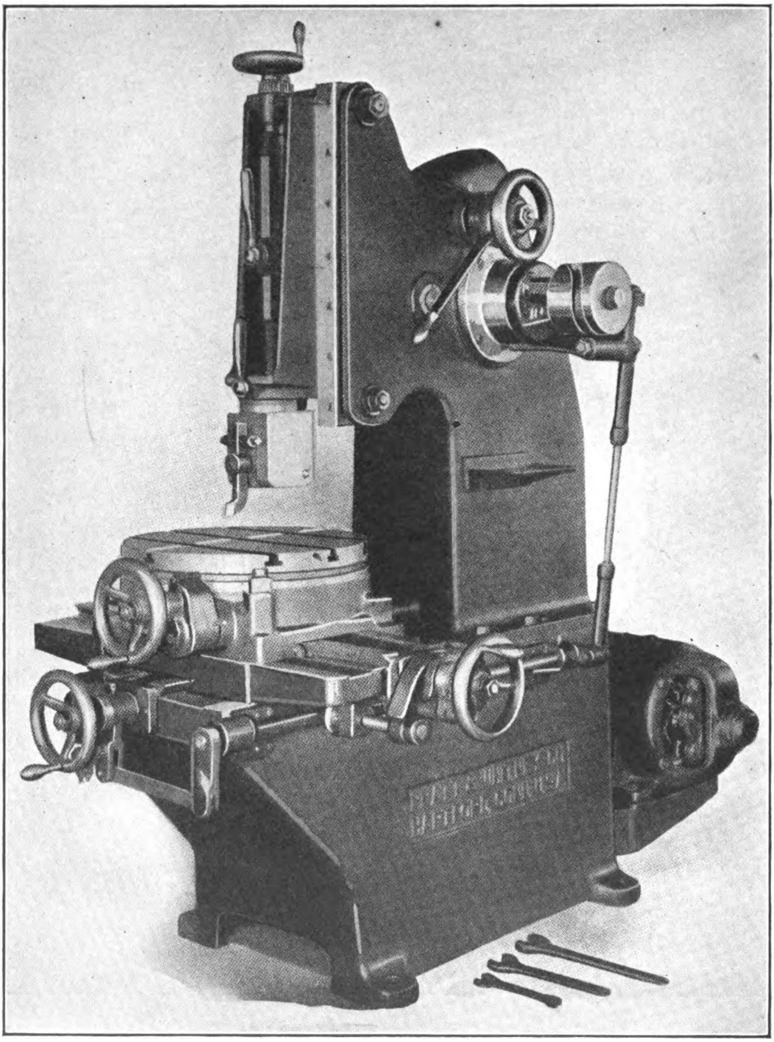


FIG. 2.—Vertical shaper or slotter for tool work.

being accomplished in various ways. The use of slotters is confined to a few kinds of shops, such as locomotive building, railroad repair shops, marine-engine work and heavy machinery of various kinds.

Work is held to the table in much the same way as in planer or vertical boring mill work. As the tool must clear the work without striking the table, the work must be supported by parallels or distance pieces as with the boring mill. On the other hand, the fact that the work does not usually revolve, at least not for a full turn, portions of it can project beyond the table in many cases.

Slotters are sometimes used for facing flat surfaces which would be planed if the piece could be held on a planer. They are also used on work which might be called circular planing, such as cutting arcs, or parts of circles as in planing the shells for driving boxes of locomotives as in Fig. 3. Here the driving box is mounted on the table so that the bore will be concentric with the center of the table. Then as the table turns the slotting tool cuts its way around the arc

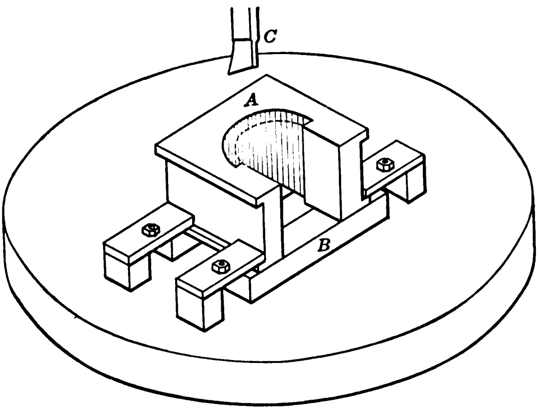


FIG. 3.—Slotting driving box for crown brass.

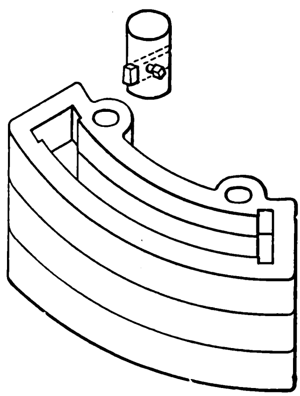


FIG. 4.—Slotting locomotive links.

to fit the driving box itself as at *A*. The dotted lines show how the journal fits into the box. The parallel strips *B* raise it from the table enough to allow the tool to clear.

Another locomotive job is shown in Fig. 4 where three locomotive valve motion links are piled up for shaping out the curved surfaces and the recesses at the ends. These are cut with a special tool instead of the inserted cutter bar as shown. This tool can cut all around the outside, shifting the holding clamps as the work changes. Figure 5 shows how such a tool is made and held in the slotter ram. The tool itself is held in the bar *A*, which is clamped in the holders *B* and *C*. These are bolted to the tool head *D* and makes a rigid cutting tool for heavy work.

A job of real slotting is shown in Fig. 6 which is the end of a steam engine connecting rod. The usual method is to drill four holes, one at each corner of the opening, these holes being large enough to admit the tool shown above. The tool started at *A* and slotted its way to the hole *D*. Then the work was turned 90 degrees and about

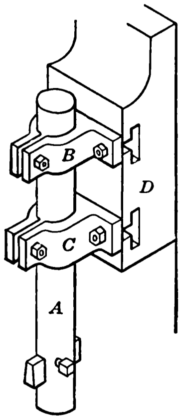


FIG. 5.—Slotting bar and holder.

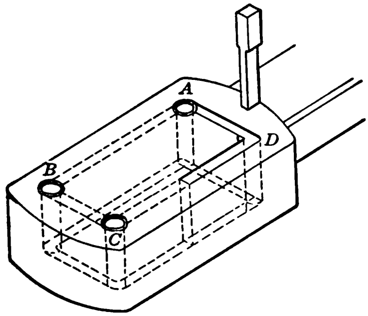


FIG. 6.—Slotting end of connecting rod.

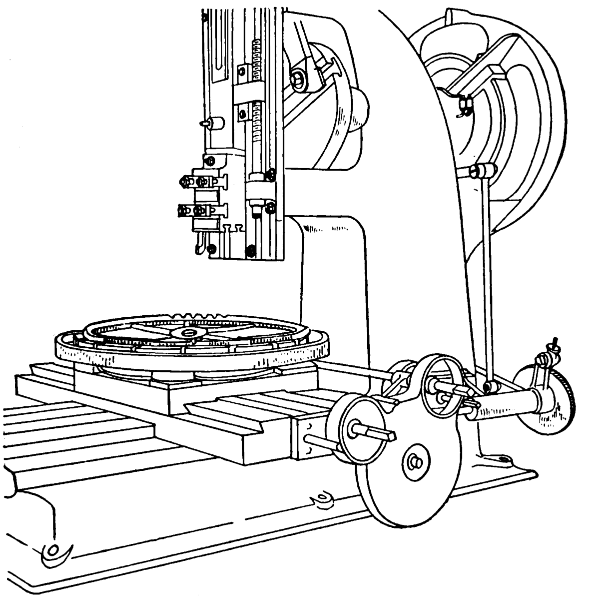


FIG. 7.

half the distance from *D* to *C* has been cut. This is continued all around the opening.

Another method is to drill but two holes at diagonally opposite corners, as *A* and *C*. In this case the slot would be cut from *A* to the solid corner *D*. Then the rod is turned to cut from *A* to *B*. The next move is to start at the other hole *C*, and cut toward *B* and *D*, meeting the slots from *A* and freeing the center block.

Slotters are also used for cutting the teeth in large gears, a formed cutter or planing tool being used as shown in Fig. 7. This requires

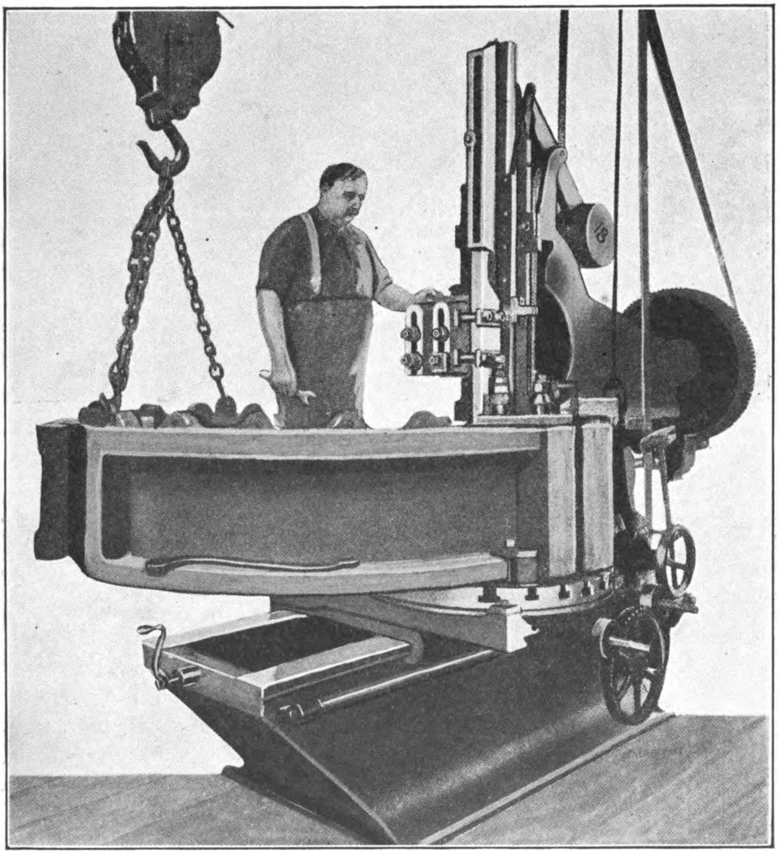


FIG. 8.—Supporting end of large piece with crane.

an indexing table the same as a gear cutter. Many large gears are cut in this way. Figure 7 shows how this is done.

SOME EXAMPLES OF SLOTTER WORK

The following illustrations give a good idea of the variety of heavy work done on a large slotter, these showing the Dill slotter with its adjustable head. Figure 8 shows the three-ton base of a heavy machine,

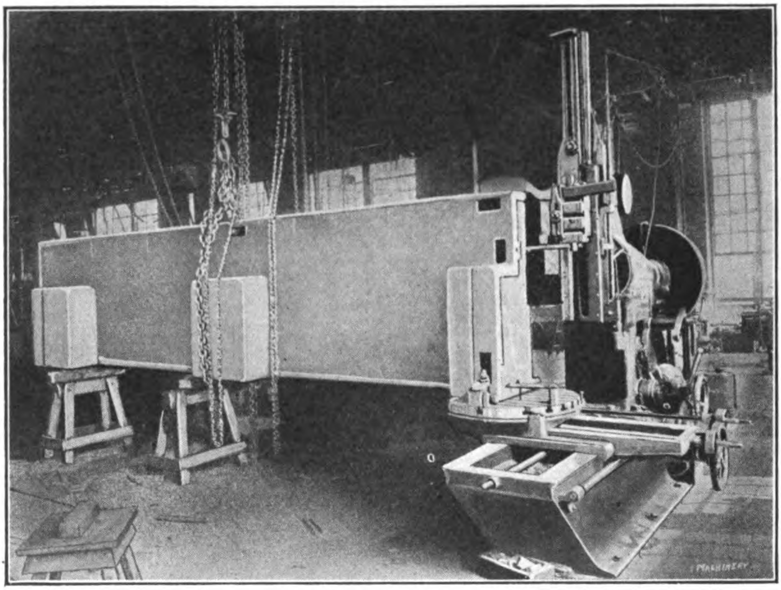


FIG. 9.—Another awkward end job.

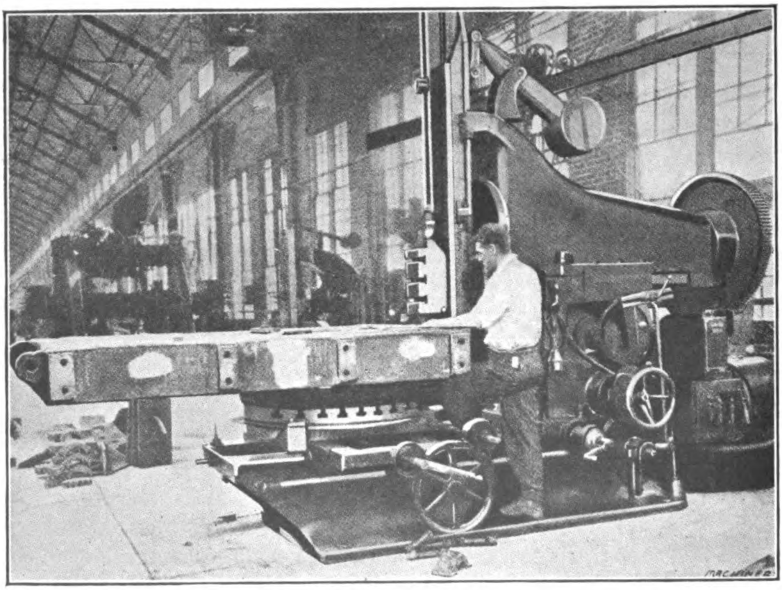


FIG. 10.—Slotting end for bearing box.

with some of its surfaces being finished by the slotting tool. The work is bolted to the slotter table but the outer end is also supported by the overhead crane. The length of the cut is 18 inches.

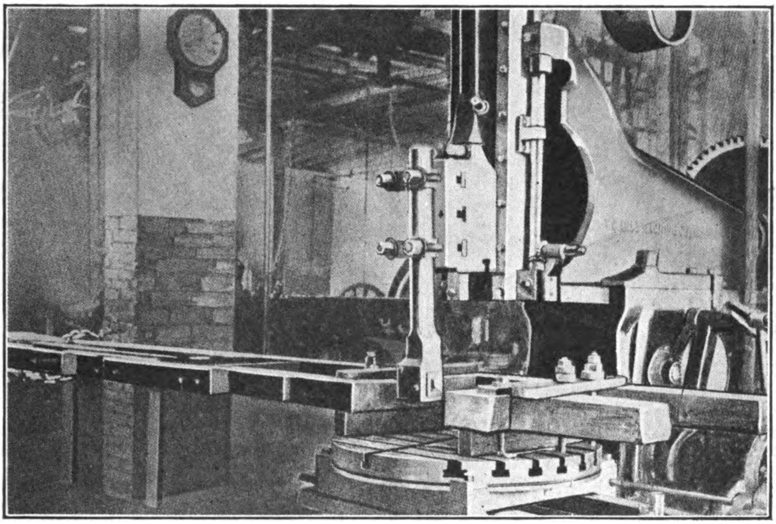


FIG. 11.—Slotting jaws of locomotive frame.

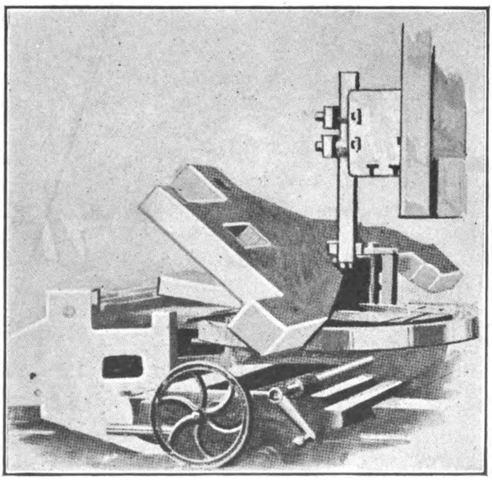


FIG. 12.—Angular slotting.

Another awkward job is shown in Fig. 9, this being the end of a 11,500 lb. machine bed. Here the outer end of the work is supported on horses and the tool is at the side of the slotter head. A third large job is seen in Fig. 10, the piece being a 3700 lb. steel casting of a steam shovel. It is 7 ft. 9 in. long by 5½ ft. wide and 15 inches thick. The work is slotting a bearing cap for a vertical drive shaft, the surface being 10 in. wide and 15 in. long, with ⅜ in. of metal to be removed. Then there is a center bearing which is also slotted. The total time for the job was 4 hours.

A railroad repair shop job is seen in Fig. 11. Here the traveling head is fed out to slot the sides of the frame jaws which saves the awkward task of feeding in the whole length and weight of the frame.

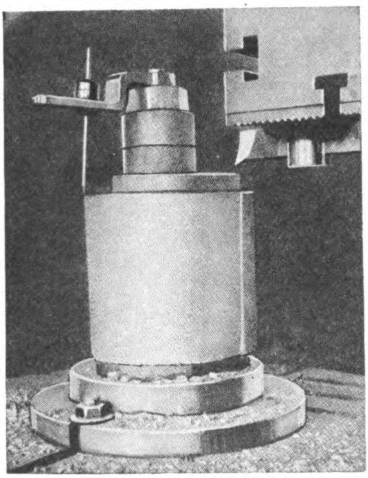


FIG. 13.—Close view of tool and holder.

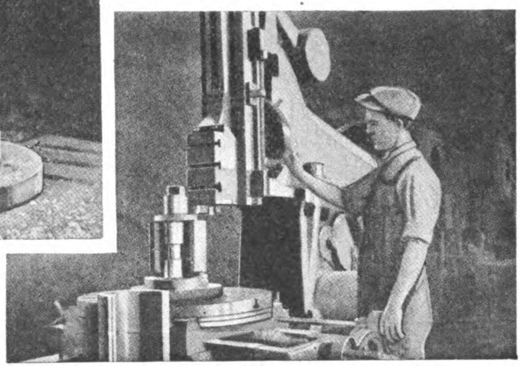


FIG. 14.—Machining crown brass in slotter.

The awkwardness of this job can be seen when we consider that the frame is 30 feet long and weighs 2½ tons. The jaws are 20 inches deep, which requires a 20 inch movement of either head or table.

It will be noted that the slotting tool or bar is very similar to the one illustrated in Fig. 5.

Two other railroad jobs are shown in Figs. 12, 13 and 14, the first being one in which it is necessary to support the work at one angle, the other, shown in two views, the machining of crown brasses which go into the driving boxes shown in Fig. 3. This is a job usually done on the lathe but the Philadelphia & Reading Railroad prefer this method. These brasses vary from 8 to 13 inches in length and they are machined in 7 to 22 minutes each.

The tools used in slotting machines are very similar to those used in the shaper or planer, with the exception of the end cutting tools which are sometimes necessary, as in the job shown in Fig. 6. They therefore need no special description or attention.

The horse power required for crank slotters is given as follows:

Slotters with 6 to 8 in. stroke	....	3 to 5	H.P.
10 " 12 " "	....	5	
14 " "	....	5 to 7½	
16 to 18 " "	....	7½ " 10	
20 " 30 " "	....	10 " 15	

While most slotters are crank driven as shown—some are made with a heavy rack on the back of a ram and this is driven by a substantial pinion. These use reversing motors of the planer type, for driving the pinion.

SECTION IV

BROACHING

Broaching, according to Ethan Viall, whose treatise on the subject is the most complete authority obtainable, "is the working out of holes or slots, or the machining of surfaces, by tools having a number of successive cutting teeth of increasing size, no matter whether these teeth are arranged singly or in multiple." The process is old and grew out of the old practice of "drifting" out an irregularly shaped hole with a special punch made with several cutting teeth arranged according to the ideas of the maker. These were driven through the piece with a hammer or sometimes forced through with an arbor press.

The use of machines for this work began with the old key-seater having the long cutting tool and has since developed to such an extent that the teeth of internal gears are broached complete at one pass of the broaching tool and outside surfaces are also finished in a similar manner. By dividing up the cut so as to give each tooth only the proper amount of work to do, it is possible to remove a large amount of metal and to work out intricate shapes which would otherwise be very expensive. On the other hand the broaching process is also growing into use for the finishing of round holes, such as the bearings for connecting rods and similar pieces. One advantage of this process is that no special holding fixtures are needed as the action of the broach holds the work against the supporting surface regardless of whether it is a pull or a push broach.

As the action of the broach in making a distinct change in the shape of the hole, such as from a round hole to a square hole, is not always understood, the diagram, Fig. 1, has been made to show just what takes place as the broach travels through the hole. Unless it is necessary to have a hole with perfectly square corners, it is better practice to leave the corners rounded and it is also customary to have the starting hole drilled somewhat larger than the small diameter of the square. This is particularly true in automobile work where this process was used quite largely for sliding gears on square shafts. This method is being replaced to a considerable extent by the use of the splined shaft instead of the square shaft, the splines being milled or hobbed solid with the shaft. The advantages of drilling the hole a trifle large can be plainly seen in Fig. 2, as it allows a larger hole through the gear and leaves less metal to be removed. The diagram, Fig. 1, does not show the cut taken by every tooth, but gives a general idea of how the shape gradually changes from the round to the square. The heavy lines show the cutting which takes place at the corners of the hole. The broach may be roughly described as being a taper bar, the small end being the diameter of the drilled hole and the large end the diameter across the corners of the hole. Then four sides are milled so as to make the flats for the hole, the milling running out as it approaches the small end of the broach. This is shown exaggerated in Fig. 3,

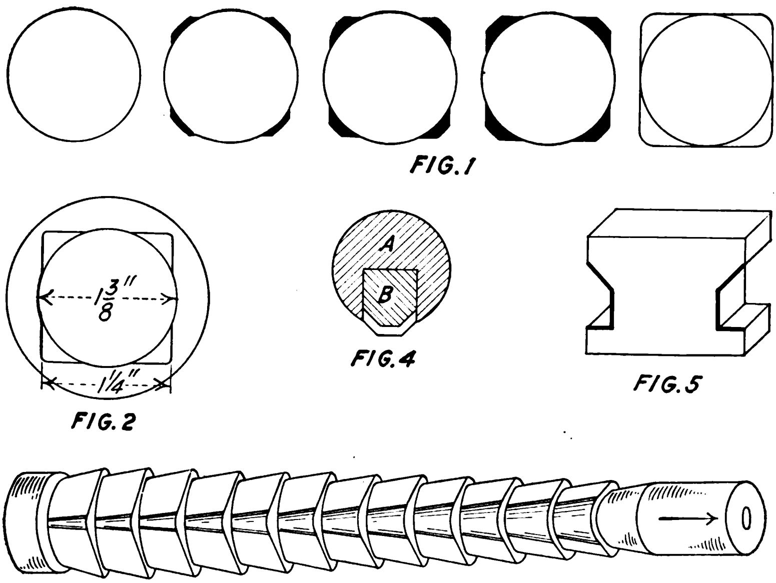


FIG. 3.
FIGS. 1–5.—Broaches and broached holes.

giving the appearance of the broach ready to be used and showing how the flat sides increase from the point to the back.

In commercial work the pull type of broaching machine is most in use. In a number of shops however, the use of the push broach is growing for certain classes of work. The cost of the long pull broach, together with the delay if one breaks and there is no reserve supply on hand, favors the other type of broaching. Push broaching, however, may easily require three or four broaches which must be pushed through, one after the other, where there is much metal to be removed. As with almost every other shop process, one method suits some conditions better than others and no one method is best in all cases.

The growth of the method has developed the machines for doing it, to a marked extent, some of them having a stroke or travel of from 5 to 6 feet and weighing considerably over two tons. One machine, for example, has a capacity of broaching holes 4 inches square and requiring a 10 horse-power motor to run it. The cutting speed varies from 3 to 6 feet per minute. The proportions of the cutters can be seen from the tables.

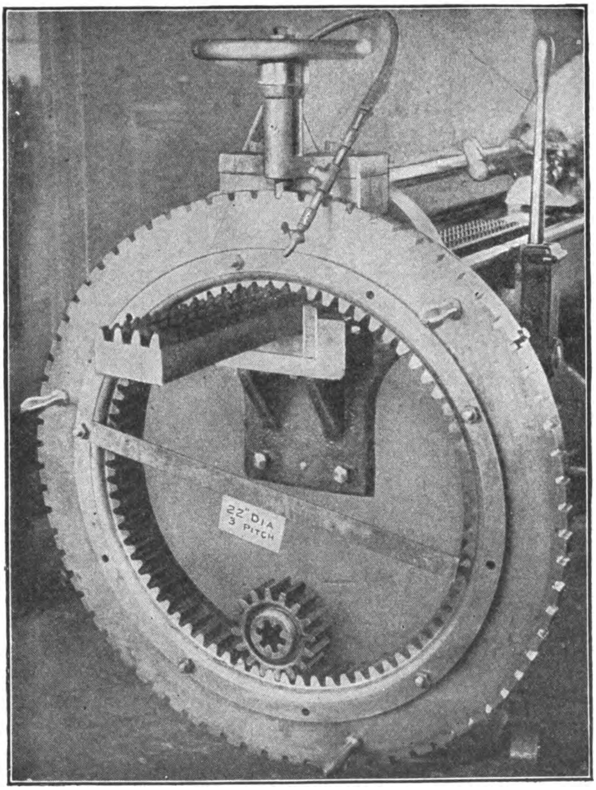


FIG. 6.—Broaching a 22-in. internal gear.

Push broaching machines, although less frequently found than the others, run all the way from the hand arbor press up to hydraulic presses with a capacity of 150 tons or more. The speed of these varies from about 35 to 100 *inches* per minute.

Not all broaching is done with teeth cut on all sides. The key seating broach cuts on only one side and this makes it necessary for the broach to be supported directly opposite the cutting edge. In the case of the broach shown in Fig. 4, the supporting piece *A* fits inside

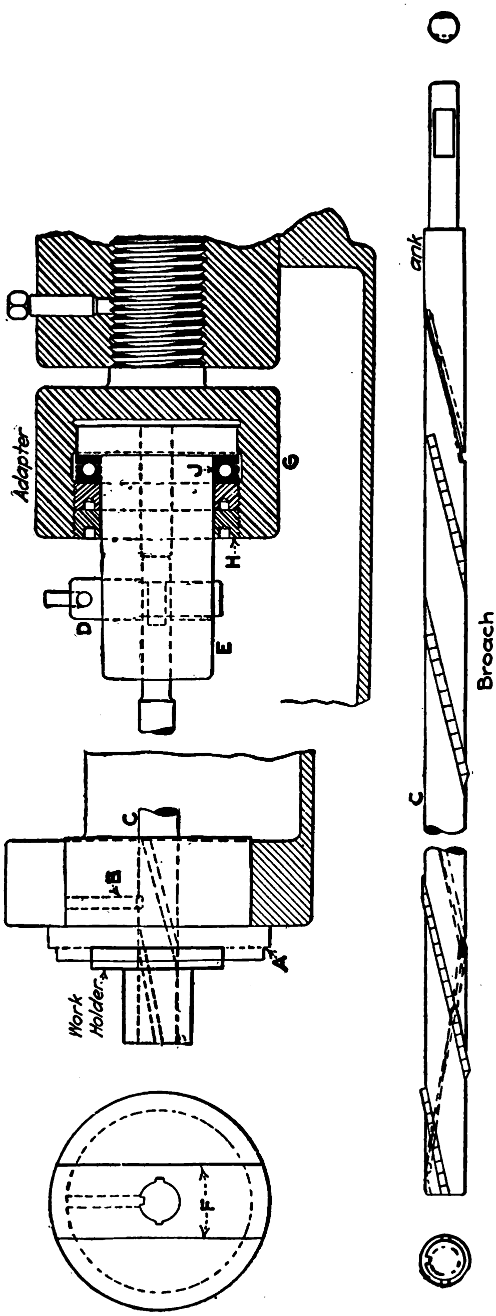


FIG. 7.—Fixtures used for broaching spiral keyways.

the bore of the pulley and the broach *B* slides through the slot in *A*. In some other cases broaches are used to machine the outside of work, being supported in a similar way by special holders which are held firmly in their proper relation to the work to be done. An example of this is shown in Fig. 5. The opposite of this is seen in Fig. 6, where four teeth of an internal gear is being broached, internal diameter being 22 inches.

Spiral broaching is also accomplished on the standard types of broaching machines, a method being described in the *American Machinist* and shown in Fig. 7. "The work was small and had two spiral keyways cut through it. The piece is mounted in the bushing at *A* and both a roughing and a finishing broach drawn through it. This bushing carries the guide pin *B*. The shank of the broach *C* with the work slipped over it, is pushed through the work bushing and gripped by the pin *D* in the broach holder *E*. An adapter is provided to allow the broach to twist in the machine as it passes through the work. This adapter consists of the broach holder *E*, in the adapter *G*, two check nuts *H* and a ball bearing *J*. All these parts are mounted on the drawbar of the machine in the regular manner.

After the work is slipped over the broach the work is held by hand against the work holder, the sides of the slot *F* preventing it from turning under the action of the broach. As the machine pulls the broach through the work the broach turns as the spiral groove follows the pin *B* in the bushing *A*.

Keyways and other cuttings can be made in taper holes as well as straight by using a little ingenuity in making the holding devices for the work. The work must be held so that the portion to be broached is parallel with the travel of the broach and there will be no trouble in work of this kind. The broach must be carefully guided as in all other broaching where the cutting teeth are not on opposite sides of the broach.

BROACHING AND BURNISHING

For finishing motor bearings, such as connecting rods, it is the custom in some shops to combine a burnisher with the broach. This simply means to have the last end of the broach smooth and a few thousandths larger than the last cutting tooth. This makes a very fine finish in the bearing and compresses the metal where it bears on the crank pin or crank shaft. It requires great power to pull such a broach through a piece of work however, and provision must be made for it.

In one special case where the bearing is 1⅞ inches in diameter and of the usual length, the broach has but 12 teeth which increase in size by 0.0005 inch from first to last, while the burnisher is 0.005 inch larger than the last tooth. This requires a pull of from 5000 to 6000 pounds, or between 5 and 6 horse power in this machine.

In cases of this kind it is customary to place the end of the connecting rod, or whatever is being broached, in a heavy steel ring which supports the outside so that the passing of the broach cannot spread the piece being broached. Such a holder is shown in Figs. 8 and 9.

In other cases the broach makers leave a blank space between every fourth or fifth tooth. This acts as a support for the broach and

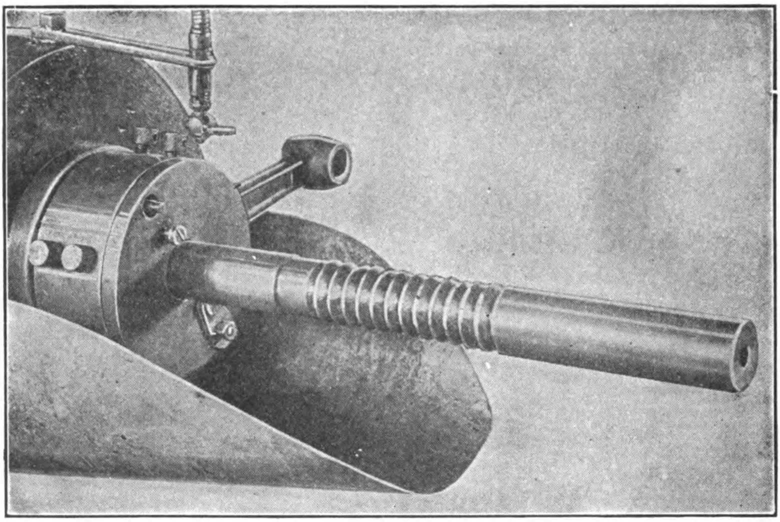


FIG. 8.—A sizing and burnishing broach.

prevents any tendency to drop or sag in the cut, and the plain portions also act as burnishers for the bearing.

In the connecting rod work just referred to nothing has been found to take the place of prime lard oil for really satisfactory work, according to the experience of those who are using broaches of this kind.

With round holes it is often a question as to whether it is best to broach or ream the hole. The experience of large shops seems to show that broaching is much the cheaper method, especially where the material is hard, such as the chrome-nickel steel so largely used in automobile work. Similar testimony is also made in cast-iron work, one specific case being where but 0.002 inch was left for broaching. While the reamer wore appreciably below size in reaming 25 holes, the broach finished 5000 holes before getting below the minimum size wanted.

In broaching cast iron a soap cutting compound gives good results, while for chrome-nickel steel a good grade of cutting oil will be found very satisfactory.

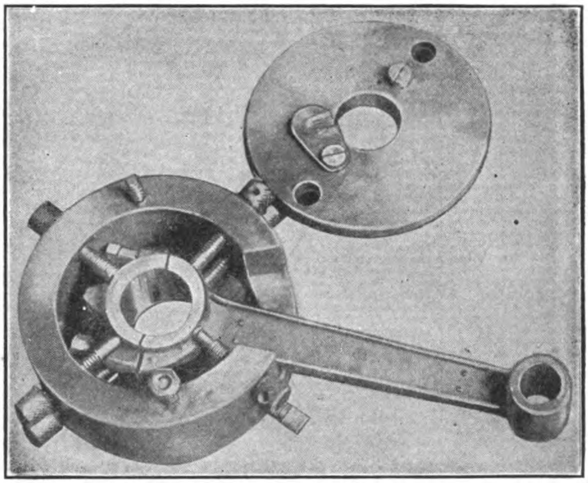


FIG. 9.—Holder used to prevent spreading.

BROACHING CASTINGS FROM THE ROUGH

In some classes of work it is possible to broach from the rough without preliminary drilling. When this is done, it is of course necessary to do the broaching first and have the other operations follow. This is because the broach naturally follows the cored hole so that the finished hole would not be in line with the other surfaces to be machined. Unless the hole is over 2 inches long the hole can usually be finished with one broach. If over 2 inches it is usually advisable to use a roughing broach before attempting to finish the piece.

One example will show the practice of one large company. The work was a bronze casting $4\frac{1}{2}$ inches long, cored to $1\frac{7}{8}$ inch and to be finished to 2 inches. This allows $^1/_{16}$ inch on a side for finishing. These are broached in $1\frac{1}{4}$ minutes each and do not require to be clamped or held in any way.

The broach should be 28 to 40 inches for removing this amount of stock. The broach should be nicely finished all over and all the roughing teeth should be nicked to break up the chips. The last six or eight teeth should not be nicked but left whole to finish the hole and behind the teeth is a short pilot which can act as a burnisher. The teeth should be so spaced that there will always be at least three teeth at work to support the broach properly in the work.

When these same bronze bushings were bored and reamed it was thought necessary to leave ¼-inch stock for boring and the work required about 10 minutes per piece. Then too, it was difficult to get the reamer to leave a good hole in the hard bronze owing to the tendency to chatter.

THE DESIGN OF BROACHES

As in most other matters of modern shop practice there is no hard and fast rule which can be applied to the design of broaches. The factors which govern the design are the shape of the work, the length of the cut, the amount of material to be removed and the kind of material used. The metal to be removed determines the length of the broach, as the work must be divided among a sufficient number of teeth to avoid undue stress upon any one. In small holes the strength which can be left in the core of the broach is often the factor which determines the depth of the cut of the teeth. It is often necessary to use two broaches on this account where but one would be needed if the broach could be made strong enough to stand the pull.

While it is unwise to attempt to stick to any fixed rule in designing broaches a few fundamental facts may help in determining what is safe practice. Two or three teeth should always be in contact with the work if possible, although on very short work this can seldom be done unless we can broach two or three pieces at the same time. On the other hand the teeth must not be spaced too closely or there will not be room for chips while the tooth is in the cut. The longer the piece and the deeper the cut the more chip room there must be between the teeth. Should the broach clog with chips it takes too much power and is also very apt to break the broach. One rule is to make the pitch of the teeth, i.e., the distance between teeth, the square root of the length of the hole multiplied by 0.35. For a hole 4 inches long this would give $\sqrt{4} \times 0.35 = 0.70$ inch as the spacing for the teeth. This would give 5 teeth in the cut at the same time.

The hardness of the metal as well as its toughness affect the shape of the tooth to some extent and also the amount which can be safely taken at a single cut. This is also affected by the size of the hole as before stated. It is also necessary to have some gage as to the number of broaches required to finished a given hole, as there are many cases where it is necessary to have a set of several broaches to secure satisfactory work. When in doubt as to the number it is safer to make an extra broach. Then if it is found unnecessary it can replace the last broach as it wears and so keep the set complete after the first one is worn out. It is quite common practice to keep sets of broaches in good shape by making all new broaches for the finish and grind the others down as they wear.

The capacity of a single broach may be said to be about twice its diameter in broaching square holes. That is, if a broach is 1½ inches square it is good for a hole 3 inches long. A longer hole requires two broaches in the set.

The depth of cut which can be taken with each tooth depends on the size of the broach and the material being cut. In mild steel and with holes of medium size it is customary to give each tooth a cut of from 0.001 to 0.003 inch. In heavy cast iron or in brass, this can be doubled. With larger work, where the holes are over 2 inches in diameter, the cut can be considerably increased because the broach is strong enough to stand a heavy pull. It must also be remembered that best results are always secured where a tool of this kind cuts instead of merely drags and scrapes, as is also the case with reamers.

While some broach makers give little or no clearance on top of the tooth, it is customary to make this from 2 to 3 degrees. A narrow land is often advisable and this can be stoned slightly.

If the front faces of the teeth can be undercut from 6 to 8 degrees, it gives a good rake and helps to curl the chip. This is aided by having a good fillet at the bottom of the tooth and this strengthens the broach at the same time. If the front face of the tooth can be curved it is easier for the chip to roll off but this is sometimes difficult to do in making the broach.

Just as we make reamers with irregular spacing so in some cases we find that broaches with irregular spaced teeth give better results. There is no definite rule regarding this spacing but some make a practice of increasing the normal pitch by 0.005 inch for each tooth up to the fifth tooth. Then the spacing drops back to normal and begins all over again to increase as before. If, for example, the normal spacing is 0.70 as cited before, the tooth spacing will be as follows: 0.70, 0.705, 0.710, 0.715, 0.720, 0.725 and then drops back to 0.70 once more, repeating the increase to the fifth tooth and again dropping back to normal. Some increase the pitch by 0.01 inch while others use as much as $^1/_{64}$ inch increase and drop back to normal after the third or fourth tooth. The exact amount is not so important so long as they are spaced differently to avoid the chatter which too often comes from regular spacing.

Broaches are made in various ways and of different materials. The great majority of broaches are made in one piece with the teeth integral with the body. In many cases, where the work is large enough to warrant, the broaches are made with a separate body and the teeth

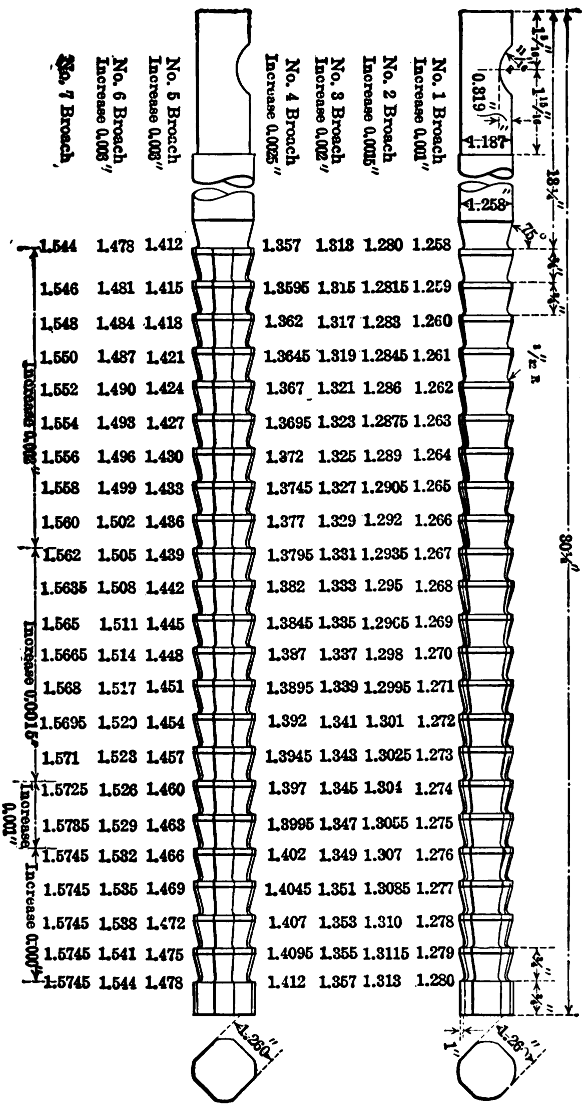
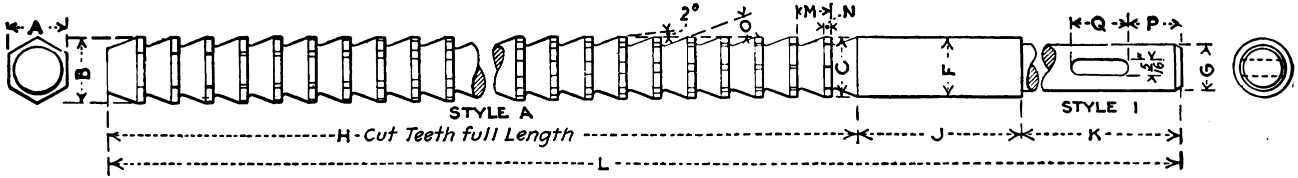
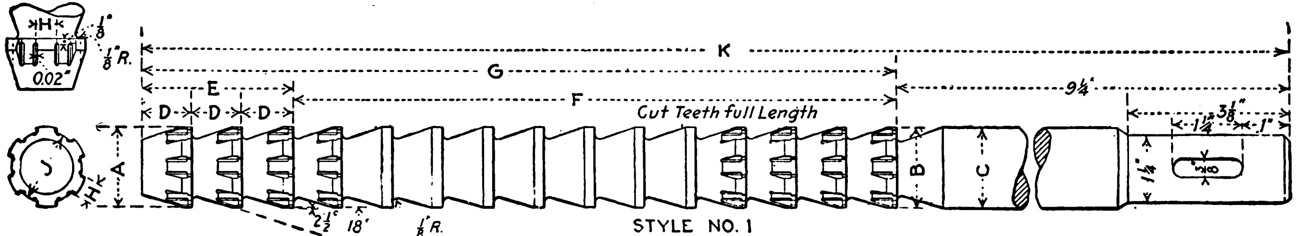


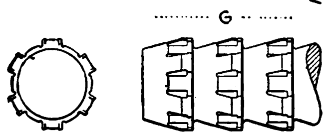
FIG. 10.—Dimensions of broaches.

inserted in some way. Some are inserted singly as with milling cutters while others are put in in sections. In some cases the cutters are in the shape of disks strung on a central rod.



BROACH	STYLE OF BROACH	STYLE OF SHANK	A	B	C	F	G	H	J	K	L	M	N	O	P	Q	REMARKS
1st Broach	A	1	1.376"	1.457"	1.406"	1.406"	1 3/16"	27"			33 7/8"	3/4"	3/16"	20°	1 1/4"	1"	
2nd Broach	"	"	"	1.504"	1.453"	"	"	"			"	"	"	"	"	"	
3rd Broach	"	"	"	1.550"	1.499"	"	"	"			"	"	"	"	"	"	
4th Broach	"	"	"	1.590"	1.546"	"	"	"			"	"	"	"	"	"	Last 4 Teeth Straight





6-Teeth equally spaced
STYLE NO. 2

BROACH	STYLE	A	B	C	D	E STR.	F TAPER	G TAPER	H	J	K
First	1	1.613"	1.555"	1.553"	1"			15"	0.4375"	1.555"	24 1/4"
Second	1	1.664"	1.606"	1.553"	1"			15"	"	"	"
Third	1	1.718"	1.657"	"	1"			"	"	"	"
Fourth	1	1.754"	1708"	"	1"	3"	12"		"	"	"
Fifth	2	1.760"	1.738"	"	1"	3"	12"	"	"	"	"

FIGS. 11–12.—Details of broaches for hexagons and splines.

Generally speaking it may be said that broaches are made of about as many kinds of steel as other tools. For medium and large sized broaches and for fine finishing cuts, carbon steel is used largely. Where the broaches are small, a tough alloy steel containing vanadium is often used. For finishing hard materials, high speed steel has been found very satisfactory. In some cases, where the broach is large, mild steel, suitably case-hardened is also found to answer nicely. This holds for both pull and push broaches.

The detailed dimensions of square pull broaches are given in Fig. 10, while Figs. 11 and 12 give similar details of a broach for a hexagon and splined holes.

Figs. 13 and 14 show the S. A. E. standards.

PUSH BROACHES

The main difference between the pull and push broach is in its length, for the push broach must not be so long as to bend or buckle under the pressure necessary to force it through the work. It has been found in practice that a much heavier cut can be taken by the last teeth of the broach than by the leading teeth. The few examples given will show the main features to be considered and also give the current practice in the making of push broaches by those who use them largely in their everyday work.

Some find it advisable to allow a little oversize in the broach to make up for the tendency of the metal to spring back after the broach had passed through. This is, of course, no different from the pull broach and depends upon the work being handled and the way in which it is supported during the broaching operation. The oversize allowance is given as 0.002 inch for sizes up to 3 inches. For bearings up to 3 inches in diameter only one broach is used.

Two examples from the Westinghouse Company show what is being done regularly in this direction. Two bearings, one $2\frac{1}{2} \times 6$ inches and the other $3 \times 7\frac{1}{2}$ inches are broached right from the casting of the bearing metal into the shell, the mandrels being made from 0.004 to 0.020 inch smaller than the finished diameter. A pressure of from 5 to 10 tons is required for this work, a hydraulic press being used for this purpose. When oil grooves are cut after broaching it is sometimes better to run the broach through the second time. The time required for these large bearings varies from one to two minutes.

The following illustrations from various sources give some idea of the way in which different shops handle their broaching problem.

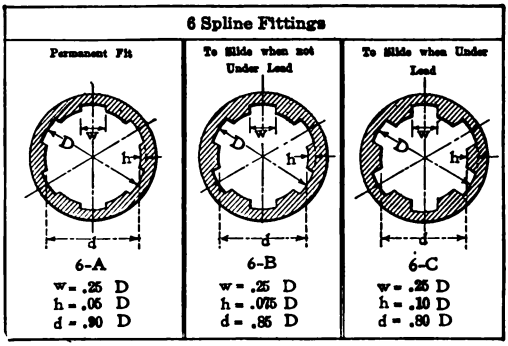


FIG. 13.—S. A. E. six-spline standards.

6-SPLINE FITTINGS FOR AUTOMOBILES

From Sixth Report of Broaches Division S. A. E. Accepted at Meeting of Society, January, 1914

Nominal Diam.	*D*	*d*	*w*	*T*	*D*	*d*	*w*	*T*	*D*	*d*	*w*	*T*
¾	0.750 0.749	0.675 0.674	0.188 0.187	80	0.750 0.749	0.638 0.637	0.188 0.187	117	0.750 0.749	0.600 0.599	0.188 0.187	152
⅞	0.875 0.874	0.788 0.787	0.219 0.218	109	0.875 0.874	0.744 0.743	0.219 0.218	159	0.875 0.874	0.700 0.699	0.219 0.218	207
1	1.000 0.999	0.900 0.899	0.250 0.249	143	1.000 0.999	0.850 0.849	0.250 0.249	208	1.000 0.999	0.800 0.799	0.250 0.249	270
1⅛	1.125 1.124	1.013 1.012	0.281 0.280	180	1.125 1.124	0.956 1.955	0.281 0.280	263	1.125 1.124	0.900 0.899	0.281 0.280	342
1¼	1.250 1.249	1.125 1.124	0.313 0.312	223	1.250 1.249	1.063 1.062	0.313 0.312	325	1.250 1.249	1.000 0.999	0.313 0.312	421
1⅜	1.375 1.374	1.238 1.237	0.344 0.343	269	1.375 1.374	1.169 1.168	0.344 0.343	393	1.375 1.374	1.100 1.099	0.344 0.343	510
1½	1.500 1.499	1.350 1.349	0.375 0.374	321	1.500 1.499	1.275 1.274	0.375 0.374	468	1.500 1.499	1.200 1.199	0.375 0.374	608
1⅝	1.625 1.624	1.463 1.462	0.406 0.405	376	1.625 1.624	1.381 1.380	0.406 0.405	550	1.625 1.624	1.300 1.299	0.406 0.405	713
1¾	1.750 1.749	1.575 1.574	0.438 0.437	436	1.750 1.749	1.488 1.487	0.438 0.437	637	1.750 1.749	1.400 1.399	0.438 0.437	827
2	2.000 1.998	1.800 1.798	0.500 0.498	570	2.000 1.998	1.700 1.698	0.500 0.498	833	2.000 1.998	1.600 1.598	0.500 0.498	1080
2¼	2.250 2.248	2.025 2.023	0.563 0.561	721	2.250 2.248	1.913 1.912	0.563 0.561	1052	2.250 2.248	1.800 1.798	0.563 0.561	1367
2½	2.500 2.498	2.250 2.248	0.625 0.623	891	2.500 2.498	2.125 2.123	0.625 0.623	1300	2.500 2.498	2.000 1.998	0.625 0.623	1688
3	3.000 2.998	2.700 2.698	0.750 0.748	1283	3.000 2.998	2.550 2.548	0.750 0.748	1873	3.000 2.998	2.400 2.398	0.750 0.748	2430

$T = 1000 \times 6$ (No. of Splines) $\times$ Mean Radius $\times h \times 1 =$ inch-pounds torque capacity per inch bearing length of 1000 lbs. pressure per square inch on sides of splines. No allowance is made for radii on corners nor for clearances.

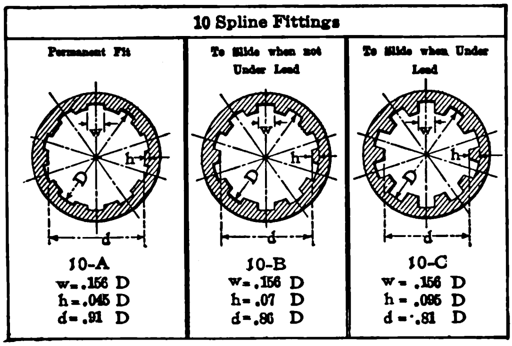


FIG. 14.—S. A. E. ten-spline standard.

10-SPLINE FITTINGS FOR AUTOMOBILES

From Sixth Report of Broaches Division S. A. E. Accepted at Meeting of Society, January, 1914

Nominal Diam.	D	d	w	T	D	d	w	T	D	d	w	T
3/4	0.750 0.749	0.683 0.682	0.117 0.116	120	0.750 0.749	0.645 0.644	0.117 0.116	183	0.750 0.749	0.608 0.607	0.117 0.116	241
7/8	0.875 0.874	0.796 0.795	0.137 0.136	165	0.875 0.874	0.753 0.752	0.137 0.136	248	0.875 0.874	0.709 0.708	0.137 0.136	329
1	1.000 0.999	0.910 0.909	0.156 0.155	215	1.000 0.999	0.860 0.859	0.156 0.155	326	1.000 0.999	0.810 0.809	0.156 0.155	430
1 1/8	1.125 1.124	1.024 1.023	0.176 0.175	271	1.125 1.124	0.968 0.967	0.176 0.175	412	1.125 1.124	0.911 0.910	0.176 0.175	545
1 1/4	1.250 1.249	1.138 1.137	0.195 0.194	336	1.250 1.249	1.075 1.074	0.195 0.194	508	1.250 1.249	1.013 1.012	0.195 0.194	672
1 3/8	1.375 1.374	1.251 1.250	0.215 0.214	406	1.375 1.374	1.183 1.182	0.215 0.214	614	1.375 1.374	1.114 1.113	0.215 0.214	813
1 1/2	1.500 1.499	1.365 1.364	0.234 0.233	483	1.500 1.499	1.290 1.289	0.234 0.233	732	1.500 1.499	1.215 1.214	0.234 0.233	967
1 5/8	1.625 1.624	1.479 1.478	0.254 0.253	566	1.625 1.624	1.398 1.397	0.254 0.253	860	1.625 1.624	1.316 1.315	0.254 0.253	1135
1 3/4	1.750 1.749	1.593 1.592	0.273 0.272	658	1.750 1.749	1.505 1.504	0.273 0.272	997	1.750 1.749	1.418 1.417	0.273 0.272	1316
2	2.000 1.998	1.820 1.818	0.312 0.310	860	2.000 1.998	1.720 1.718	0.312 0.310	1302	2.000 1.998	1.620 1.618	0.312 0.310	1720
2 1/4	2.250 2.248	2.048 2.046	0.351 0.349	1088	2.250 2.248	1.935 1.933	0.351 0.349	1647	2.250 2.248	1.823 1.821	0.351 0.349	2176
2 1/2	2.500 2.498	2.275 2.273	0.390 0.388	1343	2.500 2.498	2.150 2.148	0.390 0.388	2034	2.500 2.498	2.025 2.023	0.390 0.388	2688
3	3.000 2.998	2.730 2.728	0.468 0.466	1934	3.000 2.998	2.580 2.578	0.468 0.466	2929	3.000 2.998	2.430 2.428	0.468 0.466	3869

$T = 1000 \times 10$ (No. of Splines) $\times$ Mean Radius $\times h \times 1$ = inch-pounds torque capacity per inch bearing length at 1000 lbs. pressure per square inch on sides of splines. No allowance is made for radii on corners nor for clearances.

Figures 15 and 16 show an unusual broaching job and the broach which did it. The work is a steel casting of box-like section. The cut starts from the bottom, the broaches collapsing by sliding up a tapered center. They are enlarged to their proper size in a recess at the bottom

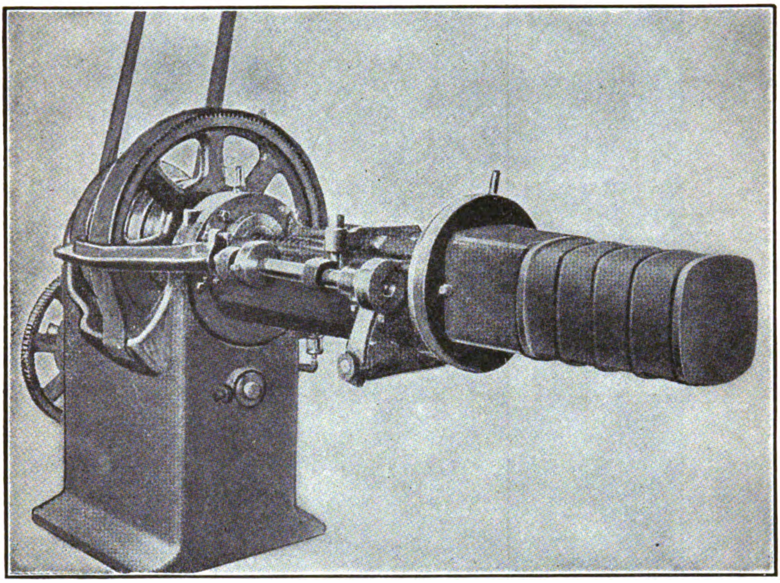


FIG. 15.—An unusual broaching job.

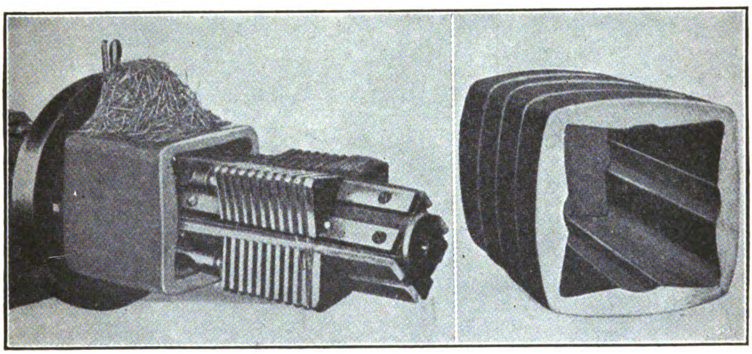


FIG. 16.—The broach used and the work.

of the casting and the broach is then pulled out, cutting the four sides to shape. The hole is about 8 inches square and the cut 14 inches long. About $^1/_{16}$ inch of stock is removed. The pull is from 75 to 100 tons.

A push broaching job, the crank bearing of a connecting rod, is shown in Fig. 17. These are usually done with a pull broach.

The irregular broaching operation in Fig. 18 shows a set of push broaches for a fire-arm part. It also shows the forging and the finished piece. Irregular shapes are often handled in this way.

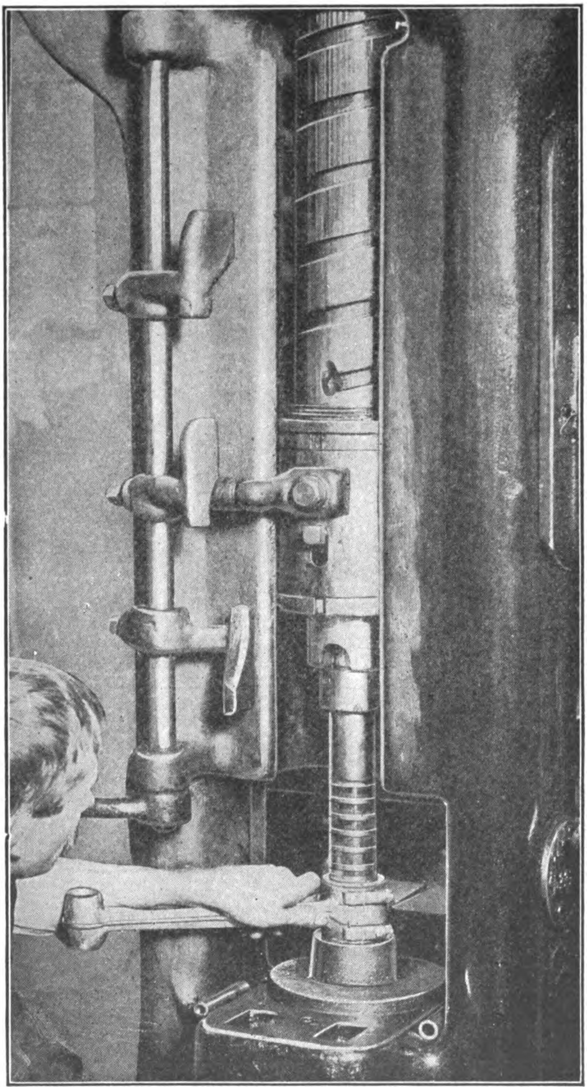


FIG. 17.—Connecting-rod work in the Packard factory.

An outside broaching job from the Ford Motor Company shop is shown in Fig. 19. The work is the bearing for the motor cam shaft. The two grooves are cut, or broached, on the outside by the two cutters

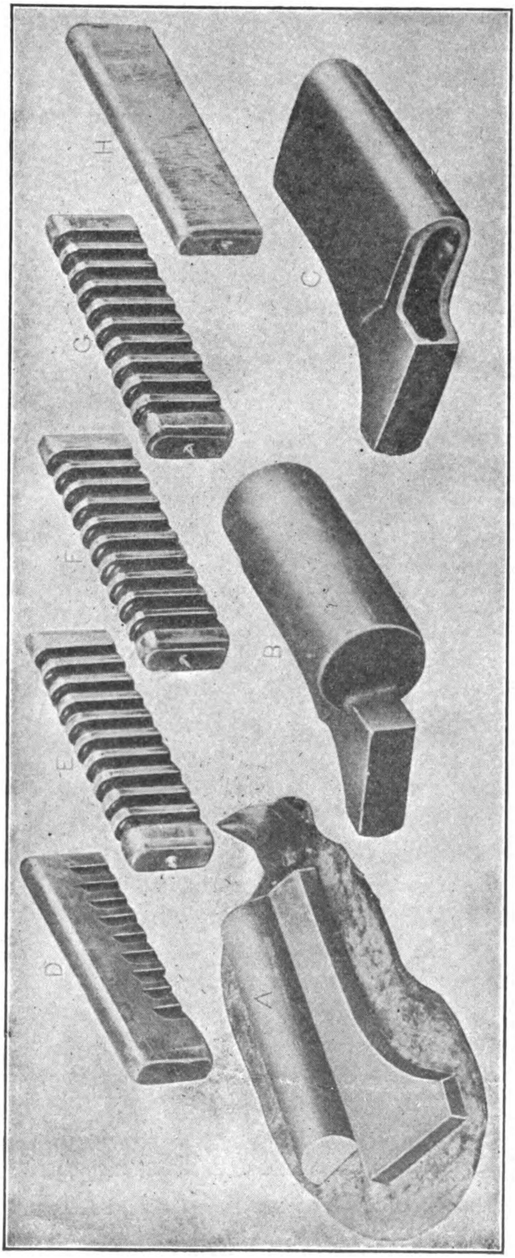


FIG. 18.—A set of follow broaches and the work.

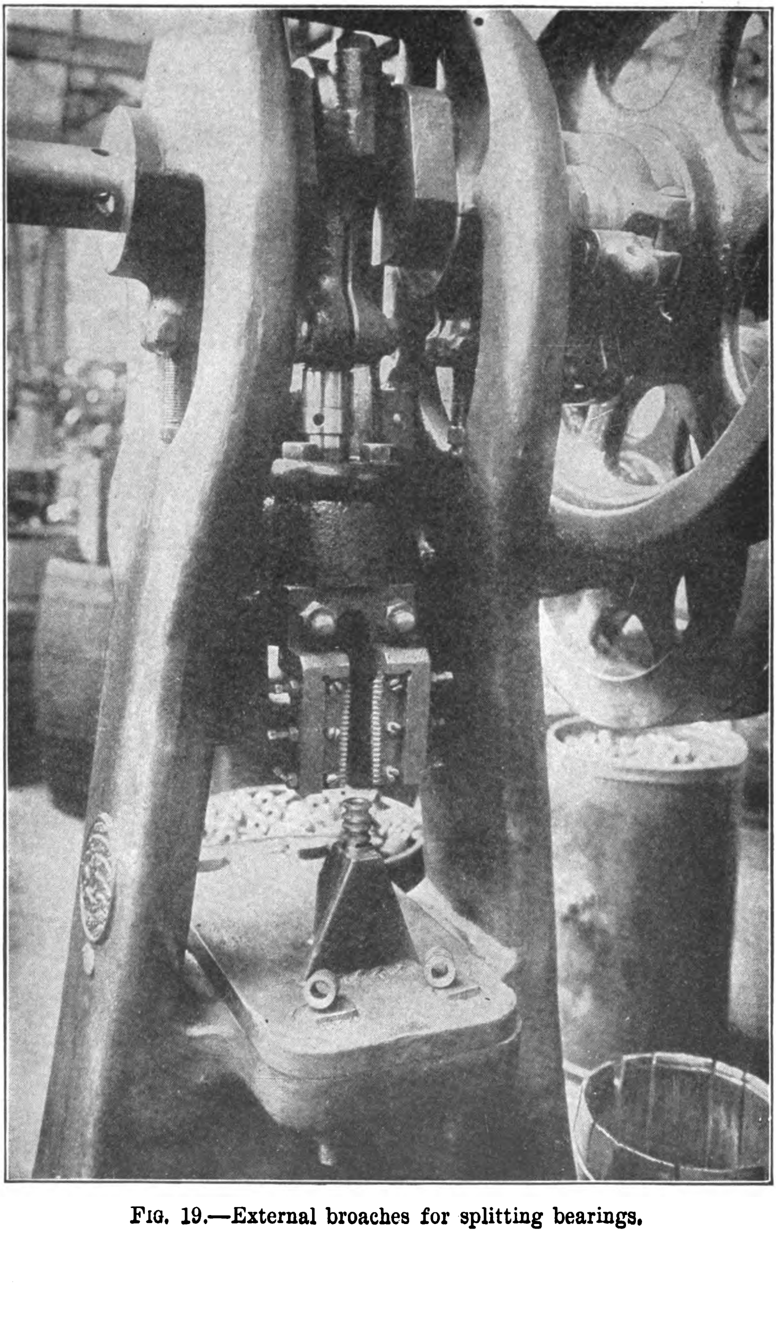


FIG. 19.—External broaches for splitting bearings.

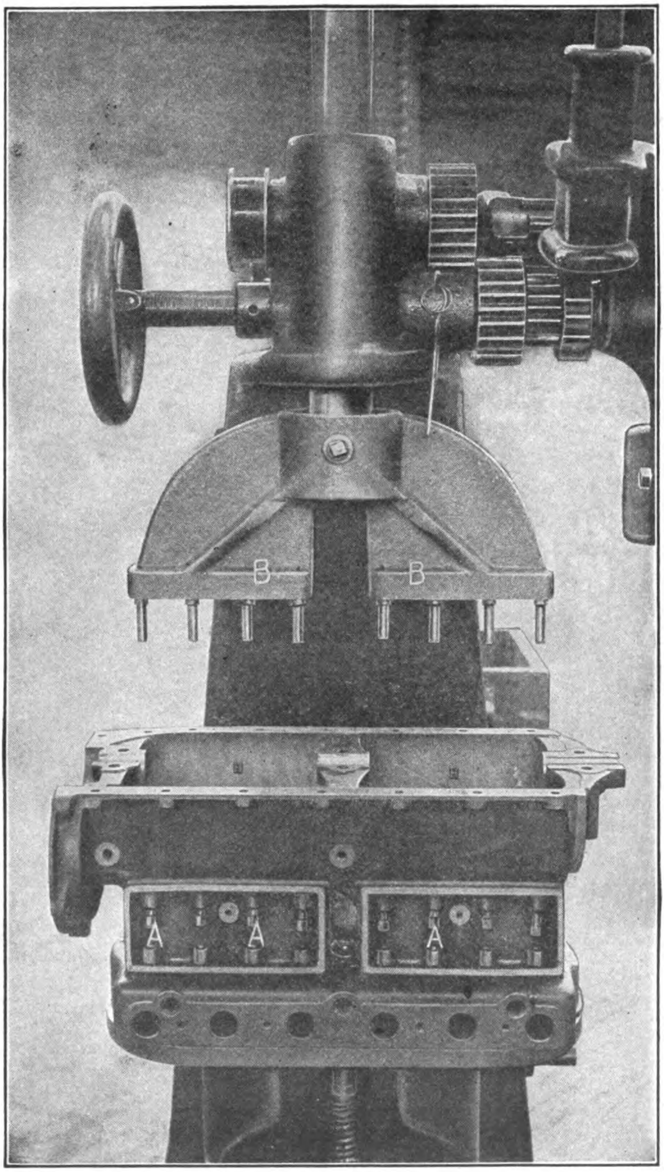


FIG. 20.—Cutting oil grooves in eight holes at once.

which cut a V groove on opposite sides of the bearing, which is held on a stud during the operation. By inserting a split shell with a taper hole and then forcing a taper plug in the shell, the bearings are split in halves without injury to the bearing surface.

Another ingenious broaching operation from the Ford shop is shown in Fig. 20, which shows the method of cutting 8 spiral oil grooves in the push rod guide holes at one movement of a hand operated arbor press. The broaches have spiral teeth and are not fastened in the head *B* but are placed in the holes to be broached.

The head *B* is then brought down and the 8 studs force the 8 broaches through the holes, allowing them to turn as they cut their way through. The broaches drop through, as shown at *A*, and are then picked up by the operater ready for the next job.

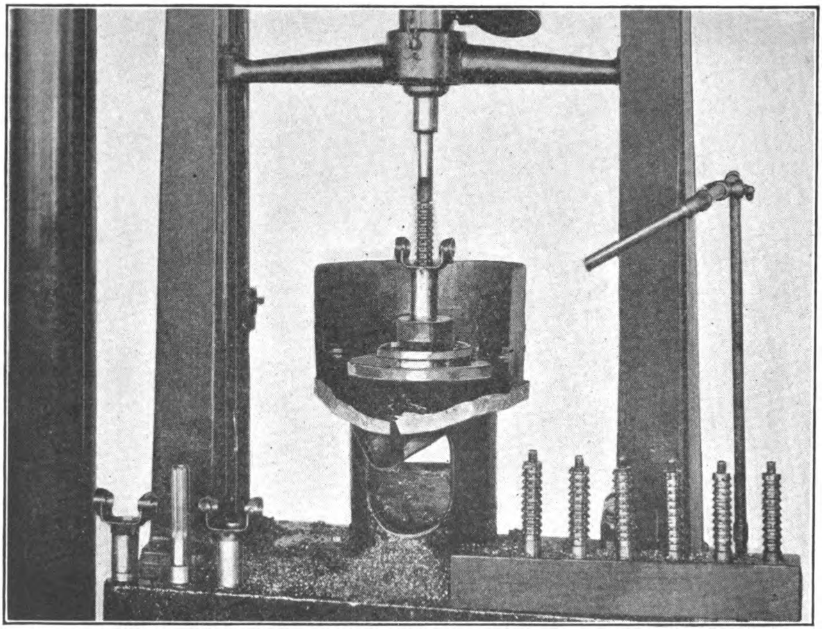


FIG. 21.—Broaching a drive yoke.

A GOOD EXAMPLE OF PUSH BROACHING

An excellent example of push broaching is shown in Figs. 21 to 24 and for this work at least, there can be no question as to their being best in every way. There is, of course, less knowledge of push broaching available so that in most cases each man has to work out his own problems. But here and there we find a place where this has been done and where the data to be obtained are of particular value. Such a shop is that of the Universal Drive Shaft Co., 6200 Carnegie Ave., Cleveland, Ohio. The man responsible for the results obtained is F. W. Peters, one of the firm, and he is securing exceptionally good splined holes 5 inches long in a driving yoke, with only 35 inches of broach, divided among seven short broaches.

The illustration, Fig. 21, shows the broaches and the piece which is broached as well as the members of a coupling. The seven broaches are short, the total length being about 7 inches each. The first tooth of the series of each broach (after the first) is the same size as the preceding broach, so as to insure easy starting.

The broaches are cut on a Fellows gear shaper with special stubbed teeth of a shorter length than usual. The spline, or piece which enters the yoke, is also generated in the same way. This form of spline centers

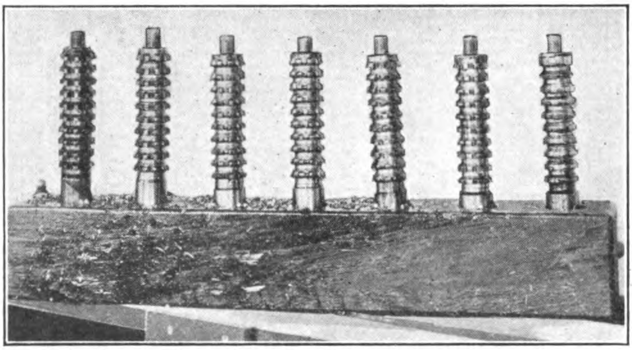


FIG. 22.—The set of seven broaches.

itself so that all the teeth bear evenly, which is not always the case when a straight sided tooth is used. Generating both the broach and the piece which fits the hole makes it possible to secure a remarkably good fit the entire length of the piece.

The short length of the broaches eliminate the difficulty of breaking, as they spring very little, so that it is not at all necessary to either straighten or grind the teeth. This makes it easier for a shop to make its own broaches and makes it possible to experiment with broaching possibilities at a lower cost.

It has been found that the teeth of the first two or three broaches can be given a cut of 0.004 inch per tooth, but that the remaining or finishing broaches do a better job if the cut is reduced to 0.003 inch per tooth. The teeth are undercut 10 degrees and have a top or cutting rake of 3 degrees so that they roll a chip off with a clean cut The spacing also gives ample room for chips.

The machine used is a Lucas power press which has been modified so as to give a faster power movement and a quick return. This enables an operator to finish the hole complete in two minutes, giving him ample time to handle the work and the seven broaches, one after the other.

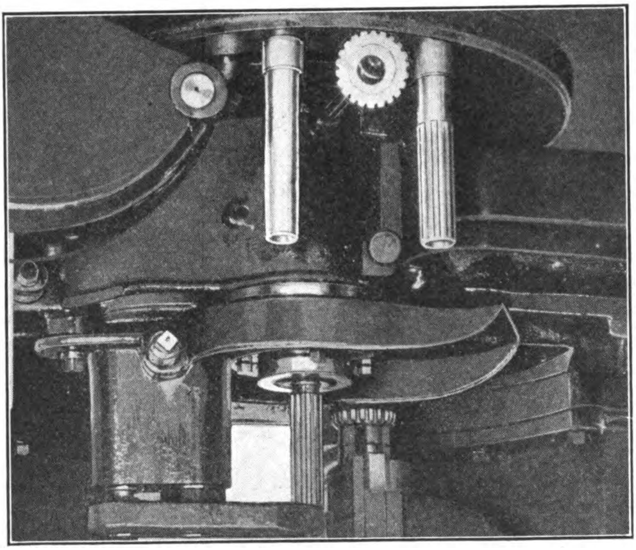


Fig. 23.—How they are made.

The work is remarkably smooth and uniform. This coupled with the low cost of broaches and equipment, makes it well worth careful consideration.

The broaches are shown more in detail in Fig. 22. It will be noted the lower end is plain where it enters the hole as a guide and that the

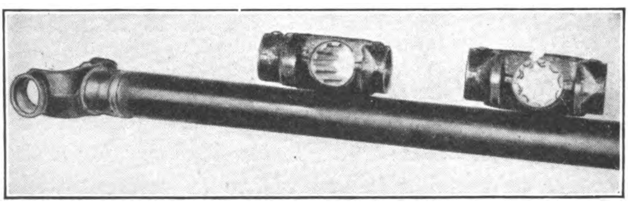


Fig. 24.—The yokes which are broached.

upper end has a pilot which it fits into the ram of the press. The first broach is on the right and the finishing broach on the left.

Figure 23 shows how both the broaches and the splined connections are generated. It also shows the special shape of the stub tooth used.

The splined units of the drive shaft are shown in Fig. 24.

SECTION V

MILLING MACHINES

CHAPTER I

GENERAL TYPES OF MILLING MACHINES

In classifying the numerous types of milling machines which are used for manufacture, tool room work and general purposes in the shop, we may place them in three groups as distinguished by appearance and features of design. These groups or classes include the Column and Knee Type, the Manufacturing Type, and the Planer or Horizontal Type. Outside of these general classes there are of course various types of special purpose milling machines, such for example as are used for the cutting of gears, the milling of threads, the milling of valves, bolt heads and so on. These special types however are outside of the scope of this treatise which is devoted mainly to the construction and operation of the three types of milling machines noted above which are used on all kinds of work and in all classes of shops.

The column and knee type of milling machine is so called because of the column shaped body or frame which carries a table support in the form of a knee shaped bracket, the knee and table being adjustable vertically on the guide face of the column. The table may be fed longitudinally, that is, crosswise of the spindle axis; it may be fed laterally, or parallel with the spindle; and it may be fed up and down toward or away from the cutter by the movement of the knee upon the column face.

In the manufacturing type of milling machine the construction is such that the height or vertical position of the table remains constant while the spindle head is adjustable up and down to bring the cutter arbor and cutters to the proper vertical position for the work. The table feeding movement is in one direction only, that is, at right angles to the cutter spindle. This machine is used extensively where large quantities of small and medium sized parts are manufactured. In its later designs this type of machine is automatic in its action after the work has been placed in the vise or holding fixture.

The planer type of milling machine which is commonly known as a horizontal miller is similar in appearance to a planer. Its table travels between housings or uprights similar to the direction of travel of a planer table and its cutter spindle and arbor supports are mounted in heads on a cross rail between the housings. Generally this type of machine is for the heavier classes of work and the cutters used range up to very large dimensions. These cutters are commonly of the slabbing and facing types and they are employed on broad slabbing cuts in surfacing heavy castings and forgings and in facing sides and

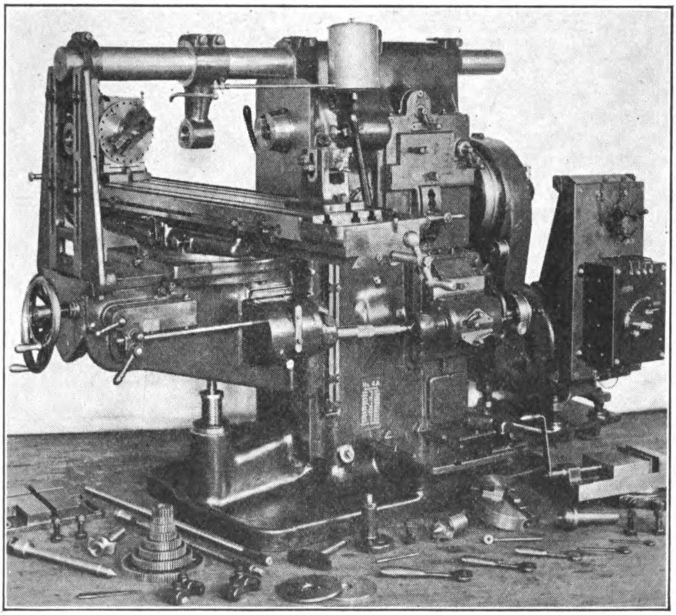


FIG. 1.—Brown & Sharpe Universal milling machine with constant speed drive.

ends of large and heavy work. Also heavy gangs of cutters are run on these machines in milling several parts at once or in machining several surfaces simultaneously on one or more pieces.

PLAIN AND UNIVERSAL MILLERS

The column and knee type of milling machine comprises plain and universal millers, and vertical spindle machines, although there are various examples of the latter construction which dispense with the knee and carry the table and saddle on the fixed base or frame of the machine. This is the case with some of the heavier sizes of vertical millers and also with the profiling machine which is another form of vertical spindle miller used extensively in the manufacture of parts for firearms, typewriters and the like.

The initial illustration in this volume represents a modern universal milling machine, this being a Brown & Sharpe No. 4-A machine. Comparing this view, Fig. 1 with the half tone Fig. 2, it will be seen that the machine in the former illustration is equipped with constant speed drive while the universal miller of the same make in Fig. 2 is driven by a cone on the spindle. The constant speed drive it may be pointed out is a development of recent years which presents many advantages for numerous classes of work to which attention will be

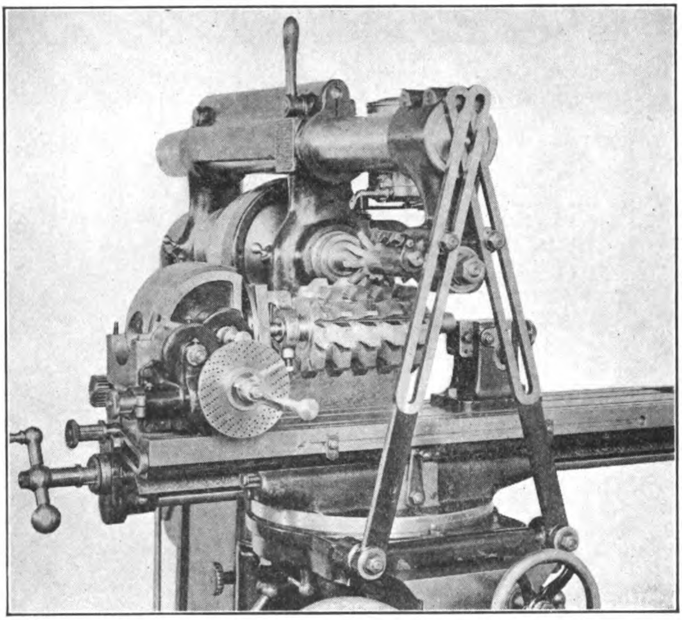


FIG. 2.—Brown & Sharpe cone driven Universal milling machine.

called a little later. Briefly, it permits of the feeds being independent of the spindle speeds, so that the table feed per minute can remain unchanged if desired even though the cutter speed be varied; complicated countershafts are done away with and constant speed motors used if desired; more power is available and changing of speeds and feeds greatly facilitated. The line drawing Fig. 3 shows a vertical section through the frame and mechanism of a miller of the type illustrated by Fig. 1. This is of interest as showing the heavy section through the column walls and base, the method of mounting the spindle in the column walls, etc.

The half tone Fig. 4, illustrates a Cincinnati No. 5 high power plain miller, with constant speed drive. As with the universal millers, the plain milling machine is equipped in both ways for driving, that is either with belt cone for the spindle or with single pulley as shown for constant speed for the drive shaft.

In the plain milling machine as distinguished from the universal, the travel of the table in longitudinal direction is fixed at right angles to the spindle. As explained in the second paragraph of this chapter, there are three table movements; longitudinal, transverse or parallel

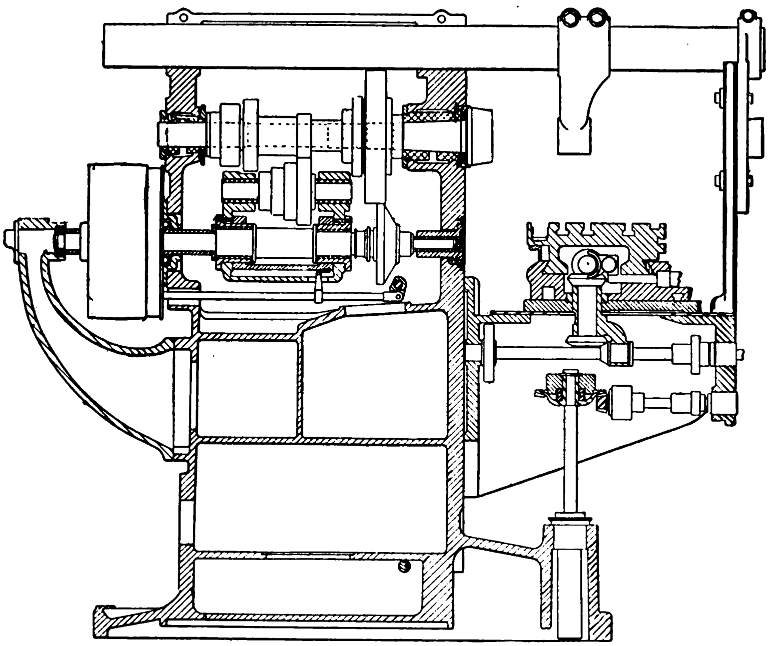


FIG. 3.—Vertical section through milling machine, spindle bearings and drive.

to the spindle, and vertical. In some machines all three movements are provided with both hand and power feeds. In others the longitudinal and transverse movements are operated either by power or hand, while the vertical movement is by hand alone. Again, other machines have the longitudinal movement of the table by hand and power and hand feed only for the transverse and vertical movements. The larger sizes of machines and many of the smaller sizes are provided with lead screws for all table movements. In some makes of smaller sizes the longitudinal movement is by rack and pinion; and in the smallest sizes, known as hand millers, the movements of table and knee are by hand levers acting thorugh pinions and racks. A hand miller is shown in Fig. 12 set up for light work carried between index centers. This type of machine is extensively used for small parts manufacture as it can be operated very rapidly and conveniently on work of this character.

The universal milling machine is in the main similar to the plain miller; the table has the same movements, but in addition it is so mounted that it may be swiveled upon its saddle, and set at any

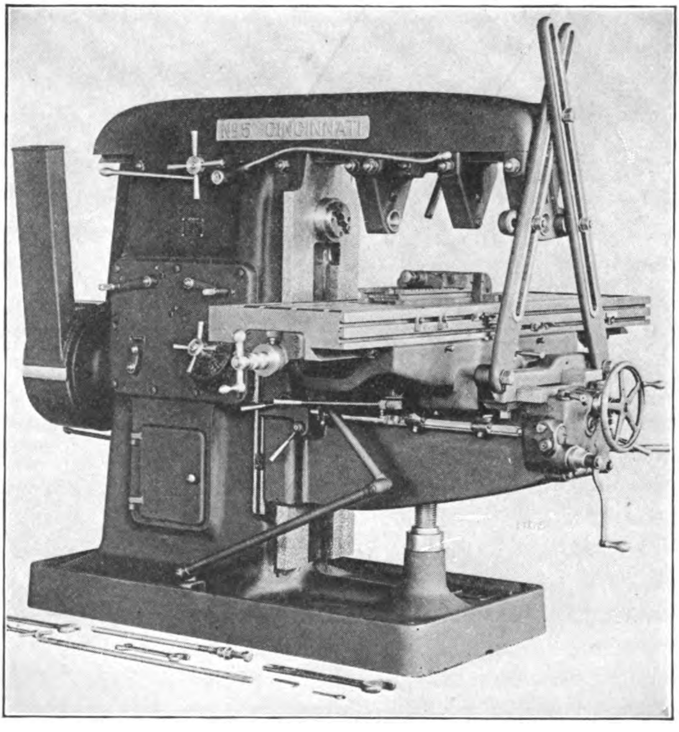


FIG. 4.—Cincinnati No. 5 plain high-power milling machine with constant speed drive.

desired angle to the spindle in the horizontal plane. It is also provided with a spiral head or universal dividing head for spiral milling and for indexing to obtain any desired number of cuts or spaces on the work. The universal miller is one of the most important machine tools in use in the shop, for in addition to its capacity for handling plain straight milling, it is adapted to an endless variety of general shop and tool room purposes, the latter including such operations as the boring and machining of jigs and fixtures of all kinds, the working out of dies and many other special tools. Details of work of this character are covered in the volume on Tool and Gage Work. Other chapters in the present volume show numerous applications of the dividing head and other appliances used on this machine.

The universal milling machine is indispensable in the cutting of twist drills; taper, straight and spiral reamers; gears whether spur, bevel, spiral or worm, and other work in great variety. It is built in heavy designs and will take heavy cuts, hence is an all around serviceable shop tool. However, its legitimate field is necessarily different in a way from that of the plain miller and where heavy milling on straight cuts is to be done continuously the latter machine is of course to be preferred.

SOME PLAIN MILLING MACHINE DETAILS

Referring now to the Cincinnati No. 5 plain high power miller shown in Fig. 4, a few particulars may be included here to give some indication of the present development of this machine as represented by its general dimensions, range of speeds, rates of feed, methods of control, etc.

The table of this miller has a working surface 79 inches long by 21 inches wide. It is provided with intermittent feed and power automatic quick traverse and reverse in either direction at 100 inches per minute. A single lever with five operating positions starts, stops and reverses both power feed and power quick traverse. The range is 50 inches longitudinal, 14 inches cross and 21 inches vertical, all power feeds in either direction.

The constant speed driving pulley is 16 inches diameter for a 6-inch belt (which is guarded) and runs at 600 revolutions per minute on ball bearings. For motor drive a 20 horse power constant speed motor is recommended.

The spindle is of chrome nickel steel, is $4^{1}/_{16}$ inches diameter in the front bearing and runs in babbitted bearings adjustable for wear. It has a No. 14 B. & S. taper hole and a $1\frac{1}{4}$-inch hole through. There are 16 spindle speeds as follows: 16, 20, 25, 31, 38, 48, 60, 74, 94, 119, 148, 183, 228, 288, 359 and 443 revolutions per minute in either direction. The spindle reverse is in the machine. All changes are made by sliding gears without tumbler, and all gears and shafts are hardened. The index plate is direct reading.

The overhanging arm is rectangular, cast iron, 10 by $9\frac{3}{4}$ inches, with a V guide in the column and arbor supports. Its underside is $8\frac{1}{2}$ inches from the spindle center. The full width between the face of the column and the braces is $38\frac{1}{2}$ inches. There are three arbor supports, one with bronze at the end and two with sleeve bearing anywhere along the length of the arbor. They may be used singly or in combination. They are all clamped to the V bearing on the underside of the rectangular overarm.

The feeds are positive and driven from a constant speed shaft. There are 16 changes in geometric progression from 3/4 inch to 30 inches per minute. A feed range from 3/8 inch to 15 inches or from 1 1/8 inch to 45 inches per minute can be obtained if desired by a special pair of change gears. All changes are made through sliding gears by means of a single lever at the front of the machine, the position of this lever also indicating on a direct reading feed plate, the feed rate being used. Independent levers for starting, stopping and reversing the table, cross and vertical feeds, are located at the front

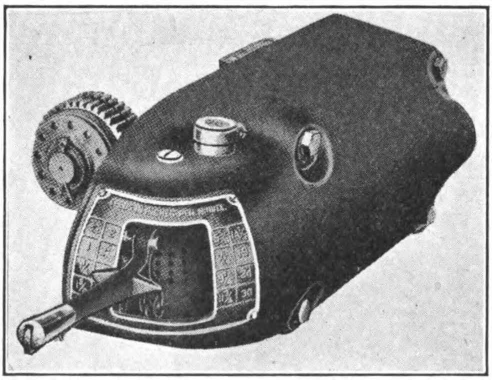


FIG. 5.—Outside of Cincinnati feed box, located at front of knee.

of the machine and also at the side of the knee for similar control of all three feeds from behind the table. There is an overload releasing device for protection of the feed mechanism.

The feed box at the front of the knee is shown by Fig. 5, which indicates the manner in which the lever is shifted up or down or from side to side or diagonally, the change from one feed to another being made by one direct movement of the lever. The control of the intermittent feed and power quick traverse is by hand by means of the table feed lever, and the table may be automatically stopped anywhere in its travel, by use of dogs in the usual way, and its operation is not in any way complicated by the intermittent feeding feature. The intermittent feed with automatic reverse and power quick traverse is brought into use by simply adding certain dogs. If these dogs are left off the operation of the feed of the machine is precisely the same as that of other millers of the same make. As the feed change lever is at the front of the machine and one direct movement of the lever enables the operator to engage the maximum feed of 30 inches per minute, this provides a convenient quick traverse as rapid as is safe for the comparatively short cross and vertical travel.

The lubrication of machine bearings and the cooling of work and cutters are matters that require important consideration in modern miller design. In the machine described there is an automatic lubrication system for the spindle bearings, the drive gears, and all other rotating parts in the column, and in addition to this there is a centralized system of six oiling stations for the other mechanisms of the machine. For cutter and work cooler there is an eleven-gallon centrifugal pump connected with the large reservoir in the base, and discharging from a $\frac{3}{4}$-inch pipe to the cutter arbor.

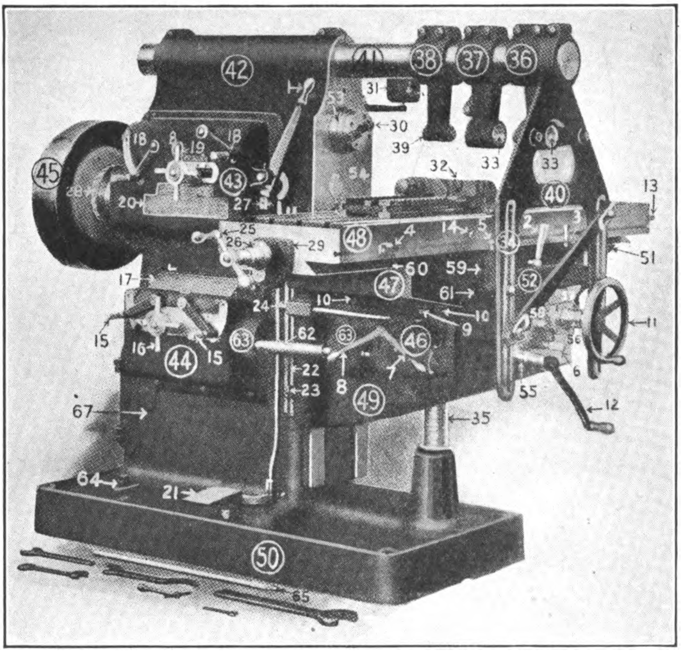


FIG. 6.—Names of Cincinnati plain miller parts.

NAMES OF MILLER PARTS

The illustrations Figs. 6, 7 and 8 are presented at this point in order to show the location and names and uses of different parts on the millers. The machine in Fig. 6 is a Cincinnati high power plain miller with constant speed drive; the miller in Fig. 7 is a Cincinnati high power vertical machine; the miller in Fig. 8 is a universal cone driven machine of the same make. The parts are numbered on the machines and the names corresponding to the numbers are given in the following parts lists. These should aid to a clear understanding of the milling machine and its operating and controlling features.

1. Clutch lever for starting and stopping machine.
2. Table feed setting lever.
3. Power quick traverse operating lever.
4. Table feed adjustable trip dogs.
5. Table feed trip plunger.
6. Cross and vertical feed setting lever.
7. Vertical and cross feed lever.
8. Lever for operating feed when standing behind the table.
9. Cross feed trip plunger.
10. Cross feed adjustable trip dogs.
11. Cross adjustment handwheel.
12. Vertical adjustment crank.

13-14. Quick traverse limit stops.

15. Feed change levers.
16. Pilot wheel for operating feed change tumbler.
17. Feed index plate.
18. Speed change levers.
19. Pilot wheel for operating speed change tumbler.
20. Speed index plate.
21. Treadle for giving the gears slight motion to facilitate speed changing.
22. Guide for vertical feed trip dogs.
23. Vertical feed, adjustable trip dogs.
24. Vertical feed trip plunger.
25. Ball crank for longitudinal table adjustment.
26. Micrometer dial for longitudinal table adjustment.
27. Rack on main clutch rod.
28. Quick traverse driving shaft.
29. Bracket containing left hand bearing for table feed screw.
30. Driving keys in flanged spindle end.
31. Oil pot.
32. All steel vise.
33. Bushings in arbor bearings.
34. Table feed operating lever (concealed behind the braces in Fig. 6. See Fig. 7).
35. Telescope elevating (vertical feed) screw sleeve. The vertical screw (35-A, Figs. 7 and 8) is inside of this sleeve.

35-A. Vertical feed screw (Fig. 7).

36. Outer arbor bearing support which can be bolted to the braces.
37. Intermediate arbor bearing support.
38. Outer support, for short arbors having a bearing on the outside of the nut.
39. Adjustable bronze bush for arbor bearing.
40. Braces for tying the overarm, outer arbor support and knee together.
41. Overarm.
42. Column of the machine.

43. Drive box.
44. Feed box.
45. Driving pulley.
46. Feed reverse box.
47. Saddle.
48. Table.
49. Knee.
50. Base.
51. Bracket containing right-hand bearing for table feed screw.

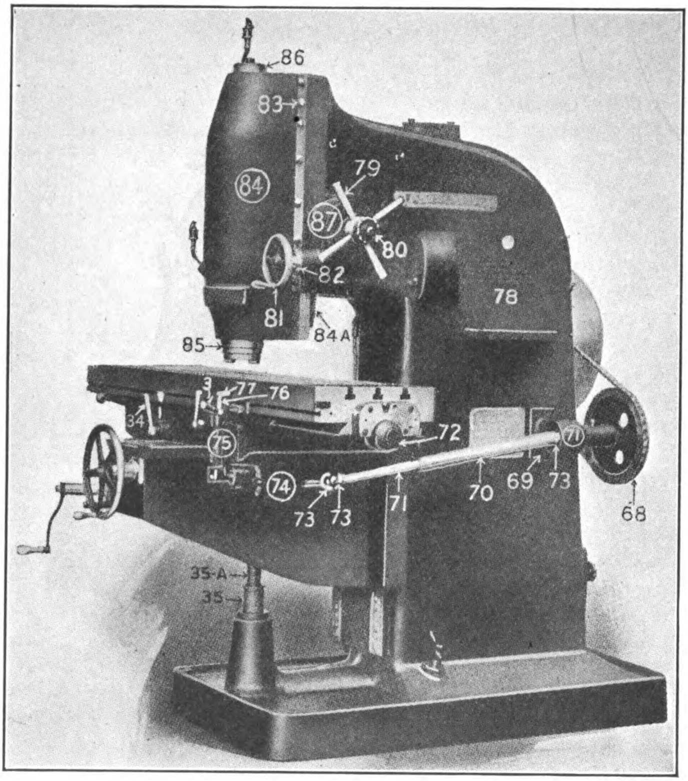


FIG. 7.—Names of vertical spindle miller parts.

52. Bridle by which the braces are fastened to the knee.
53. Front spindle bearing box.
54. Front face of column, carrying construction number and letter.
55. Micrometer dial for vertical adjustment.
56. Micrometer dial for cross adjustment.
57. Front sliding covers in top of knee. Back sliding covers corresponding with these cannot be seen.
58. Cross screw bracket at front of knee.
59. Trip plunger bracket.

60. Adjustable gib for table bearings.
61. Adjustable gib for saddle bearings.
62. Telescopic universal joint shaft (long fork).
63. Universal joints (short forks and ball in fork). The short fork connecting with the shaft in reverse box has a flange which carries the shearing pins (safety fork).
64. Oil pump connection with tank which is in the base of the machine.
65. Ejector rod.
66. Vertical feed nut on base of machine.
67. Location of oil pump.

The Following Parts Are Shown in Fig. 7

68. Power quick traverse pulley.
69. Quick traverse bracket on column.
70. Long fork on quick traverse shaft.
71. Extension shaft, quick traverse.
72. Cover over end of lead screw. (Remove when setting up for spirals.)
73. Short forks of universal joints. (These are identical with the forks used for driving the feed.)
74. Quick traverse bracket under saddle.
75. Quick traverse operating lever bracket.
76. Quick traverse lever shaft.
77. Quick traverse safety lever.
78. Cover over driving gears. (Remove when oiling inside parts.)

Additional Parts Applying to Vertical Machine, Fig. 7

79. Pilot wheel for quick adjustment of spindle (6 inches per turn).
80. Knob for engaging hand feed movement.
81. Hand wheel for hand feed movement.
82. Micrometer dial for hand feed movement.
83. One of four bolts for clamping spindle head solidly to frame of machine for heavy work.
84. Spindle head.
84-A. Rack for adjusting spindle head.
85. Lower spindle bearing box.
86. Upper spindle bearing box.
87. Head adjustment worm casing.

Additional Parts Applying to Universal Machines, Fig. 8

88. Arbor.
89. Universal Indexing and Dividing Head.
90. Tail stock.
91. Elevating center for tailstock.
92. Front index plate on spindle for direct indexing low numbers.
93. Head center.
94. Driver for dog.
95. Side index plate. Drilled both sides, reversible.
96. Sector for convenience in indexing.
97. Index pinholder.

98. Index pin (in the holder).
99. Segment for change gears. (This segment with a complete set of change gears constitutes a Driving Mechanism.)
100. Swinging arm or bracket for idler gear.
101. Change gears for cutting spirals (12 in a set).
102. Idler gear.
103. Quick return crank handle.
104. Swivel carriage or housing.
105. Vise body.
106. Swivel base for vise.

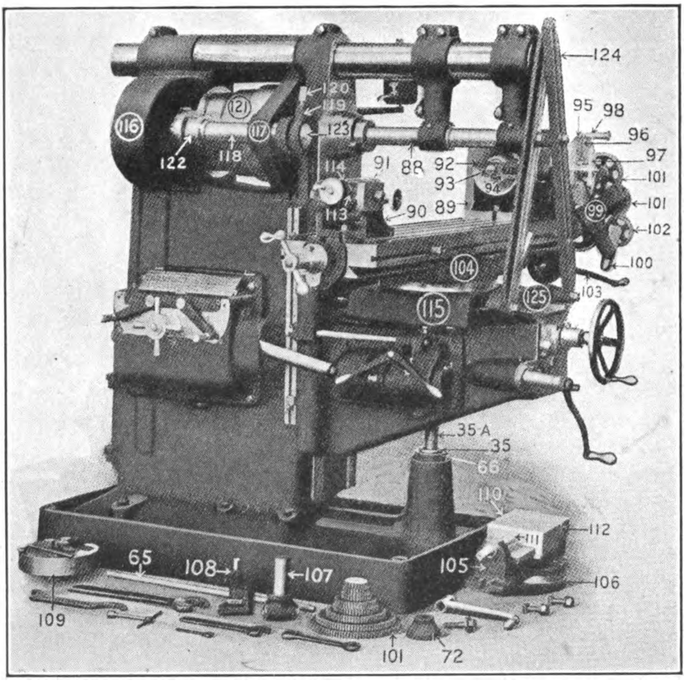


FIG. 8.—Names of universal miller parts.

107. Holder for adjustable bronze bush for outer arbor support. (This is substituted for the large bearing holder in the intermediate arbor support.)
108. Steady rest.
109. Universal Milling Machine chuck.
110. Vise housing.
111. Vise screw.
112. Vise jaws.
113. Swivel block in tailstock.
114. Tailstock center carrier.
115. Saddle of Universal Machine.

Additional Parts Applying to Cone-Driven Machines

116. Cover over back gears.
117. Cover over back gear pinion.
118. Back gear quill.
119. Back gear operating lever.
120. Back gear locking pin.
121. Driving cone.
122. Back gear sleeve.
123. Back gear shaft.
124. Braces as used on Nos. 1, 2 and 3 cone-driven machines.
125. Bridle for attaching braces to knee.

VERTICAL SPINDLE MILLING MACHINES

As already stated, the vertical spindle miller is usually of the column and knee type although there are numerous exceptions, particularly in very heavy designs and in certain other forms such as profilers and special constructions of one kind or another.

The table of the vertical miller when of the column and knee type, has all of the adjustments of the horizontal-spindle column and knee machine. In this type of vertical machine there is usually also a vertical movement of the spindle head, as is the case with other types of vertical machines where the table is without vertical adjustment. The spindle head operating either by hand or power has the movements of an accurate powerful drilling machine and the work being placed face upward on the table may oftentimes be handled with far greater convenience and facility than on a miller with horizontal spindle.

In certain manufacturing operations and in general shop work on the vertical miller the parts to be machined can often be secured directly to the table or to the simplest kind of fixtures without the necessity for the special holding tools which might be required if the same class of work were to be done on the horizontal spindle machine. With parts of irregular form it is of course essential to have adequate fixtures to assure accuracy and quick production, whether on the vertical or horizontal spindle miller. The vertical spindle machine is obviously well adapted for face milling operations of various kinds, for profiling interior and exterior surfaces, and for milling out dies, locating and boring holes in jigs, and fixtures and for other work where it is of especial advantage to be able to secure the object face upward under direct observation of the workman.

The Cincinnati vertical miller in one of its sizes has already been referred to in connection with Fig. 7. This is a column and knee type, high power machine with vertical head travel and with constant speed drive. A machine of the same build is represented by Fig. 9 in operation face milling malleable iron castings. The machine is provided with automatic reverse and the operator is working on both sides of the cutter, the table moving automatically and continuously to and fro, so that the operator's functions are confined to the chucking and releasing of the work. This method gives a roughing and finishing

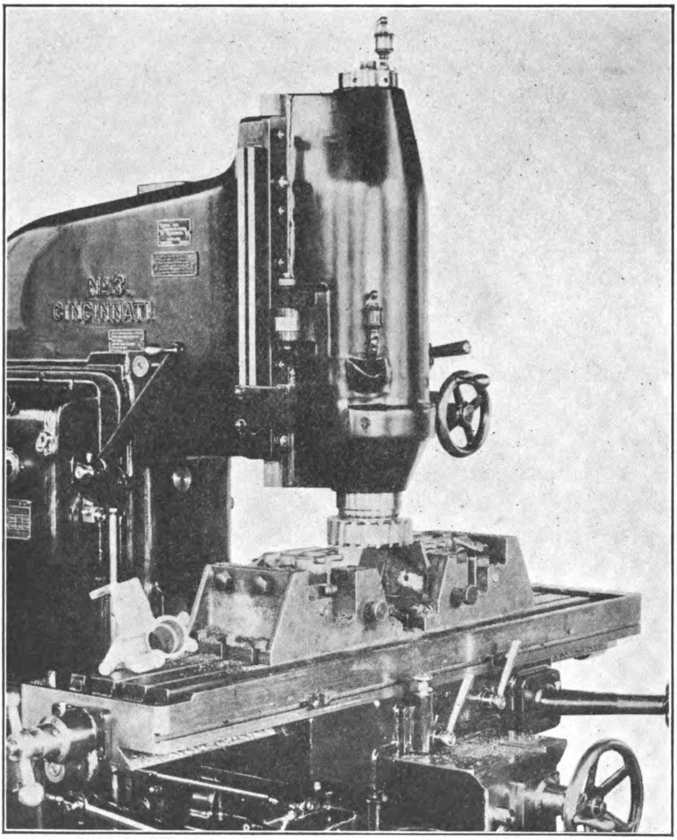


FIG. 9.—Face milling operation on vertical spindle machine.

cut over each surface, the latter serving to take out any spring due to weakness of the piece. The surface machined is approximately 6 by 7 inches. The cutter is 7½ inches in diameter and runs at 56 revolutions per minute, the table feeding at the rate of 12½ inches per minute, and producing the pieces in one and one half minute each.

Two other vertical spindle millers, both by Brown & Sharpe, are illustrated by Figs. 10 and 11. The first is of column and knee type with vertical movement of both table and spindle head. The other has vertical adjustment in the head and spindle only. Both machines as shown here are equipped with driving cones, though they are also built in their various sizes with constant speed drive.

THE MANUFACTURING MILLER

The manufacturing milling machine is the outgrowth of an early type of miller built especially for the production of firearms parts,

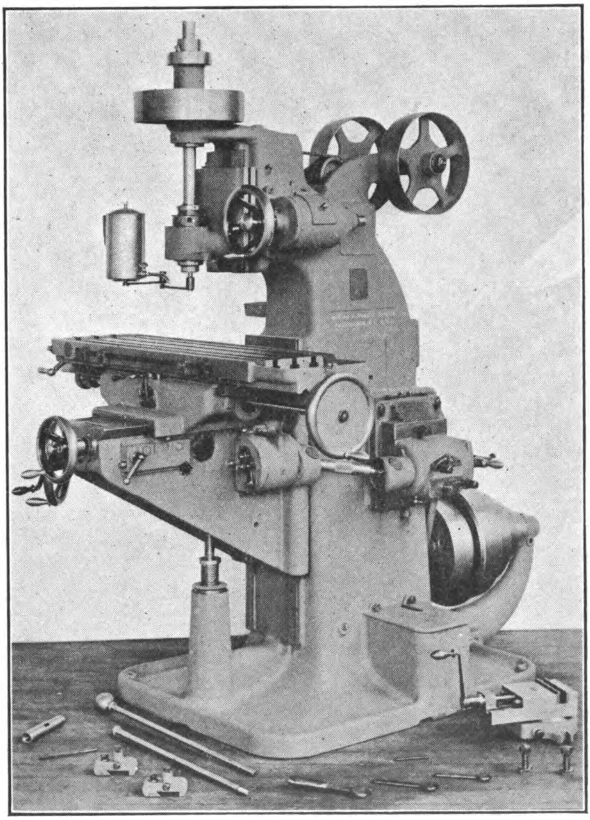


FIG. 10.—Brown & Sharpe vertical spindle miller with cone drive.

and today this machine is manufactured in various forms for milling gun parts, typewriter parts and an almost endless variety of work of small and medium dimensions, where considerable quantities are required in a lot.

The Lincoln miller is shown in one design in Fig. 13 where it is represented in operation on gun parts. The adjustment to the cut vertically is by means of the two hand wheels at the top which elevate and lower the spindle and cutter arbor support. The work table saddle is adjustable laterally to the desired position, and the feed of table and work by power and hand is at right angles to the cutter spindle.

The automatic milling machine is a development of recent times for the manufacture of large numbers of parts under rapid operation

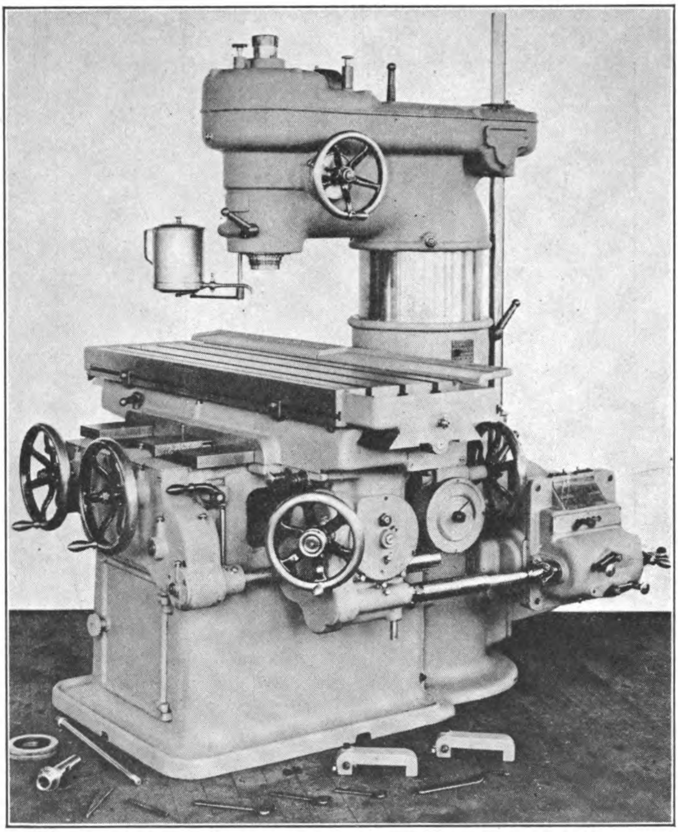


FIG. 11.—Vertical spindle miller with constant speed drive.

both as to actual milling time and setting and handling of the work itself. In Fig. 14 a view is shown of the Pratt & Whitney automatic milling machine, this being one of a line of different sizes built by this firm. This machine embodies many important features for facilitating rapid production. It has an intermittent rapid traverse and feed travel for the table which permits quick traversing of non-cutting spaces where these occur in the work. A very important feature is the receding table which permits the work to clear the cutter on the return stroke thus preventing marring of the finished surface. After the milling operation has been performed the table recedes a

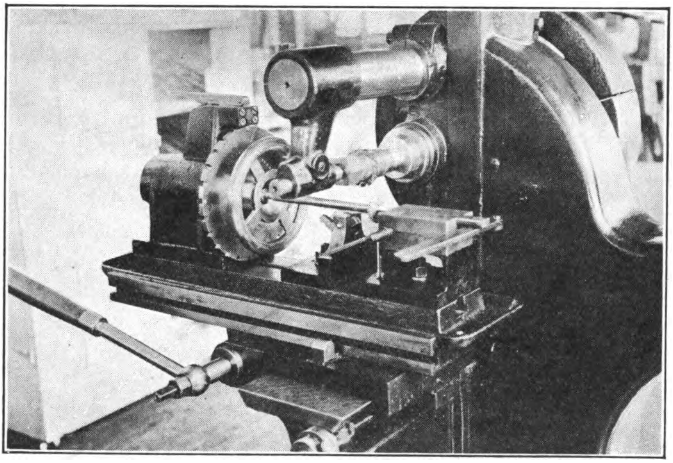


FIG. 12.—Hand miller.

sufficient amount for the work to clear the cutter and as the table approaches the end of the return stroke it is automatically elevated to its former position. This receding feature is obtained by means

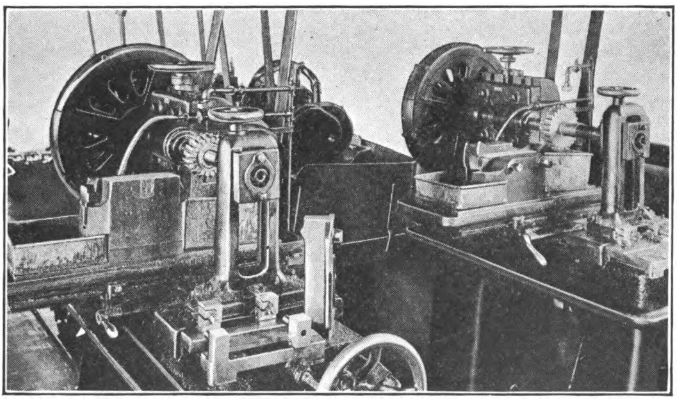


FIG. 13.—Lincoln millers.

of a wedge action in such manner as to maintain the accuracy and stability of a non-receding table.

The table feed or travel is controlled through a cam, the cam path being located on the periphery of a heavy drum. The cam paths for the forward and return movements intersect so that it is necessary to rotate the cam in only one direction to obtain both the forward and return travel. The speed at which the cam is rotated determines the rate of table travel. The mechanism through which the rotation of the cam is controlled is contained in gear unit. The gears which rotate the cam rather rapidly for the rapid traverse remain constant and are never changed. On the other hand the gears which rotate the cam rather slowly for the feed are changeable so that variations

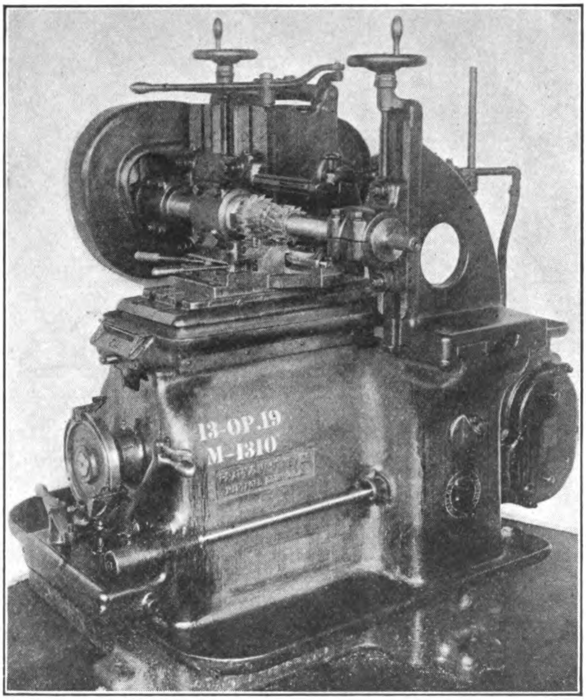


FIG. 14.—Pratt & Whitney automatic miller.

can easily be made for the various classes of work. These gear trains are brought into engagement by means of clutches and the mechanism for accomplishing this is of simple and reliable character. When the machine is in operation it is automatically controlled by means of dogs, the dog plate being located at the front in an accessible position. This plate is large enough to accommodate more than one set of dogs in cases where it is desirable to engage the rapid traverse and feeds intermittently several times during the forward travel.

The spindle speed changes are obtained by means of change gearing.

A tight and loose pulley form part of the head construction which permits belting the machine directly from a line shaft or jack shaft, thus eliminating countershafts.

The machine is shown in Fig. 14 set up for operation on a gun part. Other operations on this type of miller will be referred to in another chapter.

THE HORIZONTAL MILLER

The horizontal or planer type of miller is shown in one make in Fig. 15. Such machines are commonly used for heavy slabbing and channeling cuts and for heavy gang milling. They are of very power-

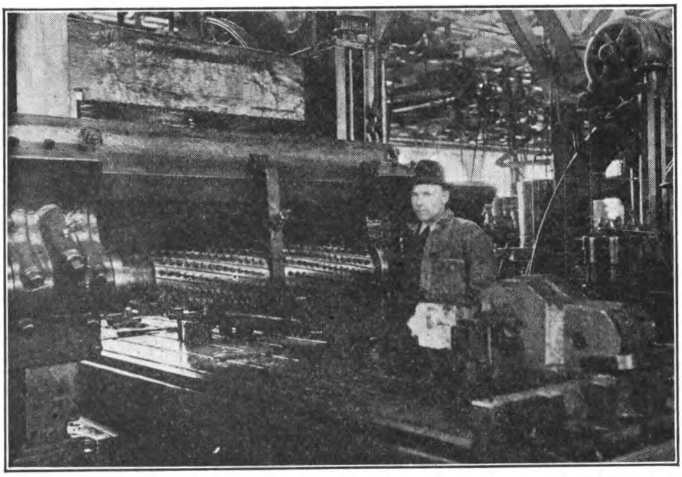


FIG. 15.—Horizontal miller, machining locomotive connecting rods.

ful construction and capable of removing large quantities of metal at each cut. They are extensively used in locomotive shops, automobile factories and in many other establishments where large parts are to be milled or where it is desired to gang up many medium sized parts for simultaneous operation at one or more passes under the cutters.

In general appearance as pointed out above, these machines resemble a planer and the work is carried as with that machine, on a long table fed between housings which here carry the cutter spindle and support in place of the planer heads and saddles. The speed of the table is varied to suit the work and the position of the cutters in respect to the work is adjusted by elevating or lowering the cross rail. The horizontal milling machine in Fig. 15 is seen in operation upon a pair of locomotive side rods. Two cutters are shown in place on the arbor and four or more rods may be machined at once.

CHAPTER II

SPINDLE DRIVING AND FEED MECHANISMS

In Chap. I different types of milling machines are illustrated, some with cone drive and others with constant speed or gear drive. In cone driven machines the belt operates directly from a cone pulley on the countershaft to the cone on the spindle. The cone is either secured directly to the spindle or with back geared machines it is carried on a sleeve mounted on the spindle so that in addition to the speeds obtained directly from the stops on the cone another series of speeds is derived through the medium of the back gears. The feed mechanism on cone drive machines is driven from the rear end of the spindle and is consequently subject to the changes of speed in the spindle.

There are two feed systems in general use, one in which the rate of feed is expressed in thousandths of an inch per revolution, the other with the feed in inches per minute. With the cone driven machine, as the feed is driven directly from the spindle, any increase in the spindle speed increases the amount of feed per minute proportionately, but the ratio between table feed and cutter speed remains unchanged; that is the feed per revolution of spindle is the same whether the spindle speed is high or low. With the constant speed drive however, the regular practice is to make the feeds entirely independent of the spindle speeds, the arrangement of the feed being such that for any given position of the feed lever there is a fixed amount of feed per minute regardless of the speed at which the spindle is driven. Therefore any change in the spindle speed will not affect the rate of table feed and the quantity of output, unless the feed is also changed at the same time. Detailed advantages of this independent feed arrangement will be considered in a later paragraph.

THE CONSTANT SPEED DRIVE

Machines with constant speed drive may be belted direct from a plain countershaft or from a main line pulley; or they may be driven by a direct connected motor. The important features of this form of drive are outlined briefly as follows: The belt delivers power to the driving pulley which runs freely upon a sleeve on the main shaft of the milling machine. There is a friction clutch on this main shaft which is controlled by levers, and by means of this clutch power is transmitted from the driving pulley to a train of hardened gears which lead to the spindle and in which there are change gears operated by conveniently located levers. The belt and main driving pulley run at a constant high rate of speed regardless of the speed of the spindle, which is dependent upon the ratio of gearing that is in mesh. The power at the spindle is practically constant regardless of its speed.

The illustration Fig. 16 shows the arrangement of the spindle

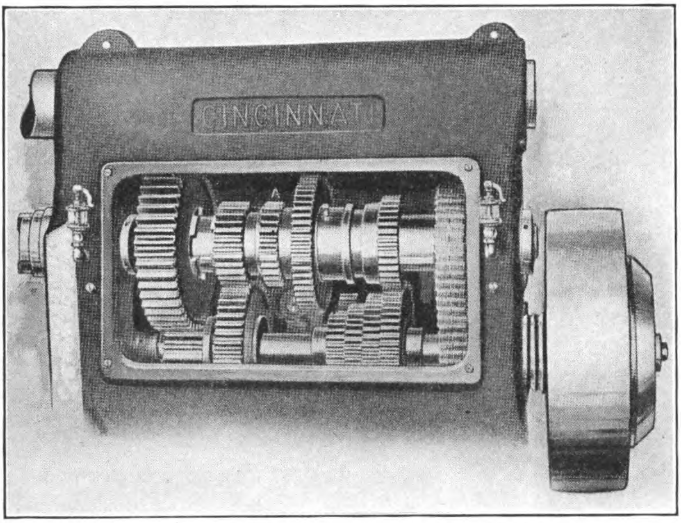


FIG. 16.—Cincinnati constant speed drive.

driving gears of the Cincinnati high power millers, and the line engraving Fig. 17 is a sectional view of the complete spindle drive. It should be noted that the chain at the right in Fig. 16 has no function in the operation of the spindle, but is solely a feed chain which is supplied in special cases where feeds are to be read in thousandths of an inch. Normally the feed is driven from the constant speed shaft and reads in inches per minute.

DETAILS OF DRIVE AND FEED

Referring to Fig. 17, there are sixteen speeds provided for in this gear drive; the small gear *M* is not used for transmission but acts as a pilot when the large gears are being engaged. The driving pulley is journaled on a bracket secured to the column of the machine and is connected to the driving shaft by a disk friction clutch, which is operated to start and stop the machine by means of a lever at the front of the miller. The gears *I, J, K* and *L* are steel forgings; all others are nickel steel heat treated, and all of the gears are hardened. In order to reduce torsional strains and consequent vibration to a minimum there are no gears keyed directly to shafts with the exception of the main gear *L* which is keyed to the front end of the spindle close to the bearings.

The engraving Fig. 18 shows the inside of the spindle drive box with the driving shaft, tumbler and chain wheel for driving the feed from the constant speed shaft. A section through the automatically clamped tumbler is reproduced in Fig. 19. The frame for this tumbler

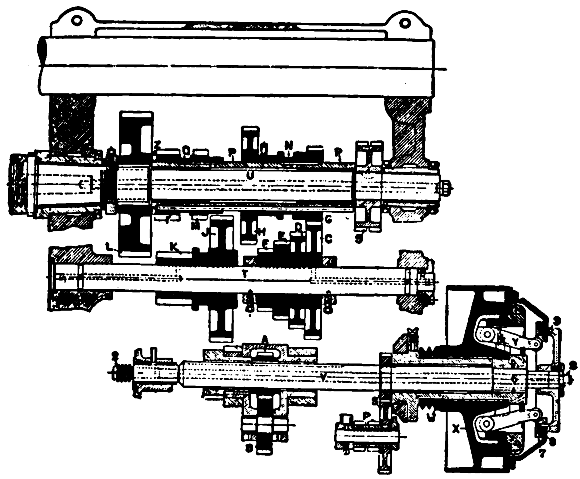


FIG. 17.—The complete spindle drive.

is supported from the machine frame and none of its weight comes on the main driving shaft. The swinging frame carrying the tumbler gear rocks on trunnions *C* and is operated by the pilot wheel on the outside of the machine through the medium of spiral gears *S*. By means of the same pilot wheel the tumbler frame can be adjusted laterally. When the pilot wheel is turned to the right the gears are brought into mesh and the lug *D* of the swinging tumbler frame abuts on the stop pins which govern the proper meshing. Now if the pilot wheel is turned further to the right, the swinging frame, the tumbler frame and the spiral gears act as a system of levers and screw which lock the tumbler frame securely to its slide on the machine frame and hold the support for the tumbler gear as rigidly as if it were bolted in position. Upon turning the pilot wheel to the left as far as it will go the tumbler gears are brought out of engagement.

The speeds are quickly changed by means of the pilot wheel men-

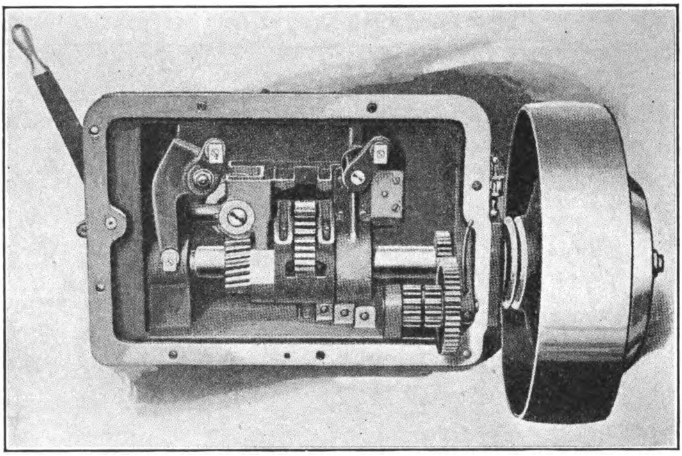


FIG. 18.—Inside of spindle drive box.

tioned above and the two levers seen on the front of the speed change box in Fig. 20. The lever positions for each speed are clearly marked. Thus, say the speed desired is 115 revolutions per minute: The index plate (shown more clearly in Fig. 21) shows the symbols corresponding

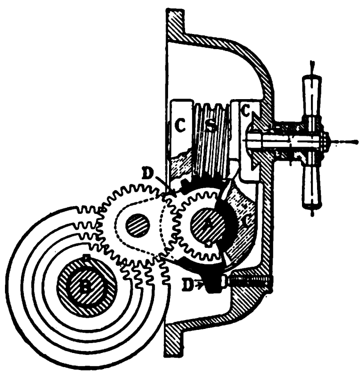


FIG. 19.—Section through tumbler.

to this speed of 115 r.p.m. to be 3-*BC*. One lever is therefore moved to *B*, the other to *C* and the tumbler moved to position No. 3. Light pressure on the treadle while these levers are moved, gives the gears sufficient motion to facilitate easy changing of the speeds.

The outside and interior of the feed box which is arranged for sixteen changes of feed, are represented by the engravings, Figs. 22 and 23. The feed is driven from the constant speed shaft and the feed plate on the gear box reads in inches per minute unless otherwise

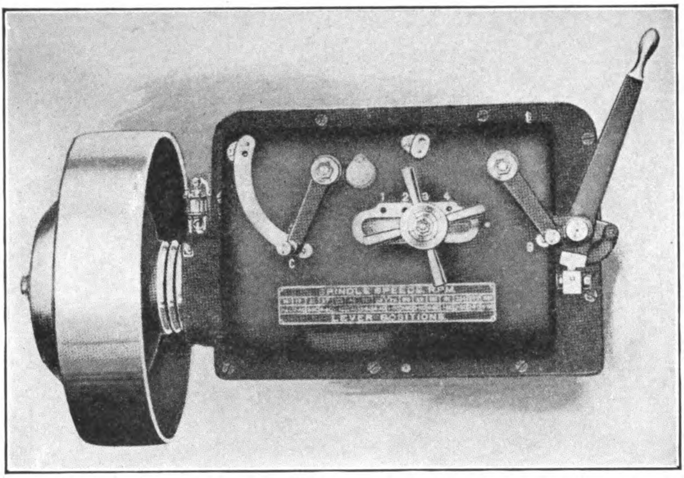


FIG. 20.—Outside of speed change box.

desired in special cases as noted in an earlier paragraph. The feed index and feed change levers are the same as for the drive box, but the feeds are best changed while the machine is running.

A CONSIDERATION OF SPEEDS AND FEEDS

Returning now to a comparison of the cone drive and the constant speed drive for milling machines there are some interesting factors

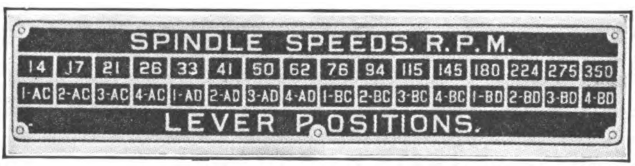


FIG. 21.—Direct-reading speed index plate.

to be considered. As pointed out by manufacturers of millers and as well known to general users of such equipment, it is seldom that in any two jobs on a milling machine there are exactly the same conditions of operation. Where the work is of the heaviest kind for which the machine is suited, large gangs of cutters may be required to operate at a relatively high rate of speed and under a coarse feed, while in contrast, with work of light character a single cutter may be required which is operated at a fast speed and with fine feed. Again, the very shape of the work is a factor of importance; it may be such as to require an altogether different cutter feed than would be entirely suitable for machining a plain straight surface. Furthermore, the differences in materials necessitate the use of different speeds and feeds. And the diameters of the cutters themselves necessarily influence the selection of the spindle speed, for where cutters say, of large diameter are used on certain work they must be driven for the proper surface speed, at a slower rate of rotation than cutters of smaller diameter. In taking finishing cuts with the same cutter as is used for the first or roughing cuts, it is usual practice to run the spindle at a higher speed and slower feed per revolution than

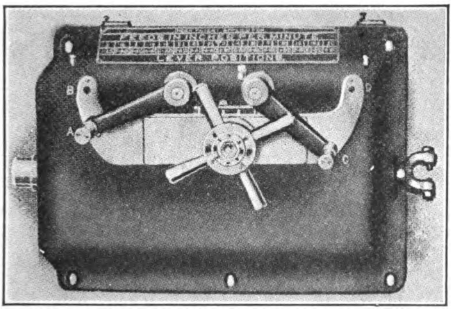


FIG. 22.—The feed box.

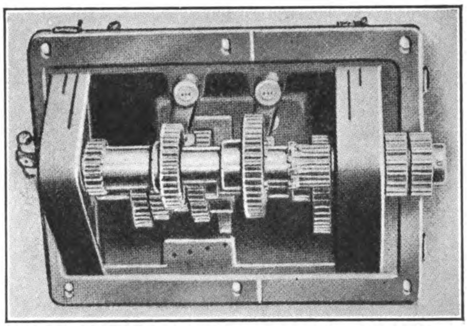


FIG. 23.—Interior of feed box.

in the roughing, in order that a smoother finish may be obtained on the work.

It is apparent from the foregoing and from other considerations that the milling machine should have a wide range of speeds and feeds with many intermediate speeds and feeds between the extremes in the range. It is also desirable in numerous instances to have speeds and feeds independent of each other, this enabling the speed of the spindle to be changed without affecting the rate of travel for the table. This desirable feature is found in the miller with constant speed drive.

The cone driven miller is admirably adapted to all classes of work where it is not necessary to use combinations of extreme speeds and feeds as with cutters of very large diameter or with very small mills. As the feed is driven from the end of the spindle it is subject to the spindle speed variations and therefore when a very large cutter is used, which must be driven at the slowest speed, the fastest rate of feed that can then be obtained is too fine; while with a very small cutter which requires the fastest spindle speed, the finest feed available is altogether too coarse. The extreme combinations however are not required in the majority of cases as cutters of moderate diameter

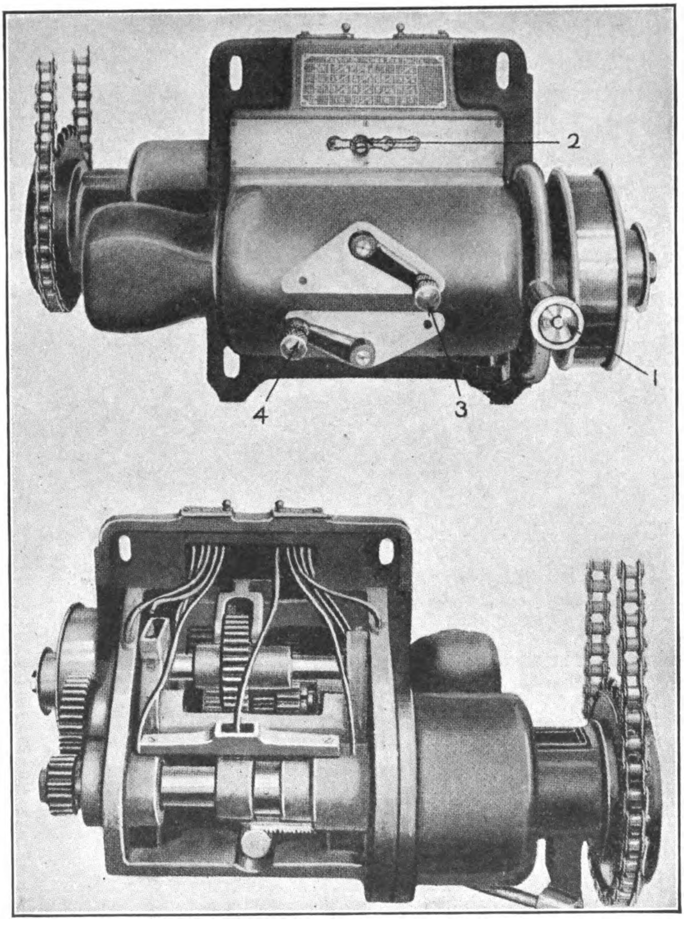


FIG. 24.—Feed changing mechanism on Brown & Sharpe miller.

are more generally used and for the operation of these the cone driven miller is well adapted. As the feeds on the cone driven miller are necessarily rated in thousandths of an inch per revolution of spindle this requires that the feed used must be multiplied by the spindle speed to give the rate of production in inches per minute.

The constant speed drive gives any desired combination of speeds and feeds within the limits of the range, so that any size of cutter large, small or medium, can be operated at the most advantageous rate of speed and feed, and the actual feed can be read directly in inches per minute, which is a marked advantage as this is the customary measure of the rate of production.

On the Brown & Sharpe constant speed drive millers there are sixteen spindle speeds and at least sixteen different feeds, and on some sizes there are as many as twenty feeds. The feed changing mechanism on this make of miller is illustrated by Fig. 24. A section through the Brown & Sharpe miller column and spindle bearings is illustrated in Fig. 25 showing the construction of boxes and method of adjustment. Like the usual practice with spindle bearings, the front bearing on this spindle is tapered and the rear one straight.

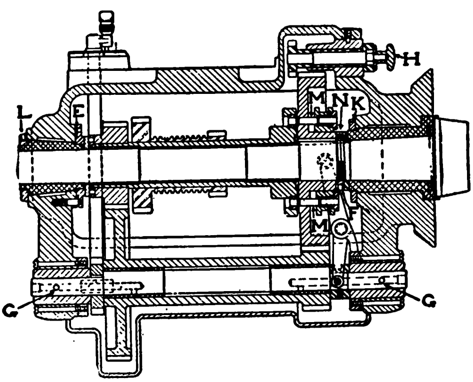


FIG. 25.—Spindle boxes and means of adjustment.

The front bearing is adjusted by loosening check nut *N* and tightening nut *F*. This draws the spindle back into the box, and as the bearing is tapered the lost motion is taken up. If it becomes necessary after running the machine for a number of years to obtain more adjustment in the front box, the spindle can be removed and the washers between the spindle collar and the front end of the box can be reduced slightly in thickness; the adjusting nut *F* will then take care of the wear for another long period. The nut *K* should not be disturbed as this is for merely holding the box in place. The rear box is split and tapered externally to fit a taper hole in the frame. The adjustment of this box is accomplished by loosening nut *L* and tightening nut *E*.

CHAPTER III

THE DIVIDING HEAD AND SOME OF ITS USES

The universal dividing head (or spiral head) forms one of the most important features of the milling machine. While primarily designed for the universal milling machine and forming part of the usual equipment for this type of miller, it is also applicable in most cases to plain and vertical spindle machines. With a vertical spindle attachment on the plain miller, work can be done on the spiral head in much the same variety as when the head is used on the universal

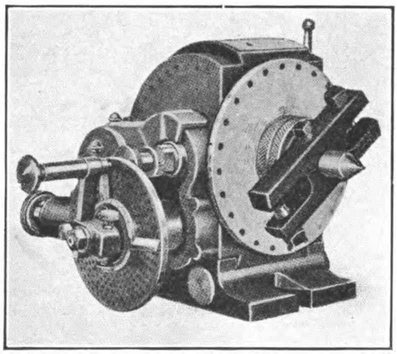


FIG. 26.—Spiral head, Brown & Sharpe.

machine. The dividing head is used today for a great variety of operations, including among others, the cutting of flutes in twist drills, milling cutters and in other spiral work; indexing or dividing for equal spacing on work as with gears, ratchets, clutch teeth, etc., and for flutes in taps, reamers, drills, and other tools. As a precision instrument for facilitating the operations of the tool maker and die maker the dividing head has become indispensable. Its possibilities in the working out of all classes of tool room problems are apparently unlimited. It may be said that each day in the modern tool room and experimental department sees some new application of this milling machine appliance. And its usefulness in the general shop increases also, though naturally in lesser degree than in the tool department. The Brown & Sharpe Mfg. Co. describes the spiral head or dividing head (Fig. 26) as follows:

SPIRAL HEAD DETAILS

The head itself consists of a hollow semi-circular casting in which is mounted a spindle that is connected to an index crank through a worm and wheel. Figure 27 shows the construction of this part. The head casting has dovetailed bearings at each side that fit the contour of a base plate, which can be clamped to the surface of the table. The alinement of the head with the table longitudinally is provided by means of a tongue on the underside of the base plate that fits a T-slot in the table.

The spiral head passes through the head and is held in place by

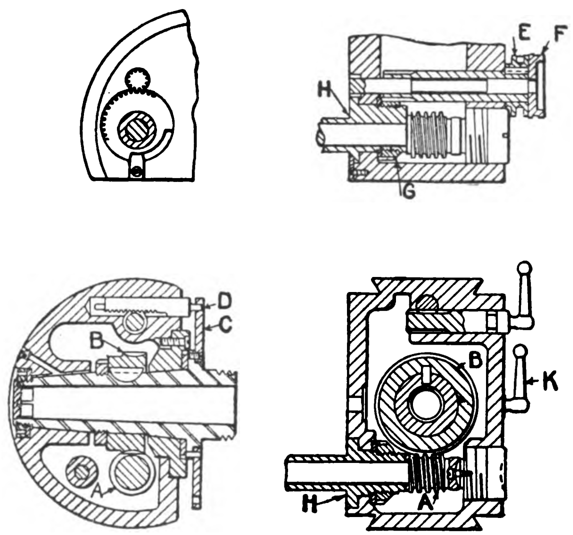


FIG. 27.—Construction of spiral head.

means of a nut at the small end. The front end is threaded and has a taper hole corresponding to that of the miller spindle. It is rotated by means of the worm wheel *B* which is driven by the hardened worm *A* that is located on the shaft to which the index crank is fastened. In order to secure accuracy the worm threads are ground after hardening. Through gearing, the index plate and worm *A* can be driven together from the table feed screw when the index pin is in position in any hole of a plate. When worm *A* is turned by means of the index crank, indexing may be accomplished, and when it is geared to the table feed screw, spiral milling, in addition to indexing, is made possible. The cutting of the spiral is due to the turning of the table feed screw, which through the interposition of change gears between this screw and the gears that drive the shaft carrying worm *A*, causes the spindle of the spiral head to rotate as the table advances, so that the cutter produces a spiral cut in the work. For rapid indexing, when cutting flutes in taps, reamers, etc., the worm *A* is disengaged and the spindle turned by hand, the divisions being made by means of the index plate *C*, which is fastened to the nose of the spindle and may be locked by the pin *D*.

The spindle may be revolved continuously as when cutting spirals, or may be securely locked after being revolved a desired amount as in indexing for cutters, the teeth of gears, clutches, ratchets, etc.

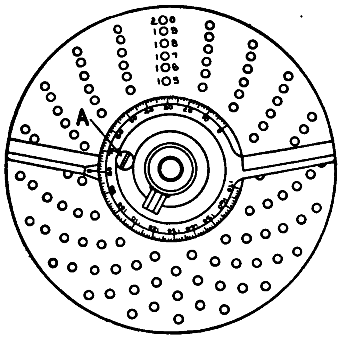


FIG. 28.—Index plate and sector.

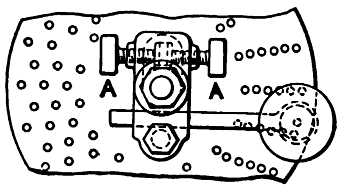


FIG. 29.—Index crank.

It is possible to swing the head in its bearings so that the front end of the spindle can be set to any desired angle from 10 degrees below the horizontal to 5 degrees beyond the perpendicular line without throwing the driving members out of mesh. Graduations on the front edge of the head indicate the angle of elevation to half degrees.

INDEX PLATES, CHANGE GEARS, SECTOR, ETC.

The three index plates with the regular equipment of the dividing head contain circles with the following number of holes:

Plate 1: 15, 16, 17, 18, 19, 20 holes.

Plate 2: 21, 23, 27, 29, 31, 33 holes.

Plate 3: 37, 39, 41, 43, 47, 49 holes.

The change gears furnished have the following number of teeth: 24 (two gears), 28, 32, 40, 44, 48, 56, 64, 72, 86, and 100 teeth.

The graduated sector which enables the correct number of holes to be obtained at each indexing is shown in Fig. 28, and consists of two arms which may be spread apart when the screw *A* is loosened slightly. The correct number of holes may be counted and the sector arms set to include them; or preferably, the graduations on the dial may be used in connection with the Index Tables on page 121. To set the sector arms by the latter method follow down the column headed "Graduation" in the tables, until opposite the number of divisions desired. Take the number that is found here and set the arms by bringing the left one against the index pin, which should be inserted in any convenient hole in the required circle, and moving the right one until the graduation corresponding to the number obtained from the table coincides with the zero on the left arm. The correct number of holes will then be contained between the two arms and counting is unnecessary. However, if the arms are set by counting the holes, the left arm should be brought against the index pin as directed above, and then the required number of holes for each division should be counted from the hole that the pin is in, considering this hole as zero.

FEATURES OF ADJUSTMENT

The index crank of the spiral head is adjustable circumferentially, as shown in Fig. 29. Many times it is desired to make a delicate adjustment of the work, or to bring the index pin to the nearest hole without disturbing the setting of the work. To adjust the index crank after the work has been placed in position, turn the thumb screws *AA*, Fig. 29, until the pin enters the nearest hole in the index plate. To rotate the work relative to the index plate, both the stop pin at the back of the plate and the index crank pin should be engaged, the adjustment being made by means of the thumb screws as before.

When it is desired to turn the spindle by hand and index the work by means of the plate on the front end of the spindle, it is necessary to disengage the driving worm *A*, Fig. 27. This is done by turning the knob *E* with the pin wrench (which is part of the equipment), about one quarter of a revolution in the reverse direction to that indicated by the arrow stamped on the knob. This will loosen nut *G*, that clamps the eccentric bushing *H*; then with the fingers turn both knobs *E* and *F*, at the same time, and the bushing *H* will revolve, disengaging the worm from the wheel. To re-engage the worm, reverse the above operation.

It is important to note the effect of change in angle of elevation on the spindle. If the angle of the spiral head spindle is changed during operation, the spindle must be rotated slightly to bring the work back to proper position, for when the spindle is elevated or depressed, the worm wheel is rotated about the worm, and the effect is the same as if the worm were turned.

The foot stock shown in Fig. 30 is for supporting work that is milled on centers or the outer ends of arbors, and work that is secured in the chuck. The center has longitudinal adjustment and can be elevated or depressed by means of a rack *V* and a pinion actuated by hexagon head *U*. It can also be set at an angle out of parallel with the base when it is desired to mill drills, taper reamers, etc., so that it can be kept in alinement with the spiral head center thus assuring the work being free from cramping and uneven spacing at any point in its revolution. When set in any position, the center is secured by nuts *W*, *X*

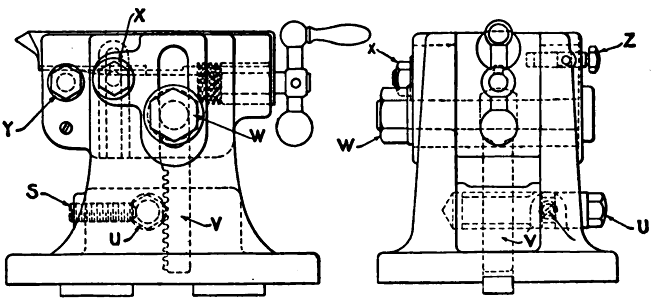


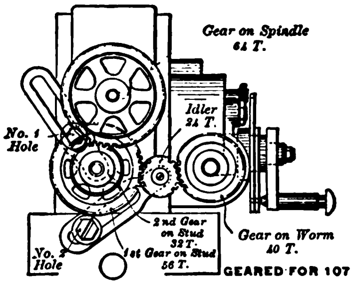
FIG. 30.—Foot or tail stock.

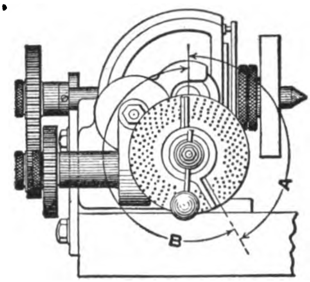
and *Y*. Set screw *S* prevents end movement of the elevating pinion. Two taper pins (one shown at *Z*) are used to locate the foot stock center in line with the spiral head center, when the centers are parallel to the top of the table.

INDEXING ON THE DIVIDING HEAD

The spiral head or as often called, universal dividing head, enables the periphery of work to be accurately indexed or divided into a number of given parts, or divisions. There are two practical methods of indexing accurately, known respectively, as plain and differential. There is a third method known as the compound, which was formerly used extensively and is today employed in some shops not equipped for differential indexing. This compound method however, involves chances for error in making the complicated indexing moves and even when the moves are correctly made exact results are not obtained. It has therefore been very largely displaced by the differential method of indexing with which the same numbers of divisions can be obtained accurately.

By the plain method of indexing, which includes rapid indexing with the plate on the spindle nose, all divisions up to 50, even numbers up to 100 except 96, and many numbers that are multiples of 5 up to 380, besides many others, can be indexed with the three plates of the





NUMBER OF DIVISIONS	INDEX CIRCLE	No. OF TURNS OF INDEX	GRADUATION
2	Any	20	
3	39	$13\frac{13}{39}$	65
	33	$13\frac{11}{33}$	65
	18	$13\frac{6}{18}$	65
4	Any	10	
5	Any	8	
6	39	$6\frac{26}{39}$	132
	33	$6\frac{22}{33}$	132
	18	$6\frac{12}{18}$	132
7	49	$5\frac{35}{49}$	140
	21	$5\frac{15}{21}$	142
8	Any	5	
9	27	$4\frac{12}{27}$	88
	18	$4\frac{8}{18}$	87
10	Any	4	
11	33	$3\frac{21}{33}$	126
12	39	$3\frac{13}{39}$	65
	33	$3\frac{11}{33}$	65
	18	$3\frac{6}{18}$	65

NUMBER OF DIVISIONS	INDEX CIRCLE	No. OF TURNS OF INDEX	GRADUATION
13	39	$3\frac{3}{39}$	14
14	49	$2\frac{42}{49}$	169
	21	$2\frac{18}{21}$	170
15	39	$2\frac{26}{39}$	132
	33	$2\frac{22}{33}$	132
	18	$2\frac{12}{18}$	132
16	20	$2\frac{10}{20}$	98
17	17	$2\frac{6}{17}$	69
18	27	$2\frac{6}{27}$	43
	18	$2\frac{4}{18}$	43
19	19	$2\frac{2}{19}$	19
20	Any	2	
21	21	$1\frac{19}{21}$	18*
22	33	$1\frac{27}{33}$	161
23	23	$1\frac{17}{23}$	147
24	39	$1\frac{26}{39}$	132
	33	$1\frac{22}{33}$	132
	18	$1\frac{12}{18}$	132
25	20	$1\frac{12}{20}$	118

NUMBER OF DIVISIONS	INDEX CIRCLE	No. OF TURNS OF INDEX	GRADUATION
26	39	$1\frac{21}{39}$	106
27	27	$1\frac{13}{27}$	95
28	49	$1\frac{21}{49}$	83
	21	$1\frac{9}{21}$	85
29	29	$1\frac{11}{29}$	75
30	39	$1\frac{13}{39}$	65
	33	$1\frac{11}{33}$	65
	18	$1\frac{6}{18}$	65
31	31	$1\frac{9}{31}$	56
32	20	$1\frac{5}{20}$	48
33	33	$1\frac{7}{33}$	41
34	17	$1\frac{3}{17}$	33
35	49	$1\frac{7}{49}$	26
	21	$1\frac{3}{21}$	28
36	27	$1\frac{3}{27}$	21
	18	$1\frac{2}{18}$	21
37	37	$1\frac{3}{37}$	15
38	19	$1\frac{1}{19}$	9
39	39	$1\frac{1}{39}$	3

NUMBER OF DIVISIONS	INDEX CIRCLE	No. OF TURNS OF INDEX	GRADUATION
40	Any	1	
41	41	$\frac{40}{41}$	3*
42	21	$\frac{20}{21}$	9*
43	43	$\frac{40}{43}$	12*
44	33	$\frac{30}{33}$	17*
45	27	$\frac{24}{27}$	21*
	18	$\frac{16}{18}$	21*
46	23	$\frac{20}{23}$	172
47	47	$\frac{40}{47}$	168
48	18	$\frac{15}{18}$	165
49	49	$\frac{40}{49}$	161
50	20	$\frac{16}{20}$	158

GRADUATIONS IN TABLE INDICATE SETTING FOR ARMS OF SECTOR WHEN INDEX CRANK MOVES THROUGH ARC "A," EXCEPT CASES MARKED * WHEN THE INDEX CRANK MOVES THROUGH ARC "B."

TABLE No. 1.—Table for plain and differential indexing.

INDEX TABLE 51 to 92.

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
51	17	14/17	33*	24			48	24	44
52	39	30/39	152						
53	49	35/49	140	56	40	24	72		
	21	15/21	142	56	40	24	72		
54	27	20/27	147						
55	33	24/33	144						
56	49	35/49	140						
	21	15/21	142						
57	49	35/49	140	56			40	24	44
	21	15/21	142	56			40	24	44
58	29	20/29	136						
59	39	26/39	132	48			32	44	
	33	22/33	132	48			32	44	
	18	12/18	132	48			32	44	
60	39	26/39	132						
	33	22/33	132						
	18	12/18	132						
61	39	26/39	132	48			32	24	44
	33	22/33	132	48			32	24	44
	18	12/18	132	48			32	24	44
62	31	20/31	127						
63	39	26/39	132	24			48	24	44
	33	22/33	132	24			48	24	44
	18	12/18	132	24			48	24	44
64	16	10/16	123						
65	39	24/39	121						
66	33	20/33	120						
67	49	28/49	112	28			48	44	
	21	12/21	113	28			48	44	
68	17	10/17	116						

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
69	20	12/20	118	40			56	24	44
70	49	28/49	112						
	21	12/21	113						
71	27	15/27	110	72			40	24	
	18	10/18	109	72			40	24	
72	27	15/27	110						
	18	10/18	109						
73	49	28/49	112	28			48	24	44
	21	12/21	113	28			48	24	44
74	37	20/37	107						
75	15	8/15	105						
76	19	10/19	103						
77	20	10/20	98	32			48	44	
78	39	20/39	101						
79	20	10/20	98	48			24	44	
80	20	10/20	98						
81	20	10/20	98	48			24	24	44
82	41	20/41	96						
83	26	10/20	98	32			48	24	44
84	21	10/21	94						
85	17	8/17	92						
86	43	20/43	91						
87	15	7/15	92	40			24	24	44
88	33	15/33	89						
89	27	12/27	88	72			32	44	
	18	8/18	87	72			32	44	
90	27	12/27	88						
	18	8/18	87						
91	39	18/39	91	24			48	24	44
92	23	10/23	86						

TABLE No. 1.—Continued.

INDEX TABLE 93 to 125.

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole	Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
93	27	12/27	88	24			32	24	44		39	13/39	65	24			48	44	
	18	8/18	87	24			32	24	44	114	33	11/33	65	24			48	44	
94	47	20/47	83								18	6/18	65	24			48	44	
95	19	8/19	82							115	23	8/23	68						
96	49	21/49	83	28			32	24	44	116	29	10/29	68						
	21	9/21	85	28			32	24	44		39	13/39	65	24			24	56	
97	20	8/20	78	40			48	44		117	33	11/33	65	24			24	56	
98	49	20/49	79								18	6/18	65	24			24	56	
99	20	8/20	78	56	28	40	32				39	13/39	65	48			32	44	
100	20	8/20	78							118	33	11/33	65	48			32	44	
101	20	8/20	78	72	24	40	48		24		18	6/18	65	48			32	44	
102	20	8/20	78	40			32	24	44		39	13/39	65	72			24	44	
103	20	8/20	78	40			48	24	44	119	33	11/33	65	72			24	44	
104	39	15/39	75								18	6/18	65	72			24	44	
105	21	8/21	75								39	13/39	65						
106	43	16/43	73	86	24	24	48			120	33	11/33	65						
107	20	8/20	78	40	56	32	64		24		18	6/18	65						
108	27	10/27	73								39	13/39	65	72			24	24	44
109	16	6/16	73	32			28	24	44	121	33	11/33	65	72			24	24	44
110	33	12/33	71								18	6/18	65	72			24	24	44
	39	13/39	65	24			72	32			39	13/39	65	48			32	24	44
111	33	11/33	65	24			72	32		122	33	11/33	65	48			32	24	44
	18	6/18	65	24			72	32			18	6/18	65	48			32	24	44
	39	13/39	65	24			64	44			39	13/39	65	24			24	24	44
112	33	11/33	65	24			64	44		123	33	11/33	65	24			24	24	44
	18	6/18	65	24			64	44			18	6/18	65	24			24	24	44
	39	13/39	65	24			56	44		124	31	10/31	63						
113	33	11/33	65	24			56	44			39	13/39	65	24			40	24	44
	18	6/18	65	24			56	44		125	33	11/33	65	24			40	24	44
											18	6/18	65	24			40	24	44

TABLE No. 1.—Continued.

INDEX TABLE 126 to 168.

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole	Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
126	39	13/39	65	24			48	24	44	143	49	14/49	55	28			24	24	44
	33	11/33	65	24			48	24	44		21	6/21	56	28			24	24	44
	18	6/18	65	24			48	24	44	144	18	5/18	54						
127	39	13/39	65	24			56	24	44	145	29	8/29	54						
	33	11/33	65	24			56	24	44	146	49	14/49	55	28			48	24	44
	18	6/18	65	24			56	24	44		21	6/21	56	28			48	24	44
128	16	5/16	61							147	49	14/49	55	24			48	24	44
129	39	13/39	65	24			72	24	44		21	6/21	56	24			48	24	44
	33	11/33	65	24			72	24	44	148	37	10/37	53						
	18	6/18	65	24			72	24	44	149	49	14/49	55	28			72	24	44
130	39	12/39	60								21	6/21	56	28			72	24	44
131	20	6/20	58	40			28	44		150	15	4/15	52						
132	33	10/33	59							151	20	5/20	48	32			72	44	
133	49	14/49	55	24			48	44		152	19	5/19	51						
	21	6/21	56	24			48	44		153	20	5/20	48	32			56	44	
134	49	14/49	55	28			48	44		154	20	5/20	48	32			48	44	
	21	6/21	56	28			48	44		155	31	8/31	50						
135	27	8/27	58							156	39	10/39	50						
136	17	5/17	57							157	20	5/20	48	32			24	56	
137	49	14/49	55	28			24	56		158	20	5/20	48	48			24	44	
	21	6/21	56	28			24	56		159	20	5/20	48	64	32	56	28		
138	49	14/49	55	56			32	44		160	20	5/20	48						
	21	6/21	56	56			32	44		161	20	5/20	48	64	32	56	28		24
139	49	14/49	55	56	32	48	24			162	20	5/20	48	48			24	24	44
	21	6/21	56	56	32	48	24			163	20	5/20	48	32			24	24	44
140	49	14/49	55							164	41	10/41	47						
	21	6/21	56							165	33	8/33	47						
141	18	5/18	54	48			40	44		166	20	5/20	48	32			48	24	44
142	49	14/49	55	56			32	24	44	167	20	5/20	48	32			56	24	44
	21	6/21	56	56			32	24	44	168	21	5/21	47						

TABLE No. 1.—Continued.

INDEX TABLE 169 to 214.

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
169	20	5/20	48	32			72	24	44
170	17	4/17	45						
171	21	5/21	47	56			40	24	44
172	43	10/43	44						
173	27	6/27	43	72	56	32	64		
	18	4/18	43	72	56	32	64		
174	27	6/27	43	24			32	56	
	18	4/18	43	24			32	56	
175	27	6/27	43	72	40	32	64		
	18	4/18	43	72	40	32	64		
176	27	6/27	43	72	24	24	64		
	18	4/18	43	72	24	24	64		
177	27	6/27	43	72			48	24	
	18	4/18	43	72			48	24	
178	27	6/27	43	72			32	44	
	18	4/18	43	72			32	44	
179	27	6/27	43	72	24	48	32		
	18	4/18	43	72	24	48	32		
180	27	6/27	43						
	18	4/18	43						
181	27	6/27	43	72	24	48	32		24
	18	4/18	43	72	24	48	32		24
182	27	6/27	43	72			32	24	44
	18	4/18	43	72			32	24	44
183	27	6/27	43	48			32	24	44
	18	4/18	43	48			32	24	44
184	23	5/23	42						
185	37	8/37	42						
186	27	6/27	43	48			64	24	44
	18	4/18	43	48			64	24	44

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
187	27	6/27	43	72	48	24	56		24
	18	4/18	43	72	48	24	56		24
188	47	10/47	40						
189	27	6/27	43	32			64	24	44
	18	4/18	43	32			64	24	44
190	19	4/19	40						
191	20	4/20	38	40			72	24	
192	20	4/20	38	40			64	44	
193	20	4/20	38	40			56	44	
194	20	4/20	38	40			48	44	
195	39	8/39	39						
196	49	10/49	38						
197	20	4/20	38	40			24	56	
198	20	4/20	38	56	28	40	32		
199	20	4/20	38	100	40	64	32		
200	20	4/20	38						
201	20	4/20	38	72	24	40	24		24
202	20	4/20	38	72	24	40	48		24
203	20	4/20	38	40			24	24	44
204	20	4/20	38	40			32	24	44
205	41	8/41	37						
206	20	4/20	38	40			48	24	44
207	20	4/20	38	40			56	24	44
208	20	4/20	38	40			64	24	44
209	20	4/20	38	40			72	24	44
210	21	4/21	37						
211	16	3/16	36	64			28	44	
212	43	8/43	35	86	24	24	48		
213	27	5/27	36	72			40	44	
214	20	4/20	38	40	56	32	64		24

TABLE No. 1.—Continued.

INDEX TABLE 215 to 270.

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
215	43	$\frac{8}{43}$	35						
216	27	$\frac{5}{27}$	36						
217	21	$\frac{4}{21}$	37	48			64	24	44
218	16	$\frac{3}{16}$	36	64			56	24	44
219	21	$\frac{4}{21}$	37	28			48	24	44
220	33	$\frac{6}{33}$	35						
221	17	$\frac{3}{17}$	33	24			24	56	
222	18	$\frac{3}{18}$	32	24			72	44	
223	43	$\frac{8}{43}$	35	86	48	24	64		24
224	18	$\frac{3}{18}$	32	24			64	44	
225	27	$\frac{5}{27}$	36	24			40	24	44
226	18	$\frac{3}{18}$	32	24			56	44	
227	49	$\frac{8}{49}$	30	56	64	28	72		
228	18	$\frac{3}{18}$	32	24			48	44	
229	18	$\frac{3}{18}$	32	24			44	48	
230	23	$\frac{4}{23}$	34						
231	18	$\frac{3}{18}$	32	32			48	44	
232	29	$\frac{5}{29}$	33						
233	18	$\frac{3}{18}$	32	48			56	44	
234	18	$\frac{3}{18}$	32	24			24	56	
235	47	$\frac{8}{47}$	32						
236	18	$\frac{3}{18}$	32	48			32	44	
237	18	$\frac{3}{18}$	32	48			24	44	
238	18	$\frac{3}{18}$	32	72			24	44	
239	18	$\frac{3}{18}$	32	72	24	64	32		
240	18	$\frac{3}{18}$	32						
241	18	$\frac{3}{18}$	32	72	24	64	32		24
242	18	$\frac{3}{18}$	32	72			24	24	44
243	18	$\frac{3}{18}$	32	64			32	24	44
244	18	$\frac{3}{18}$	32	48			32	24	44

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
245	49	$\frac{8}{49}$	30						
246	18	$\frac{3}{18}$	32	24			24	24	44
247	18	$\frac{3}{18}$	32	48			56	24	44
248	31	$\frac{5}{31}$	31						
249	18	$\frac{3}{18}$	32	32			48	24	44
250	18	$\frac{3}{18}$	32	24			40	24	44
251	18	$\frac{3}{18}$	32	48	44	32	64		24
252	18	$\frac{3}{18}$	32	24			48	24	44
253	33	$\frac{5}{33}$	29	24			40	56	
254	18	$\frac{3}{18}$	32	24			56	24	44
255	18	$\frac{3}{18}$	32	48	40	24	72		24
256	18	$\frac{3}{18}$	32	24			64	24	44
257	49	$\frac{8}{49}$	30	56	48	28	64		24
258	43	$\frac{7}{43}$	31	32			64	24	44
259	49	$\frac{7}{49}$	26	24			72	44	
	21	$\frac{3}{21}$	28	24			72	44	
260	39	$\frac{6}{39}$	29						
261	29	$\frac{4}{29}$	26	48	64	24	72		
262	20	$\frac{3}{20}$	28	40			28	44	
263	49	$\frac{8}{49}$	30	56	64	28	72		24
264	33	$\frac{5}{33}$	29						
265	49	$\frac{7}{49}$	26	56	40	24	72		
	21	$\frac{3}{21}$	28	56	40	24	72		
266	49	$\frac{7}{49}$	26	32			64	44	
	21	$\frac{3}{21}$	28	32			64	44	
267	27	$\frac{4}{27}$	28	72			32	44	
268	49	$\frac{7}{49}$	26	28			48	44	
	21	$\frac{3}{21}$	28	28			48	44	
269	20	$\frac{3}{20}$	28	64	32	40	28		24
270	27	$\frac{4}{27}$	28						

TABLE NO. 1.—Continued.

INDEX TABLE 271 to 310

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole	Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
271	49	7/49	26	56			72	24		287	49	7/49	26	24			24	24	44
	21	3/21	28	56			72	24			21	3/21	28	24			24	24	44
272	49	7/49	26	56			64	24		288	49	7/49	26	28			32	24	44
	21	3/21	28	56			64	24			21	3/21	28	28			32	24	44
273	49	7/49	26	24			24	56		289	49	7/49	26	56	24	24	72		24
	21	3/21	28	24			24	56			21	3/21	28	56	24	24	72		24
274	49	7/49	26	56			48	44		290	29	4/29	26						
	21	3/21	28	56			48	44		291	15	2/15	25	40			48	44	
275	49	7/49	26	56			40	44		292	49	7/49	26	28			48	24	44
	21	3/21	28	56			40	44			21	3/21	28	28			48	24	44
276	49	7/49	26	56			32	44		293	15	2/15	25	48	32	40	56		
	21	3/21	28	56			32	44		294	49	7/49	26	24			48	24	44
277	49	7/49	26	56			24	44			21	3/21	28	24			48	24	44
	21	3/21	28	56			24	44		295	15	2/15	25	48			32	44	
278	49	7/49	26	56	32	48	24			296	37	5/37	26						
	21	3/21	28	56	32	48	24			297	33	4/33	23	28	48	24	56		
279	27	4/27	28	24			32	24	44	298	49	7/49	26	28			72	24	44
280	49	7/49	26								21	3/21	28	28			72	24	44
	21	3/21	28							299	23	3/23	25	24			24	56	
281	49	7/49	26	72	24	56	24		24	300	15	2/15	25						
	21	3/21	28	72	24	56	24		24	301	43	6/43	26	24			48	24	44
282	43	6/43	26	86	24	24	56			302	16	2/16	24	32			72	24	
283	49	7/49	26	56			24	24	44	303	15	2/15	25	72	24	40	48		24
	21	3/21	28	56			24	24	44	304	16	2/16	24	24			48	44	
284	49	7/49	26	56			32	24	44	305	15	2/15	25	48			32	24	44
	21	3/21	28	56			32	24	44	306	15	2/15	25	40			32	24	44
285	49	7/49	26	56			40	24	44	307	15	2/15	25	72	48	40	56		24
	21	3/21	28	56			40	24	44	308	16	2/16	24	32			48	44	
286	49	7/49	26	56			48	24	44	309	15	2/15	25	40			48	24	44
	21	3/21	28	56			48	24	44	310	31	4/31	24						

TABLE No. 1.—Continued.

INDEX TABLE 311 to 355

NUMBER OF DIVISIONS	INDEX CIRCLE	No. OF TURNS OF INDEX	GRADUATION	GEAR ON WORM	No. 1 HOLE		GEAR ON SPINDLE	IDLERS		NUMBER OF DIVISIONS	INDEX CIRCLE	No. OF TURNS OF INDEX	GRADUATION	GEAR ON WORM	No. 1 HOLE		GEAR ON SPINDLE	IDLERS	
					1ST GEAR ON STUD	2ND GEAR ON STUD		No. 1 HOLE	No. 2 HOLE						1ST GEAR ON STUD	2ND GEAR ON STUD		No. 1 HOLE	No. 2 HOLE
311	16	2/16	24	64	24	24	72			339	27	3/27	21	24			56	44	
312	39	5/39	24								18	2/18	21	24			56	44	
313	16	2/16	24	32			28	56		340	17	2/17	22						
314	16	2/16	24	32			24	56		341	43	5/43	21	86	24	32	40		
315	16	2/16	24	64			40	24		342	27	3/27	21	32			64	44	
316	16	2/16	24	64			32	44			18	2/18	21	32			64	44	
317	16	2/16	24	64			24	44		343	15	2/15	25	40	64	24	86		24
318	16	2/16	24	56	28	48	24			344	43	5/43	21						
319	29	4/29	26	48	64	24	72		24	345	27	3/27	21	24			40	56	
320	16	2/16	24								18	2/18	21	24			40	56	
321	16	2/16	24	72	24	64	24		24	346	27	3/27	21	72	56	32	64		
322	23	3/23	25	32			64	24	44		18	2/18	21	72	56	32	64		
323	16	2/16	24	64			24	24	44	347	43	5/43	21	86	24	32	40		24
324	16	2/16	24	64			32	24	44	348	27	3/27	21	24			32	56	
325	16	2/16	24	64			40	24	44		18	2/18	21	24			32	56	
326	16	2/16	24	32			24	24	44	349	27	3/27	21	72	44	24	48		
327	16	2/16	24	32			28	24	44		18	2/18	21	72	44	24	48		
328	41	5/41	23							350	27	3/27	21	72	40	32	64		
329	16	2/16	24	64	24	24	72		24		18	2/18	21	72	40	32	64		
330	33	4/33	23							351	27	3/27	21	24			24	56	
331	16	2/16	24	64	44	24	48		24		18	2/18	21	24			24	56	
332	16	2/16	24	32			48	24	44	352	27	3/27	21	72	24	24	64		
333	27	3/27	21	24			72	44			18	2/18	21	72	24	24	64		
	18	2/18	21	24			72	44		353	27	3/27	21	72	24	24	56		
334	16	2/16	24	32			56	24	44		18	2/18	21	72	24	24	56		
335	33	4/33	23	72	48	44	40		24	354	27	3/27	21	72			48	24	
336	16	2/16	24	32			64	24	44		18	2/18	21	72			48	24	
337	43	5/43	21	86	40	32	56			355	27	3/27	21	72			40	24	
338	16	2/16	24	32			72	24	44		18	2/18	21	72			40	24	

TABLE No. 1.—Continued.

INDEX TABLE 356 to 399.

Number of Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole: 1st Gear on Stud	No. 1 Hole: 2nd Gear on Stud	Gear on Spindle	Idlers: No. 1 Hole	Idlers: No. 2 Hole
356	27	3/27	21	72			32	24	
	18	2/18	21	72			32	24	
357	27	3/27	21	72			24	44	
	18	2/18	21	72			24	44	
358	27	3/27	21	72	32	48	24		
	18	2/18	21	72	32	48	24		
359	43	5/43	21	86	48	32	100		24
360	27	3/27	21						
	18	2/18	21						
361	19	2/19	19	32			64	44	
362	27	3/27	21	72	28	56	32		24
	18	2/18	21	72	28	56	32		24
363	27	3/27	21	72			24	24	44
	18	2/18	21	72			24	24	44
364	27	3/27	21	72			32	24	44
	18	2/18	21	72			32	24	44
365	20	2/20	18	32	48	24	56		
366	27	3/27	21	48			32	24	44
	18	2/18	21	48			32	24	44
367	27	3/27	21	72	24	24	56		24
	18	2/18	21	72	24	24	56		24
368	27	3/27	21	72	24	24	64		24
	18	2/18	21	72	24	24	64		24
369	41	4/41	18	32	56	28	64		
370	37	4/37	20						
371	21	2/21	18	32	56	24	64		
372	27	3/27	21	48			64	24	44
	18	2/18	21	48			64	24	44
373	20	2/20	18	40	48	32	72		
374	27	3/27	21	72	56	32	64		24
	18	2/18	21	72	56	32	64		24
375	27	3/27	21	24			40	24	44
	18	2/18	21	24			40	24	44
376	47	5/47	19						
377	29	3/29	19	24			24	56	
378	27	3/27	21	32			64	24	44
	18	2/18	21	32			64	24	44
379	20	2/20	18	48	56	40	72		
380	19	2/19	19						
381	27	3/27	21	24			56	24	44
	18	2/18	21	24			56	24	44
382	20	2/20	18	40			72	24	
383	20	2/20	18	40			68*		
384	20	2/20	18	40			64	44	
385	20	2/20	18	32			48	44	
386	20	2/20	18	40			56	44	
387	43	4/43	15	32	56	28	64		
388	20	2/20	18	40			48	44	
389	20	2/20	18	40			44	56	
390	39	4/39	17						
391	20	2/20	18	48	24	40	72		
392	49	5/49	16						
393	20	2/20	18	40			28	44	
394	20	2/20	18	40			24	56	
395	20	2/20	18	64			32	44	
396	20	2/20	18	56	28	40	32		
397	20	2/20	18	64	24	40	32		
398	20	2/20	18	100	40	64	32		
399	21	2/21	18	32			64	44	

* SPECIAL GEAR.

TABLE NO. 1.—Continued.

Brown & Sharpe spiral head. With the addition of the change gears furnished, divisions obtained by plain indexing together with those that cannot be obtained by that method, from 1 to 382, and many others beyond, can be indexed by the differential method. While the tables given on pages 121 to 129 enable the head to be set up at once for the desired number of divisions, it is desirable to understand the general principles involved in calculating for a given number of divisions. The above company gives the following explanation of plain and direct indexing:

PLAIN AND DIRECT INDEXING

Plain indexing on the spiral head is very similar to indexing with ordinary index centers. It depends entirely upon how many times the index crank must be turned to cause the work to make one revolution. When this ratio is known, it is an easy matter to calculate the number of turns or fractions of a turn of the index crank to produce a given number of spaces on the periphery of the work.

The worm wheel on the spindle contains 40 teeth and the worm is single threaded, hence for every turn of the index crank, the worm wheel is advanced one tooth, or the spindle makes $^1/_{40}$ part of a revolution. This should be remembered, for it is used in all indexing calculations on the spiral head. If the crank is turned 40 times, the spindle and work will make one complete revolution. To find how many turns of the crank are necessary for a certain division of the work, 40 is divided by the number of the divisions which are desired. The quotient will be the number of turns, or the part of a turn of the crank, which will give each desired division. Applying this rule, 40 divisions would be made by turning the crank completely around once for each division, or 20 divisions would be obtained by turning around twice. When the quotient contains a fraction, or is a fraction, it will be necessary to give the crank a part revolution in indexing. The numerator of the fraction represents the number of holes that should be indexed for each division. If the fraction is so small that none of the plates contains the number of holes represented by the denominator, both numerator and denominator should be multiplied by a common multiplier that will give a fraction, the denominator of which represents a number of holes that is available. On the other hand, if the fraction is of large terms, it should be reduced so that its denominator will represent a number of holes that is available. For example, seven divisions are desired. 40 divided by 7, equals $5^5/_7$ turns of the index crank to each division. There is no plate containing so few holes as 7, so this should be raised. Multiplying by the common multiplier 3, we have $^5/_7 \times ^3/_3 = ^{15}/_{21}$. Hence, for one division of the work, the index crank pin is placed in the 21 hole circle, and the crank is given 5 complete revolutions and then is moved ahead 15 additional holes. 35 holes in the 49 hole circle might also be used in place of 15 in the 21 hole circle, as $^{35}/_{49}$ is a multiple of the original fraction $^5/_7$.

The table on page 121 gives the correct circles of holes and numbers to index for each division of all numbers that are obtainable by plain indexing as well as those obtainable by the differential method, up to 400.

INDEXING IN DEGREES

When it is desired to divide the circumference of a piece of work in degree or fractions of degrees, it can often be done by plain indexing. One complete turn of the index crank produces $^1/_{40}$ of a turn or $\frac{360}{40}° = 9$ degrees. Then following this method

2 holes in the 18 hole circle $= 1$ degree

2 holes in the 27 hole circle $= \frac{2}{3}$ degree

1 hole in the 18 hole circle $= \frac{1}{2}$ degree

1 hole in the 27 hole circle $= \frac{1}{3}$ degree

Other odd fractional parts of a degree can be easily found by dividing the number of holes in any given circle into 9 degrees. It will be noticed that ¼ degree spacing cannot be obtained in this way, but with differential indexing it is easy to get ¼ degree and other fractional spacings.

DIFFERENTIAL INDEXING

Differential indexing enables a wide range of divisions to be indexed which cannot be obtained by plain indexing. With the differential method, the index crank is moved in the same circle of holes, and the operation is like that of plain indexing. The spiral head spindle and index plate are connected by a train of gearing as shown in Fig. 31, and the stop pin at the back of the plate is thrown out. As the index crank is turned, the spindle is rotated through the worm and wheel and the plate moves either in the same or opposite direction to that of the crank. The total movement of the crank at every indexing is, therefore, equal to its movement relative to the plate, plus the movement of the plate, when the plate revolves in the same direction as the crank, or minus the movement of the plate, when the plate revolves in the opposite direction to the crank. The spiral head cannot be used for cutting spirals when it is geared for differential indexing, for when cutting spirals, the head is geared to the table feed screw.

The index tables referred to make it unnecessary to figure out the change gears whenever a certain number of divisions is required. These tables cover all numbers up to 400 as obtained either by differential or plain indexing, together with the correct circle and number of holes to be indexed, graduations for setting the index sector, and the proper change gears to use. These numbers as covered in the present tables provide for a very wide range of work but occasionally

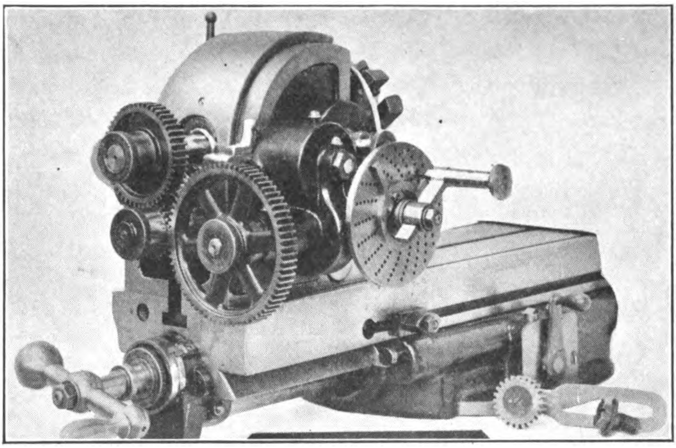


FIG. 31.—Spiral head geared for differential indexing.

even higher numbers of divisions are desired. In the "American Machinists Hand Book," tables will be found extended to cover indexing of much higher numbers of divisions and the reader is referred to this book for the settings for such high numbers, as well as for detailed explanation of the methods of figuring the gears for differential indexing of any given number.

EXAMPLES OF DIFFERENTIAL INDEXING

Two concrete illustrations of this method of indexing are shown in Figs. 32 and 33. The first of these illustrates the spiral head as geared for 271 divisions, the other shows the head geared for 391 divisions. The head in Fig. 32 is set up with simple gearing for 271 divisions. Referring to the table on page 127, the gears called for 271 divisions are: *C*, 56 teeth and *E*, 72 teeth, with one idler *D*. The idler serves to rotate the index plate in the same direction as the crank, thus in making 280 turns of the crank, nine divisions are lost, giving the correct number of divisions, 271. The sector should be set

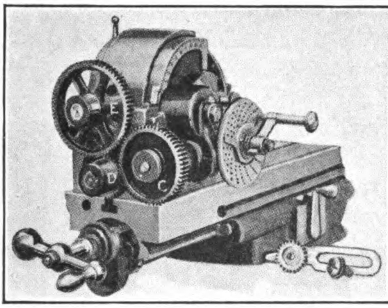


FIG. 32.—Head geared for 271 divisions.

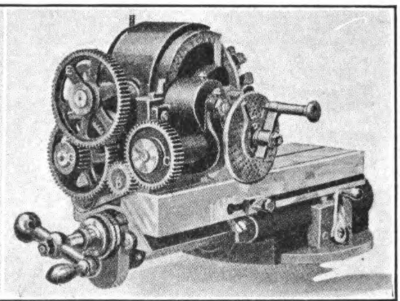


FIG. 33.—Head geared for 319 divisions.

to indicate $^1/_7$ turns, or 3 holes in the 21 hole circle, and the head is ready for 271 divisions, the indexing being done the same as for plain indexing.

In Fig. 33 the head is set up with compound gearing for 319 divisions.

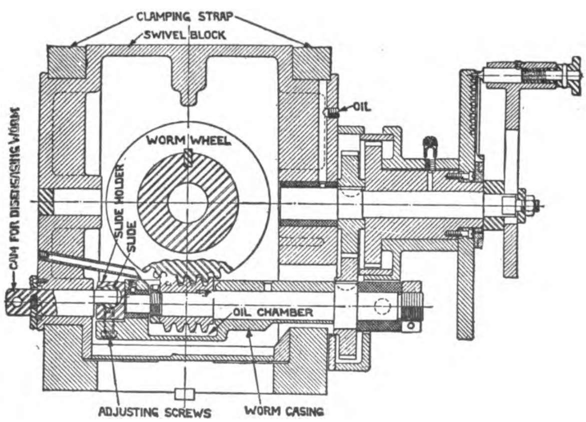


FIG. 34.—Cross section through Cincinnati dividing head.

Referring to the table on page 128, the gears called for are as follows: *C*, 48 teeth; *F*, 64 teeth; *G*, 24 teeth; *E*, 72 teeth, and one idler, *D*, 24 teeth. The sector should be set to $^4/_{29}$ turns, or 4 holes in the 29 hole circle. The head is now ready for 319 divisions.

INDEXING FOR 1/4 AND 1/6 DEGREES

The table herewith shows the gearing for spacing $^1/_4$ and $^1/_6$ degrees. Other fractional degree indexing is given under the explanation of plain indexing.

Divisions	Index Circle	No. of Turns of Index	Graduation	Gear on Worm	No. 1 Hole		Gear on Spindle	Idlers	
					First Gear on Stud	Second Gear on Stud		No. 1 Hole	No. 2 Hole
$\frac{1}{6}°$	49	$\frac{1}{49}$	...	28	64	56	100	...	24
$\frac{1}{4}°$	33	$\frac{1}{33}$	...	44	64	40	100	...	24

ANOTHER DESIGN OF DIVIDING HEAD

The Cincinnati Milling Machine Company's universal dividing head is illustrated by the sectional views in Figs. 34, 35 and 36 which show clearly the essential features of construction, including the worm wheel and worm for operating the spindle; the cam for disengaging the worm so that the spindle may be indexed direct by the front plate; the gearing connecting the worm shaft and index crank; the method of mounting the side index plate; the provision for clamping the spindle; etc. The spindle clamps consist as shown in Fig. 36, of a split ring *C* which is spread by the wedge *B* by tightening the screw *A*, thus clamping the spindle securely endwise.

The front plate has three circles of holes, namely 24, 30 and 36. It will therefore index any number that divides evenly into any one of these. For universal indexing, that is, indexing by means of the crank pin and index plate at the side of the head, there is a single plate which is drilled on both sides and reversible. This plate is $8^{13}/_{16}$ inches in diameter and owing to its large size has space for many circles of holes with a large number of holes in each circle, so that a wide range of indexing can be done from the one plate. The divisions obtainable with the plate include all numbers, odd and even up to 60, even numbers and those divisible by 5 up to 120, and many useful divisions beyond these. Additional divisions are possible by means of a high number indexing attachment consisting of three plates of the same size and interchangeable with the regular index plate. These will index all numbers up to and including 200, all even and those divisible by 5 up to 400, except 225, 275, 325 and 375. The indexing in all cases is simple indexing direct through the plates without compounding or use of change gears.

An interesting feature of the index plate on this head is the series of fine notches around the periphery and the correspondingly notched

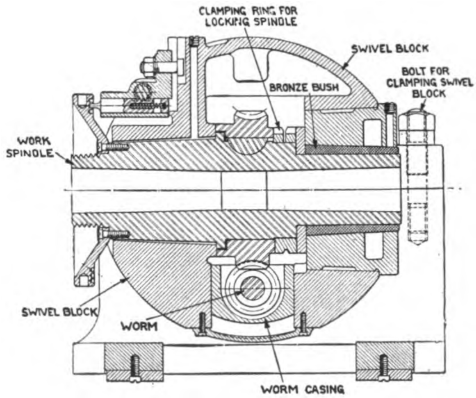


FIG. 35.—Longitudinal section through dividing head.

lock shown in Fig. 37. It often times occurs in tool and other work that a piece of work that has been milled must be put back in the machine for remilling, as in the case, say, of a tooth disk where the teeth are found to be too thick and therefore require a second cut

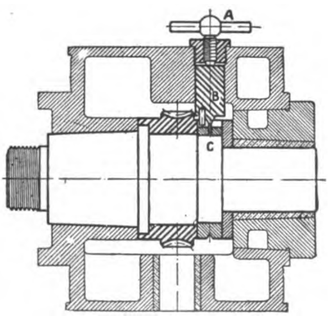


FIG. 36.—Horizontal section through dividing head.

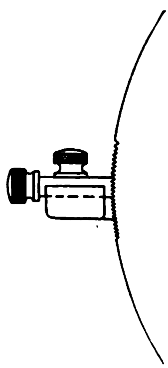


FIG. 37.—Section of index plate showing lock.

to bring them all to size. Upon placing the work back in the miller the job must be revolved a certain amount to bring the tooth space into correct position in respect to the cutter, but this cannot be done by indexing for when the work is in the proper relation to the cutter the index pin will come somewhere between two holes in the index plate. But with the notched plate and the lock referred to, by releasing the lock and holding the index pin stationary, the plate can be revolved until one of the holes coincides with the pin. The plate can then be locked again, by the lock entering another set of notches. The device is similarly serviceable with numerous other classes of work where it is necessary to reset the piece after a cut has been made around the work, as for example, in remilling slots that require to be recut to a deeper dimension; or again in bevel gear cutting when the blank is revolved toward the center after the offset has been made, the index pin will naturally fall between two holes and by revolving the index plate as above, one of the holes can be brought around to the pin.

The translation of the value of the notches into thousandths of an inch movement upon the part of the work is also of importance in connection with certain kinds of work handled upon the dividing head. That is, the movement of one notch past the lock corresponds to a peripheral movement of 0.00017 inch on a piece of work 1 inch in diameter. Thus a piece 5 inches diameter would be revolved toward the cutter 5 times 0.00017 or 0.00085 inch and a ten-inch piece would revolve 0.0017 and so on.

CHAPTER IV

CUTTING SPIRALS ON THE MILLING MACHINE

Among the important operations performed with the aid of the spiral head are the milling of spiral fluted cutters and reamers, the cutting of spiral gears, the fluting of twist drills, the milling of cams, etc. These are a few of the numerous lines of work which are readily accomplished with this milling machine appliance.

The selection of change gears for the spiral head is similar in principle to the finding of change gears for cutting threads on the engine lathe. With the spiral head, as explained in the preceding chapter, forty turns of the worm accomplishes one turn of the spiral head spindle; and as the table feed screw is cut four threads to the inch, if equal change gears are used the work will be rotated through one complete turn while it is moved lengthwise ten inches, so that the spiral cut in the work will have a lead of ten inches. This lead then as obtained with equal diameter gears is the lead of the miller.

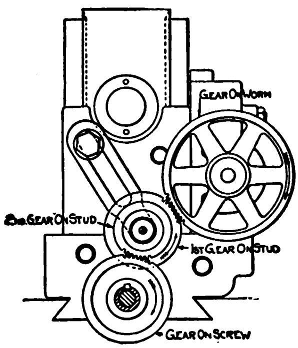


FIG. 38.—Showing gearing when idler is required.

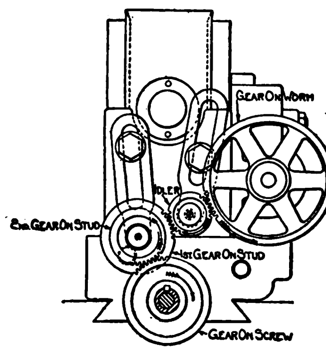


FIG. 39.—Showing gearing with idler in use.

Referring now to Figs. 38 and 39 which show the gearing at the back of the Brown & Sharpe spiral head, the four change gears are called Gear on Screw, First Gear on Stud, Second Gear on Stud, and Gear on Worm. The Gear on Screw and the First Gear on Stud are the drivers and the Second Gear on Stud and the Gear on Worm are the driven gears. These change gears as selected from the set supplied with the miller govern the ratio of table movement to the rotation of the work and thus control the lead of the spiral to be cut just as the change gears on a lathe give the desired lead for the cutting of a given thread.

It wil be understood from the views Figs. 38 and 39 that the gears are compounded; and the compound ratio of driven to driving gears equals in every case the ratio of the lead of the desired spiral to the lead of the machine itself. As stated above, gears of the same size give a spiral with a lead of 10 inches, or the same as the lead of the miller. Using three gears of equal diameter and a driven gear twice this size a spiral is produced having a lead double that of the machine or 20 inches. If both of the driven gears are twice as large as the drivers the spiral cut has a lead four times that of the machine, or 40 inches. Or if we reverse these conditions and use driving gears twice the diameter of the driven gears we cut a spiral of 2½ inches lead or ¼ the lead of the machine.

We may express the ratio as follows:

$$\frac{\text{Product of Driven Gears}}{\text{Product of Driving Gears}}=\frac{\text{Lead of Required Spiral.}}{10}$$

Or we may express the ratio if preferred as

$$\frac{\text{Lead}}{10}=\frac{\text{Driven Gears}}{\text{Driving Gears}}=\frac{\text{2d}\times\text{Worm}}{\text{1st}\times\text{Screw}}$$

While the tables in this chapter give the gears for cutting practically all the leads likely to be required, it may be of interest to consider briefly the methods of finding the gears by calculation. First, suppose we desire to find the ratio of the gears required to cut a certain spiral: Note the ratio of the desired lead to 10; this is the compound ratio of the driven gears to the drivers. Thus, if we wish to cut a lead of 24 inches the ratio of the gears will be 24 to 10. Having this ratio we now find the number of teeth in the gears for cutting the given spiral by resolving this fraction of $^{24}/_{10}$ into two factors and then raising these factors to higher terms corresponding with the teeth of gears that are available for the work. Thus,

$$\frac{24}{10}=\frac{3}{2}\times\frac{8}{5}=\left(\frac{3}{2}\times\frac{24}{24}\right)\times\left(\frac{8}{5}\times\frac{8}{8}\right)=\frac{72}{48}\times\frac{64}{40}$$

As the numerator of the fractional expression of the ratio represents the driven gears and the denominator the driving gears, the two gears 72 and 64 are the driven gears and 48 and 40 the drivers. The driven gears can of course be transposed one with another and so also can the drivers; drivers and driven however cannot be substituted one for the other. The order in which the drivers or the driven gears are placed in the compound train of the miller does not effect the lead mathematically but in actual practice it will be found that with many sizes of gears there may be interference, so the tables beginning on page 195 are of especial value as they show at a glance the location of each gear in any combination for the desired lead.

THE ANGULAR SETTING OF TABLE

In setting the miller to cut a spiral it is necessary to swing the table around to a definite angle corresponding to the angle of helix

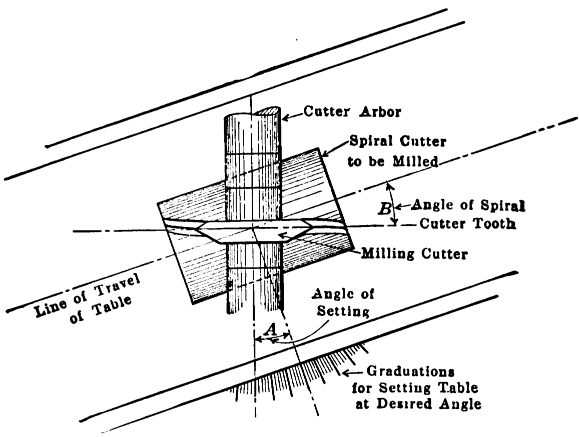


FIG. 40.—Set-up for spiral milling.

of the lead as formed around the circumference of the work. That is the table is set around to the angle necessary to bring the spiral in line with the cutter. Thus in Fig. 40 a set up is shown for milling the teeth in a spiral cutter with the table swung around to the proper

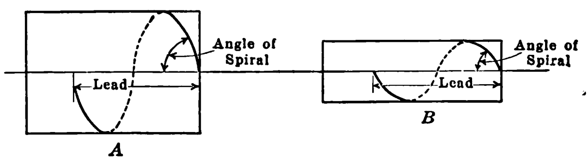


FIG. 41.—Effect of diameter upon angle of spiral.

angle as represented by the graduations at the front, angle *A* of course being equivalent to angle *B* which is the angle of the spiral to which the cutter teeth are milled.

This angle of spiral will obviously depend upon the lead of the spiral and the diameter of the work. The effect of different diameters with any given lead of spiral is indicated by Figs. 41 and 42 where piece *A* has a diameter twice that of piece *B*, the lead of spiral around the surface of the two being uniform. In Fig. 42 the cylinder surfaces are shown developed and the difference of angle of the two oblique lines representing the spirals is clearly seen.

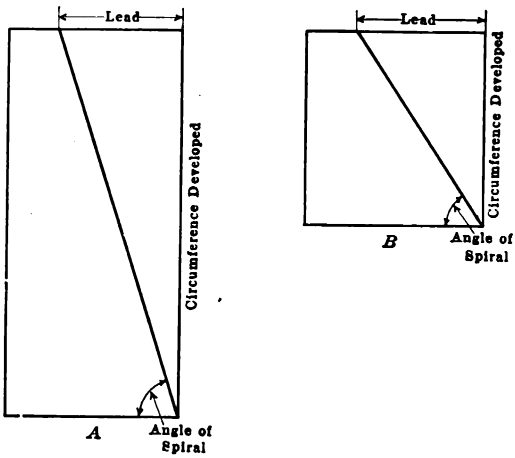
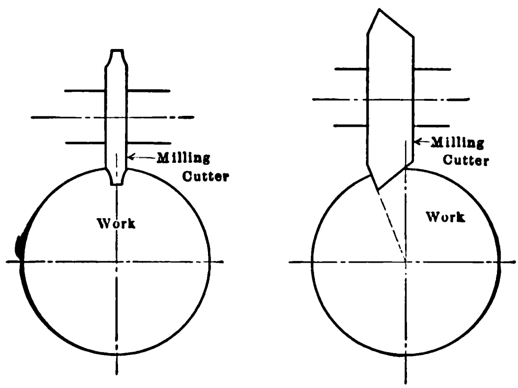


FIG. 42.—*A* and *B* of FIG. 41 developed.

Ordinarily the angular setting of the milling machine table may be taken directly from the tables on pages .... where spirals of all common leads are included with angles and gears to be used. For



FIGS. 43–44.—Setting cutters.

unusual leads of spiral a lay out can be made as in Fig. 42, with one side of the triangle representing the circumference of the work and the other side the lead of spiral. The hypothenuse or sloping side connecting the other sides completes the triangle and if the layout is made accurately the angle can be measured directly with a protractor to a sufficient degree of accuracy for all ordinary work. A more precise method however is to compute the angle which is accomplished by dividing the circumference of the piece by the lead of spiral to obtain the tangent of the angle and then find the angle by referring to a table of tangents such as is given in the "American Machinists' Handbook."

Where spiral cuts are made which are the same on each side of the cutter is in the case of spiral gears, etc., Fig. 43, the work must be set centrally up and down with the cutter center line before the saddle is adjusted to the angle for the spiral cut. Spiral milling cutters, spiral reamers and other work having one radial face for the teeth are usually milled with a cutter such as shown by Fig. 44 as the angular face of the cutter for milling the face of the tooth readily clears the work face and gives smooth results.

In cutting left hand spirals the saddle is swung around to the opposite side of the center line and an intermediate gear is placed upon the stud on the spiral head to mesh with the change gears and so change the direction of rotation of the spindle in the spiral head.

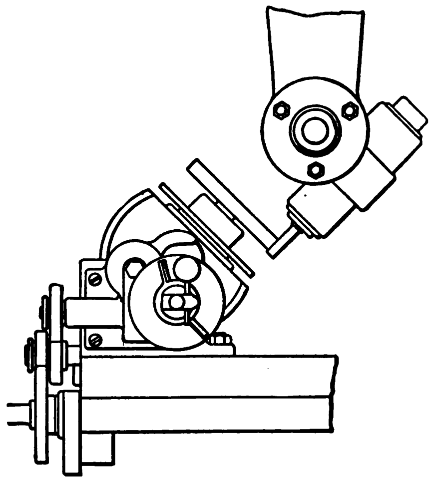


FIG. 45.—Milling a screw machine cam.

MILLING CAMS ON THE SPIRAL HEAD

Another important use of the spiral head is found in connection with the milling of cams for screw machines and other purposes. A cam for a screw machine is shown in place on the miller in Fig. 45 where the edge is being milled with an end mill carried by a vertical spindle attachment. Cams of any desired rise or lead may be milled in this manner. The principle is as follows: If the dividing head were set vertically the lead of the cam thus milled would of course be the same as the lead to which the machine is geared; if the dividing head were set horizontally and the vertical spindle attachment set the same, the edge of the cam would be milled in a true circle, as the work would merely rotate in a circular path while at the same time it would feed under the horizontal cutter and thus the operation would be a rotary milling one. But with the dividing head set at an angle between vertical and horizontal and the cutter spindle set to correspond, there will be a lead milled on the cam periphery coming somewhere between zero and the lead to which the machine is geared. Each lead of cam must therefore require a certain angular setting the exact degree of which can be worked out by simple calculation. This is however unnecessary as complete tables have been compiled to cover all ordinary leads, and these will be found in the "American Machinists' Handbook" with full explanation of the method of following the calculation. Lack of space makes it impossible to reproduce the tables in the present volume.

CHAPTER V

SOME MILLING MACHINE ATTACHMENTS

In addition to the universal dividing head or spiral head which has been described in preceding chapters, there are many other useful appliances used on the milling machine and a few of the more important of these will be shown briefly in the present chapter.

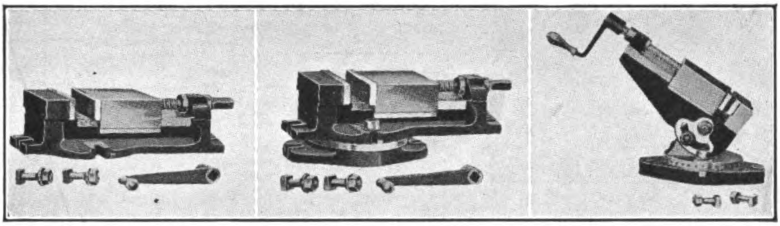


FIG. 46 FIG. 47 FIG. 48

FIGS. 46–48.—Milling machine vises.

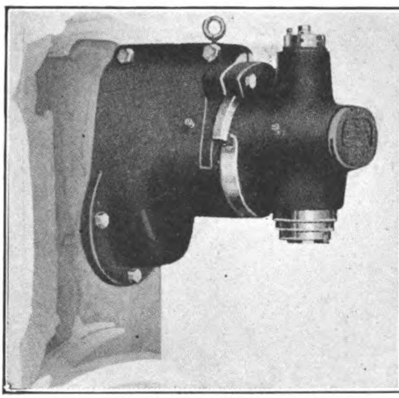


FIG. 49.—Vertical attachment.

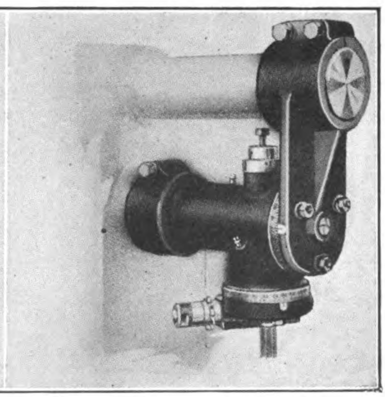


FIG. 50.—Universal milling attachment.

Figures 46, 47, and 48 represent miller vises, the first being a plain vise, the second a swivel vise with graduated base, the last a tool maker's vise intended for use where angular settings are required.

In Figs. 49, 50 and 51 a number of spindle attachments are shown, these views representing only a few of the various appliances of this general character as made by different machine builders. Thus the half tone Fig. 49 shows a vertical attachment by means of which the miller with horizontal spindle may be adapted to handling work that would naturally be done on a vertical spindle machine if such

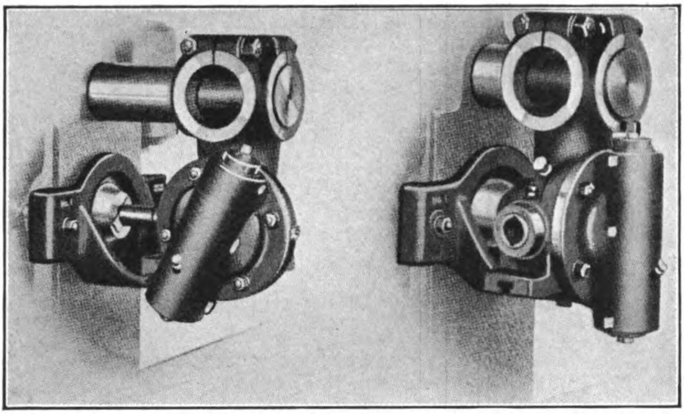


FIG. 51.—Compound vertical spindle milling attachment.

were available. The attachment in Fig. 50 is a universal appliance which can also be used as a vertical spindle attachment. In Fig. 51 a compound vertical spindle milling attachment is illustrated which is applicable to a large variety of operations as it can be set in two

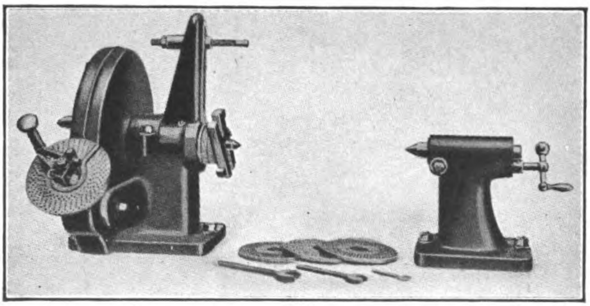


FIG. 52.—Gear-cutting attachment.

different planes. This flexibility of adjustment is indicated by the two settings represented in Fig. 51. It is of especial advantage when it is necessary to set the spindle at an angle with the table, as, for example, when milling strips with angular edges, guides, etc., for when the spindle is so set the entire length of the table travel may be used and an ordinary end mill applied in place of the angle cutter which would otherwise be required.

The illustration Fig. 52 shows a gear cutting attachment which is similar in a way to the usual index centers but which will swing spur gears for cutting, up to 16 inches diameter. This device has an extra large worm wheel thus reducing possibilities of error, and steadiness of the gear being cut is insured by the adjustable rim rest on the side of the head.

A rack cutting attachment is shown by Fig. 53 which may also be used in connection with the spiral head for cutting worms. It is

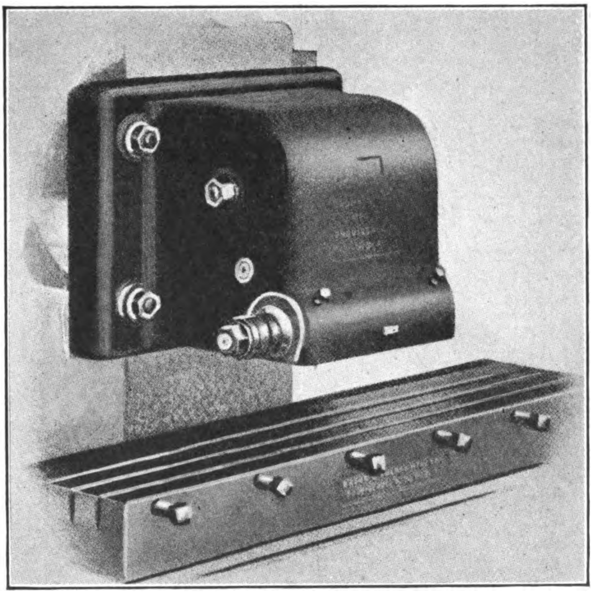


Fig. 53.—Rack-cutting attachment.

also useful for various other purposes. The cutter spindle is here carried in the head in parallel relation to the T-slots of the table. The spindle is driven from the regular machine spindle by bevel and spur gearing.

The circular milling attachment in Fig. 54 is adapted for milling circles, arcs, segments, circular slots, etc. It has a rotary table driven by power or operated by hand where desired. When it is desired to set the table quickly the worm is disengaged and the table is then turned to any position. It may be used on a vertical miller or with a vertical spindle attachment it allows the same variety of work to be machined on the horizontal spindle machine. With suitable fixtures attachments of this kind can be used for continuous milling where the table is kept constantly in operation and the workman merely removes and replaces the parts undergoing machining.

A cam cutting attachment is illustrated by Fig. 55. This will cut

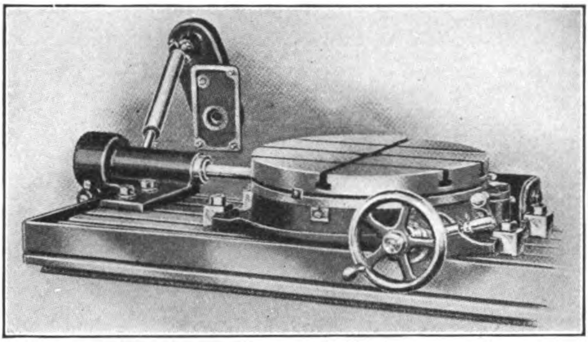


FIG. 54.—Circular-milling attachment.

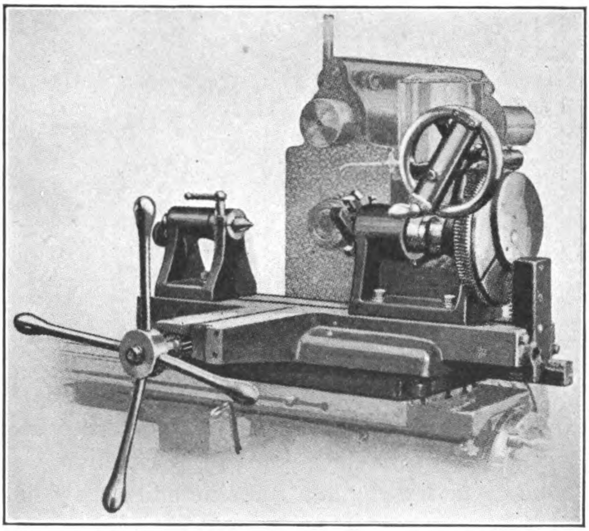


FIG. 55.—Cam-cutting attachment.

face cams, peripheral cams, or cylindrical cams from a flat former or master which is made of a disk about one half inch thick. In operation the miller table remains fixed as set, and the longitudinal and rotary movements are obtained in the attachment itself. Rotary motion is secured through a worm which drives a wheel secured to the spindle of the attachment. The former plate is attached to the worm wheel face and as the wheel revolves the former forces down a sliding rack that drives a pinion meshing with a second rack in the sliding bed of the attachment; in this way the required longitudinal movement is obtained. The attachment may be driven automatically by means of a round belt leading from a jack shaft to a three step cone pulley fastened on the end of the worm shaft.

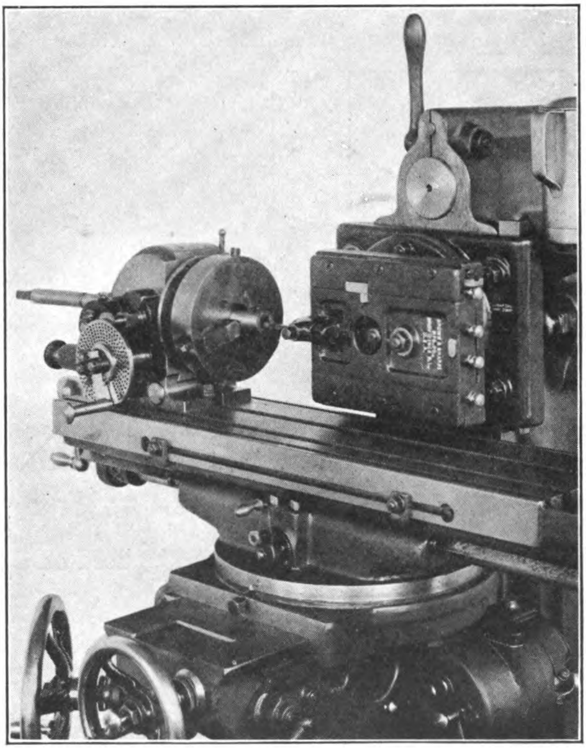


FIG. 56.—Slotting attachment.

Another attachment of interest is the slotting device in Fig. 56. This is used extensively in connection with the work of the tool room, as in working on box tools, templets, cutting keyways and so on. The tool slide is driven by an adjustable crank from the machine spindle and the stroke may be varied at will. The attachment can be set at any angle from zero to 90 degrees either side of the center line.

Two other appurtenances which may be included here are the high speed attachment, Fig. 57, and the spiral milling attachment, Fig. 58. The former attachment is of value where it is desired to use a small cutter which must be driven at a high rate of speed and for which no suitable speed is available with the regular spindle series of the machine. Such work might be found say in the sinking of dies, the cutting of small slots and keyways, etc. The high speed spindle of the attachment is driven by a set of gears from the main spindle of the miller.

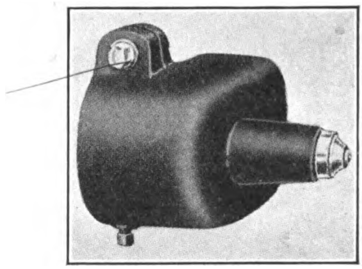


FIG. 57.—High-speed attachment.

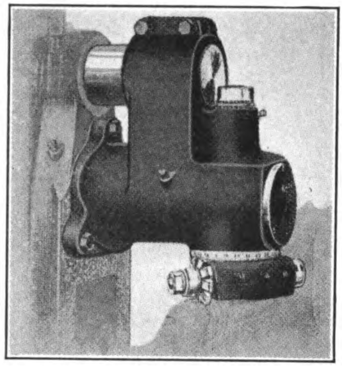


FIG. 58.—Spiral milling attachment.

The spiral milling attachment, Fig. 58, is of advantage on different classes of operations as for instance where it is required to mill short lead spirals where the angle is greater than that to which the table of the universal miller can be swiveled. Or the device can be used for such work as the cutting of racks. It can be used on a plain miller in conjunction with a dividing or spiral head.

CHAPTER VI

MILLING CUTTERS AND THEIR USES

We come now to a consideration of various types of milling cutters and some of their common applications. The line engravings, Figs. 59 to 99 inclusive, illustrate general forms of cutters and the text immediately below explains briefly the uses to which they are applied. For convenience in reference these cutters and the explanatory matter have been arranged alphabetically.

TYPES OF CUTTERS

Angular Cutters—(Figs. 59, 60, 61). Such cutters are used for milling straight and spiral mills, ratchet teeth, etc. Cutters for spiral mill grooving are commonly made with an angle of 12 degrees on one side and 40-, 48-, or 53-degree angle on the other.

Concave and Convex Cutters—(Figs. 62, 63). Concave and convex cutters are used for milling half circles. The convex cutter is often used for fluting taps and other tools. Like all other formed cutters the shape is not affected by the process of sharpening.

Corner Rounding Cutters—(Figs. 64, 65, 66). Left-hand, double and right-hand cutters of this type are used for finishing rounded corners and edges of work. The shape of the cutter is not altered by grinding on the face of the teeth.

Cotter Mill—(Fig. 67). This type of mill is used for cutting keyseats and other slots and grooves.

Dovetail Cutters—(Figs. 68, 69). Male and female dovetails are milled with these tools, and edges of work conveniently beveled.

End Mill—(Fig. 70). This mill sometimes called a butt mill, is used for machining slots, milling edges of work, cutting cams, etc. Right and left shown at 70 A and B.

End Mill (with center cut)—(Fig. 71). This end mill has clearance on the inner side of the end teeth and is adapted to cut into the work to a depth equal to the length of the end teeth and then feed along, dispensing with the necessity of first drilling a hole which has to be done when the inner sides of the teeth are not relieved.

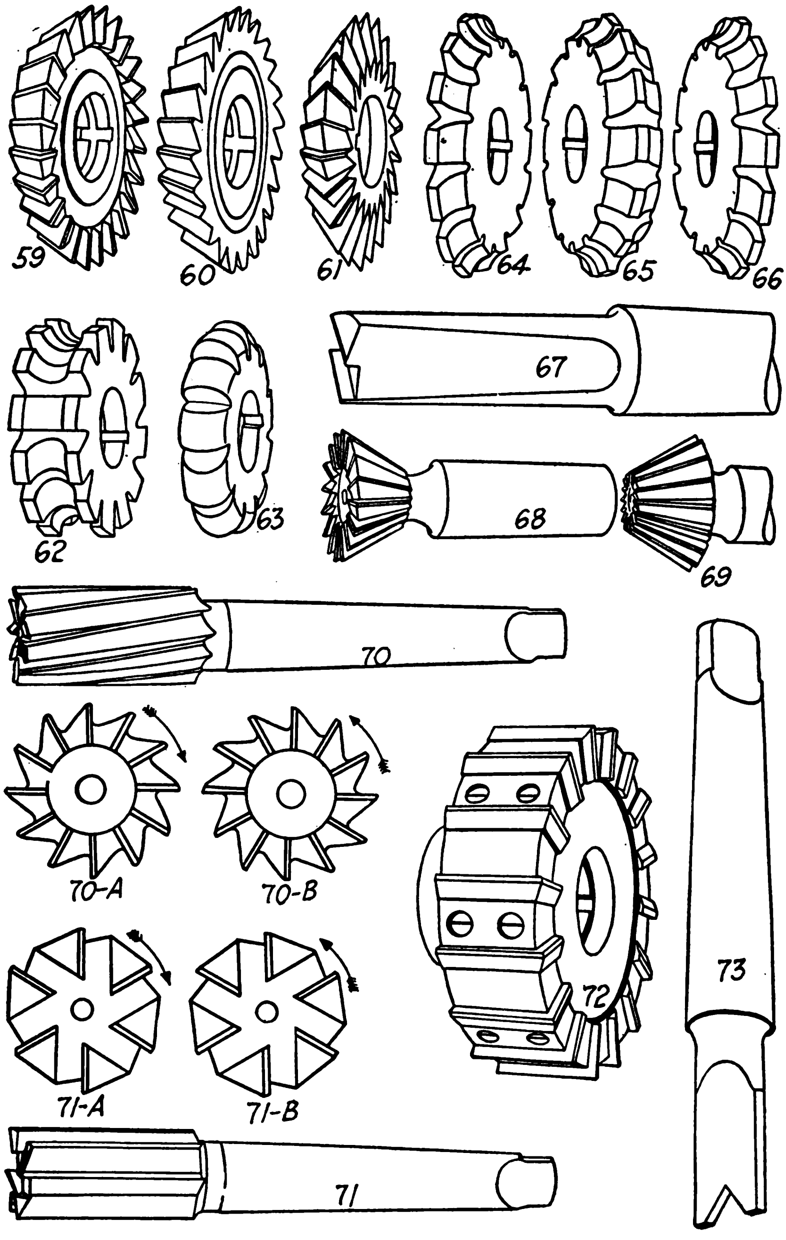
The mills are often used for heavy cuts particularly in cast iron.

Face and Formed Cutters—(Figs. 72, 78). The face cutter to the left, of Brown & Sharpe inserted tooth type is made in large sizes and cuts on the periphery and ends of teeth.

The formed cutter Fig. 78 may be sharpened by grinding on the face without changing the shape. For milling wide forms several cutters are often placed side by side in a gang.

Fish Tail Cutter—(Fig. 73). A simple cutter for milling a seat or groove in a shaft or other piece. Usually operated at rapid speed and light cut and feed.

Fluting Cutters—(Figs. 74, 75, 76). Fig. 74 is an angular mill for cutting the teeth in spiral mills, Fig. 76 is for tap fluting and Fig. 75 for milling reamer flutes. In each case the cutter is shown with one face set radial to the center of the work.



FIGS. 59–73.—Types of milling cutters.

Fly Cutters—(Fig. 77). Fly cutters are simple formed cutters which may be held in an arbor like that shown at the top of the group. The arbor is placed in the miller spindle and the tool or other work to be formed is given a slow feed past the revolving cutter. After roughing out, the cutter can be held stationary and used like a planer tool for finishing the work which is fed past it and so given a scraping cut.

Gang Cutters—(Fig. 79). Cutters are used in a gang on an arbor for milling a broad surface of any desired form. The cutters shown have interlocking and overlapping teeth so that proper spacing may be maintained. In extensive manufacturing operation the gangs of cutters are usually kept set up on their arbor and never removed except for grinding.

Gear Cutter (Involute)—(Fig. 80). In the Brown & Sharpe system of involute gear cutters, eight cutters are regularly made for each pitch, as follows:

No. 1 will cut wheels from 135 teeth to a rack.
No. 2 will cut wheels from 55 teeth to 134 teeth.
No. 3 will cut wheels from 35 teeth to 54 teeth.
No. 4 will cut wheels from 26 teeth to 34 teeth.
No. 5 will cut wheels from 21 teeth to 25 teeth.
No. 6 will cut wheels from 17 teeth to 20 teeth.
No. 7 will cut wheels from 14 teeth to 16 teeth.
No. 8 will cut wheels from 12 teeth to 13 teeth.

Such cutters are always accurately formed and can be sharpened without affecting the shape of the teeth.

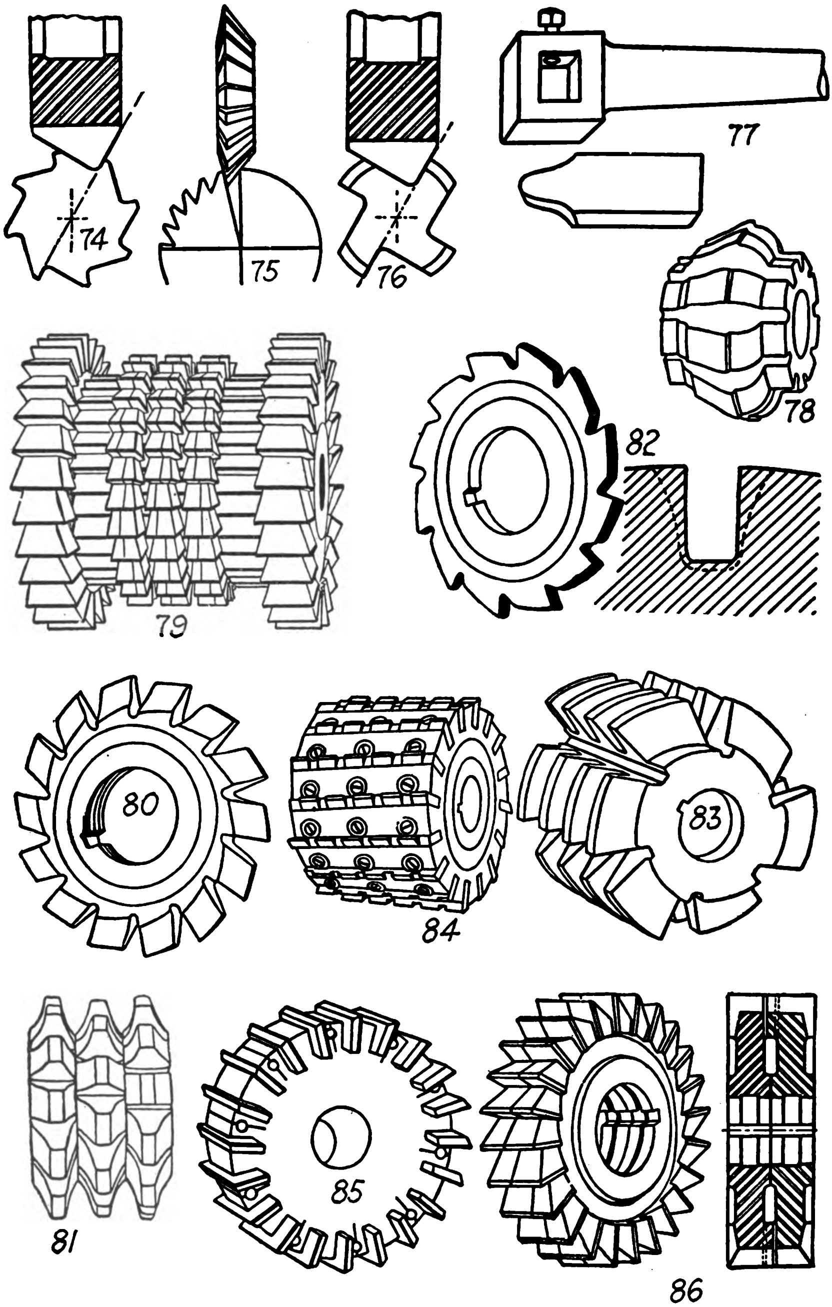
Gear Cutters, Duplex—(Fig. 81). The Gould & Eberhart duplex cutters are used in gangs of two or more, the number of cutters in the gang depending on the number of teeth in the gear to be cut. The following table gives the number of cutters which may be used in cutting different numbers of teeth:

Under	30 teeth	1 cutter
Under	30 teeth	2 cutters
Over	50 teeth	3 cutters
Over	70 teeth	4 cutters
Over	95 teeth	5 cutters
Over	120 teeth	6 cutters
Over	150 teeth	7 cutters
Over	180 teeth	8 cutters
Over	230 teeth	10 cutters
Over	260 teeth	12 cutters.

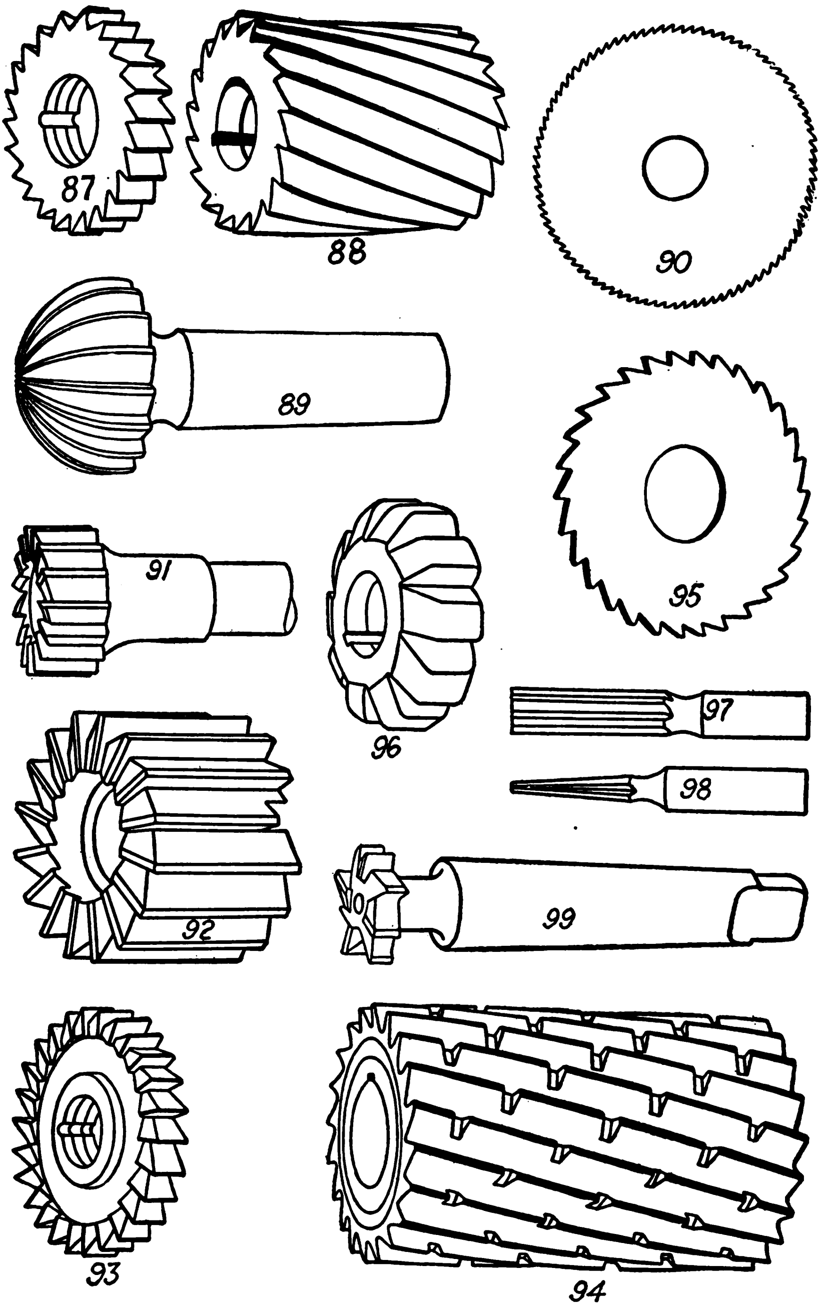
Gear Stocking Cutter—(Fig. 82). The object of stocking cutters is to rough out the teeth in gears, leaving a smaller amount of metal to be removed by the finishing cutter. They increase the accuracy with which gears may be cut, and save the finishing cutter as well.

In all cases where accuracy and smooth running are necessary the gears should first be roughed out. One stocking cutter answers for all gears of the same pitch.

Hob—(Fig. 83). A form of milling cutter with teeth spirally arranged like a thread on a screw and with flutes to give cutting edges as indicated. Used for cutting the teeth of worm gears to suit the worm which is to operate the gear. Hobs are formed and backed off so that the faces of the teeth may be ground without changing the shape.



Figs. 74–86.—Types of milling cutters.



FIGS. 87–99.—Types of milling cutters.

Inserted Tooth Cutter—(Fig. 84). Brown & Sharpe inserted tooth cutters have taper bushings and screws for holding the blades in position in the bodies. Inserted tooth construction is generally recommended for cutters 6 inches or larger in diameter. There are many types of inserted tooth cutters and in most cases the blades are readily removed and replaced when broken or worn out.

Inserted Tooth Cutter (Pratt & Whitney)—(Fig. 85). In this type of cutter the teeth or blades are secured in position by taper pins driven into holes between every other pair of blades; the cutter head being slotted as shown to allow the metal at each side of the taper pin to be pressed firmly against the inserted blades.

Interlocking Side Cutters—(Fig. 86). These cutters have overlapping teeth and may be adjusted apart to maintain a definite width for milling slots, etc., by using packing between the inner faces.

Plain Cutters—(Figs. 87, 88). These cutters are for milling flat surfaces. When over $\frac{3}{4}$ inch wide the teeth are usually cut spirally to give an easy shearing cut. When of considerable length relative to diameter they are called slabbing mills.

Rose Cutter—(Fig. 89). The hemispherical cutter known as a rose mill is one of a large variety of forms employed for working out dies and other parts in the profiler. Cutters of this form are also used for making spherical seats for ball joints, etc.

Screw Slotting Cutter—(Fig. 90). Screw slotting cutters have fine pitch teeth especially adapted for the slotting of screw heads and similar work. The cutters are not ground on the sides. They are made of various thicknesses corresponding to the numbers of the American Wire Gauge.

Shank Cutter—(Fig. 91). Shank milling cutters are made in all sorts of forms with shanks which can be conveniently held true in miller or profiler while in operation.

Shell End Cutter—(Fig. 92). Shell end mills are designed to do heavier work than that for which the regular type of end mills are suited. They are made to be used on an arbor and are secured by a screw in the end of the arbor. The end of the cutter is counter-bored to receive the head of the screw and the back end is slotted for driving as indicated.

Side or Straddle, and Slabbing Cutters—(Figs. 93, 94). Side cutters, Fig. 49, have teeth on the periphery and sides, are suitable for milling slots and when used in pairs are called straddle mills. May be packed out to mill any desired width of slot or opposite faces of a piece of any thickness.

Slabbing cutters, Fig. 94, are frequently made with nicked teeth to break up the chip and so give an easier cut than would be possible with a plain tooth.

Slitting Saw, Metal—(Fig. 95). Metal slitting saws are thin milling cutters. The sides are finished true by grinding, and a little thicker at the outside edge than near the center, for proper clearance. Coarse teeth are best adapted for brass work and deep slots and fine teeth for cutting thin metal.

Sprocket Wheel Cutter—(Fig. 96). Cutters for milling the teeth on sprocket wheels for chains are formed to the necessary outline and admit of grinding on the face like regular gear cutters, without changing the form of the tooth.

Straight Shank Cutter—(Figs. 97, 98). Straight shank cutters of small size are extensively used in profilers and vertical millers for die sinking, profiling, routing, etc. They are held in spring chucks or collets.

T-Slot Cutter—(Fig. 99). Slots for bolts in miller and other tables are milled with T-slot cutters. They are made to standard dimensions to suit bolts of various sizes. The narrow part of the slot is first milled in the casting, then the bottom portion is widened out with the T-slot cutter.

CARBON STEEL AND HIGH-SPEED STEEL CUTTERS

Milling cutters of ordinary diameters are made of a solid piece of steel, either carbon tool steel or high speed steel. Larger sizes of cutters are made with inserted teeth in a body of steel or iron, the teeth being of carbon or high speed steel. High speed steel cutters are more and more commonly used in modern practice, particularly on roughing cuts as they may be subjected to more severe service than carbon cutters, while the latter are extensively employed for finishing operations especially where the work is of an exacting nature. In determining whether carbon steel or high speed steel shall be used for a given cutter, consideration must be given to such factors as the amount of material to be removed from the work, the amount of work to be machined, the quality of finish desired on the surface, etc. In other words, the special requirements of each line of work, and experience in the operation of milling equipment must be a guide in selecting the kind of steel which will result in economy of production and satisfactory results in general. As pointed out above, carbon steel is commonly used for finishing cuts on very exacting work; it holds a finer edge than high speed steel as the latter is apt to be of a more or less brittle nature which may result in a finely serrated tooth edge that is undesirable when a fine surface is to be finished on the work.

COARSE PITCH AND FINE PITCH CUTTER TEETH

Early forms of cutters were made with fine pitch of tooth giving many teeth to the cutter and leaving small amount of chip space between the teeth. Moreover the cutters were formerly made of small diameter. These conditions produced results that were far from satisfactory as viewed from a present day angle, and in many shops the use of the milling machine was retarded and its extension to new applications delayed indefinitely because of a lack of knowledge in such shops of what should constitute a good cutter. The fine tooth cutter necessarily had too many teeth in contact with the work surface, preventing a free cutting action, providing little room for chips and causing both cutter and work to become unduly heated even under the moderate speeds and feeds employed at that time. Later experience and experiment led to the use of larger sizes of cutter bodies, and teeth of much coarser pitch, which coupled with the advance in the design and construction of milling machines themselves have made possible the present economy and facility of the milling operation. Another important factor in the development of milling practice has been the general adoption of spiral toothed cutters wherever feasible in place of the earlier straight tooth mills, the latter form being seldom employed for other than narrow face cutters. The spiral tooth necessarily gives a much freer and smoother cutting action and enables heavier cuts to be taken without chatter.

A good comparison of some fine pitch and coarse pitch cutters will be seen in Figs. 100 and 101. Figure 102 shows a group of modern

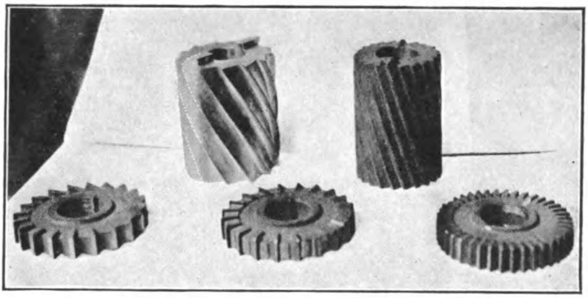


FIG. 100.—Coarse- and fine-pitch cutters.

cutters of various kinds, including long slotting mills, formed cutters and general purpose tools.

Figures 103 and 104 illustrate a number of cutters of different kinds with wide spaced teeth as designed and recommended by the Cincinnati Milling Machine Company. This company made a series of experiments some years ago to determine the advantages of wide

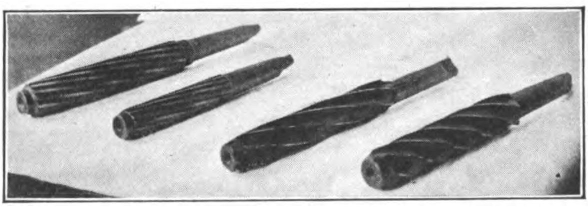


FIG. 101.—Fine- and coarse-pitch mills.

spacing in cutter teeth and from these experiments dimensions were developed for various styles of cutters. Their latest design of spiral cutter is shown in Fig. 105 this representing a mill 4½ inches in diameter. This cutter as shown is provided with ten teeth giving a spacing of approximately 1.4 inch. It was formerly the practice to cut spiral mills with an angle of spiral of 10 to 12 degrees, but as a result of experiments referred to above, the firm increased the angle of spiral until it is now 25 degrees except where there are end teeth as in the case of end mills, when the angle is 20 degrees. The faces of the teeth are undercut to give them rake, and this rake is 15 degrees where the cutter is to be used for steel only; but with standard cutters

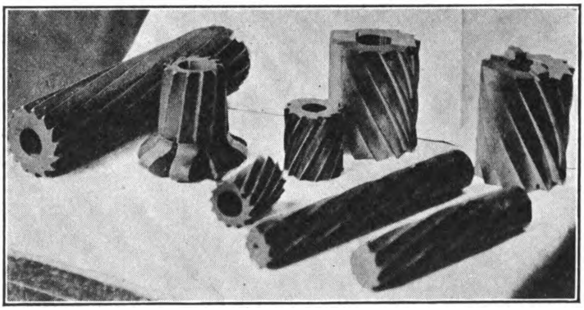


FIG. 102.—Examples of modern cutters.

which are used for both steel and cast iron the rake is at an angle of 10 degrees. To prevent weakening of the tooth because of this under cut the back of the tooth is milled with a double angle as represented in the engraving, this form of tooth being stronger than

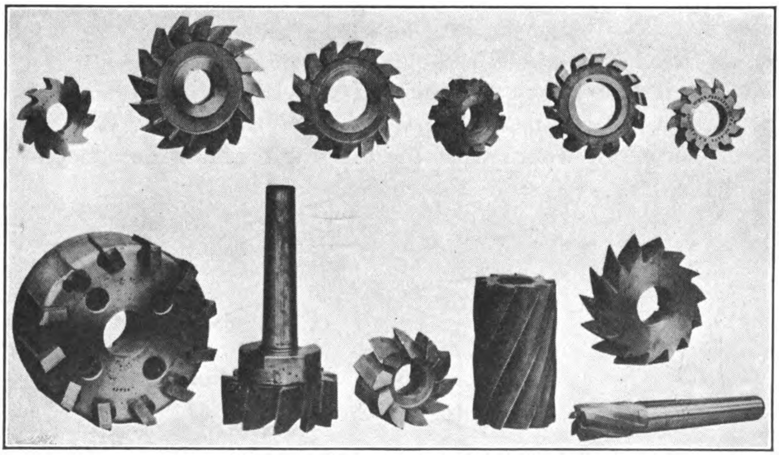


FIG. 103.—Modern milling cutters.

earlier cutters without rake. It will be noticed that there is a large fillet at the bottom of the tooth which not only strengthens the tooth but prevents lodging of chips between the teeth. It was found that the angle of spiral of 25 degrees was a great improvement over the old angle. The 25-degree angle gives a freer cutting action, the length of tooth embedded in the work is never very great thus reducing spring in the arbor and the consequent hammering, and making it

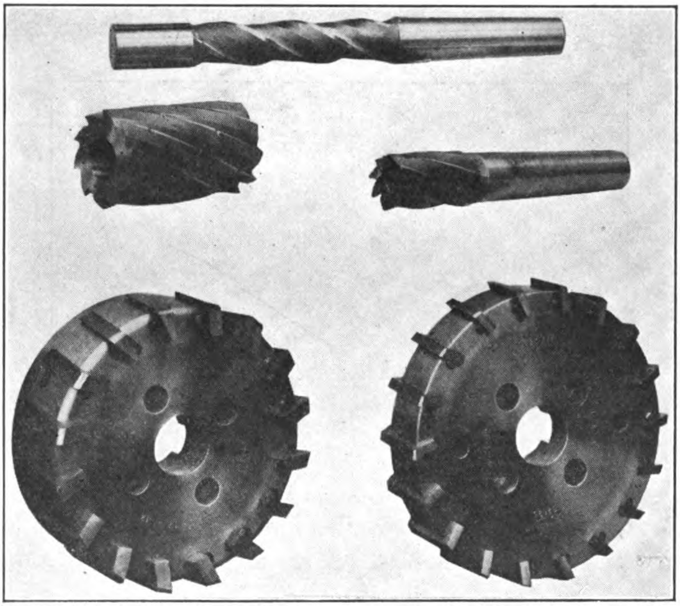


Fig. 104.—Modern milling cutters.

unnecessary to provide chip breakers (or notches) in the edges of the teeth. Unless the cut is very shallow there are always two teeth in action on the work where with the old angle and wide spaced teeth

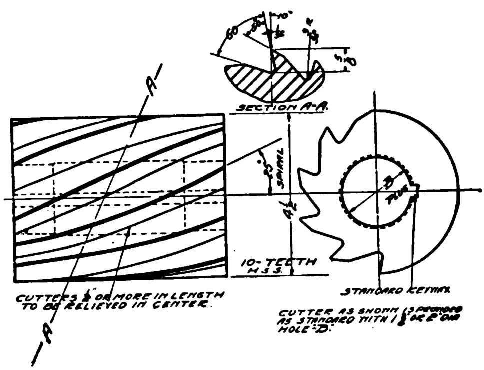


Fig. 105.—A Cincinnati spiral mill with wide-spaced undercut teeth.

one tooth would get out of action before the next engaged the work thus causing hammering to a greater or lesser extent.

The table below gives the results of the above company's tests with three spiral mills of 3 inches diameter to determine the influence of wide spaced teeth. These cutters were made with 25-degree spiral for the teeth and the teeth ground with 5 degrees clearance but the faces of the teeth were without undercut or rake, that is they were milled radially. The three cutters had respectively 22, 16 and 10 teeth,

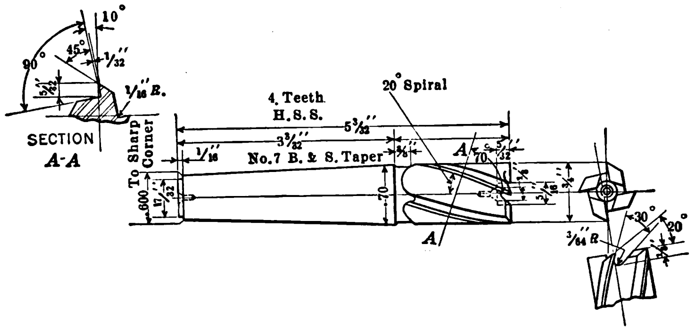


FIG. 106.—End mill.

the spacing being for cutter *A* 0.43 inch, cutter *B* 0.59 inch, cutter *C* 0.94 inch. The tests were made of milling machine steel 2¾ inches wide and the cuts were all of the same depth.

TABLE IV.—SHOWING INFLUENCE OF WIDE SPACED TEETH

Cutter	*A*—22 Teeth			*B*—16 Teeth			*C*—10 Teeth		
Width of cut	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$	$2\frac{3}{4}$
Depth of cut	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$
Revolutions	80.4	80	80	82	68	67	69	68	68
Actual feed in inches per min.	11.70	14.8	18.46	11.9	15.11	18.64	11.9	15.11	18.77
Cubic inches of metal removed per minute	5.94	7.63	9.52	6.14	7.79	9.62	6.14	7.79	9.68
Amperes	60	70	74	54	56	64	46	52	60
Volts	200	200	198	196	198	198	195	197	196
Actual h. p. at machine corrected for motor efficiency	13.44	15.75	16.5	11.77	12.32	14.28	9.84	11.39	13.24
Cubic inches of metal removed by 1 h. p. in one minute	.442	.484	.577	.522	.631	.674	.625	.684	.731

The above figures show conclusively the advantage of wide spacing alone. Cutter *B*, removed an average of 21% more metal than cutter *A*, and cutter *C* removed an average of 36% more metal than cutter *A*.

Other tests show equally interesting results as to the effect of rake or undercut on the tooth faces. One of many important tables covering these tests is reproduced below. The tests were made on a steel bar 5 inches wide, with cutters 3½ inches diameter 6-inch face, used on a 1¼-inch arbor. Cutter *A* in the table is a Cincinnati design as in Fig. 105, 25-degree spiral angle, 10 teeth, 1.11-inch spacing, with 10 degrees undercut or rake. Cutter *B* is similar to the above but has radial tooth faces, that is without rake. The tests were made on a No. 5 Plain Cincinnati High Power Miller direct connected to a 35 horse power motor and fitted with the stream lubrication system of this company. This table shows that under the cut of $^3/_{16}$ inch the cutter *A* with rake removed 48 per cent more metal per horse power minute than the cutter *B* without rake.

Table V.—Showing the Influence of Rake

Cuts $\frac{3}{16}$ inch deep. Machine set for 16 inch feed per minute

Cutter	*A*—25°Spiral, 10 Teeth, 10° Rake	*B*—25°Spiral, 10 Teeth, No Rake	*E*—Helical Mill
Width of cut	5	5	5
Depth of cut	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$
Revolutions	65	65.5	67.7
Feed in inches per minute (actual)	14.4	14.56	15.04
Cubic inches of metal removed per minute	13.5	13.65	14.10
Amperes	56	86	68
Volts	202	195	198
Total h. p. at machine corrected for motor efficiency	12.58	18.88	14.20
Cubic inches of metal removed by 1 h. p. at machine in one minute	1.074	.724	.99

With cuts ⅜ inch deep there is a still greater difference in the relative efficiencies of the two mills, the cutter with rake removing approximately 60 per cent more metal than the one without rake.

OTHER CUTTER DETAILS

The line engravings that immediately follow are of value as showing details of some of the Cincinnati cutters already referred to in connection with the group representations in Figs. 103 and 104. Thus Fig. 106 shows a form of end mill with taper shank. Here the angle is 20 degrees instead of 25 as the spiral angle becomes also the rake angle and 25 degrees would be too great hence 20 is selected as a satisfactory compromise. The teeth it will be seen are also under cut 10 degrees.

The side mill in Fig. 107 is 5 inches diameter. Its peripheral teeth are undercut 10 degrees.

The face mill, Fig. 108, has inserted blades in a steel body, this mill being 9½ inches in diameter. The slots for the blades are milled in the body at an angle of 7 degrees with the center line, and the blades are held in place by pins flattened on one side to form a wedge. The rake angle, that is the angle which the face of the blade makes with the radial line is 15 degrees. The clearance angle on the peripheral edge is 7 degrees. The portion of the blade which has this clearance angle is only $^3/_{32}$ inch wide the blade being ground away at an angle of 25

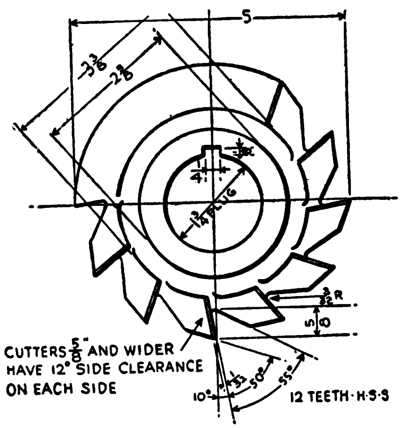


FIG. 107.—Side mill.

degrees back of this narrow land. The face edges have a clearance of 10 degrees and are ground away at an angle of 20 degrees, or at 13 degrees with the body of the mill. The face edge of the blade is not straight; it has a rounded corner of $^3/_{16}$ radius, then a flat portion $^3/_{16}$ wide, and the rest of the edge is ground away at an angle of 7 to 10 degrees. Other dimensions of interest will be gathered by inspection of the drawing.

Figure 109 is a form relieved cutter which retains its original shape when ground radially and straight on the tooth faces. Figure 110 is an angular mill used on an arbor. Figure 111 is a helical mill which cuts with a shearing cut, that is it pushes off the chips sidewise and makes tooth marks instead of revolution marks. It does not spring away from the work and is valuable when milling thin work. A modification of this helical cutter, Fig. 112, is used for milling out the ends of connecting rods for locomotives. Further reference to the latter operation will be found in another chapter.

A brief explanation of the method of milling the wide spaced spiral

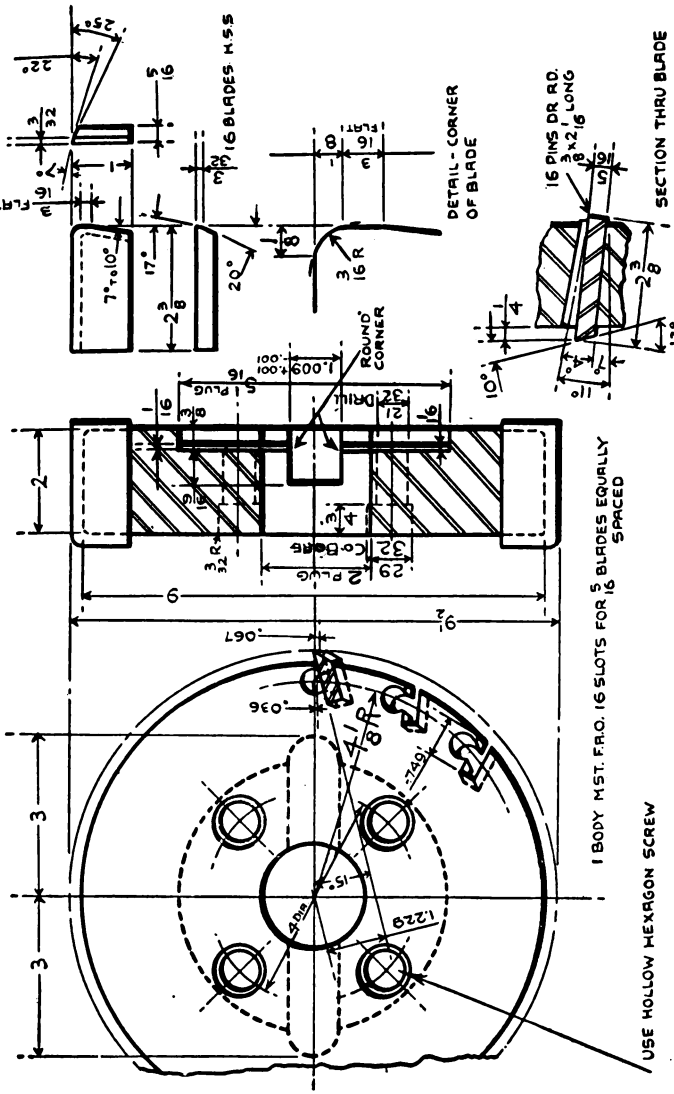


Fig. 108.—Inserted tooth-face mill.

cutters may be of value here. A comparison is shown in Figs. 113 and 114 of the settings for the usual cutter and the wide spaced mills described above. Figure 115 shows a machine in operation on a spiral cutter. With a radial face tooth as in Fig. 113 the work is adjusted off center so that when the double angle milling cutter used for the

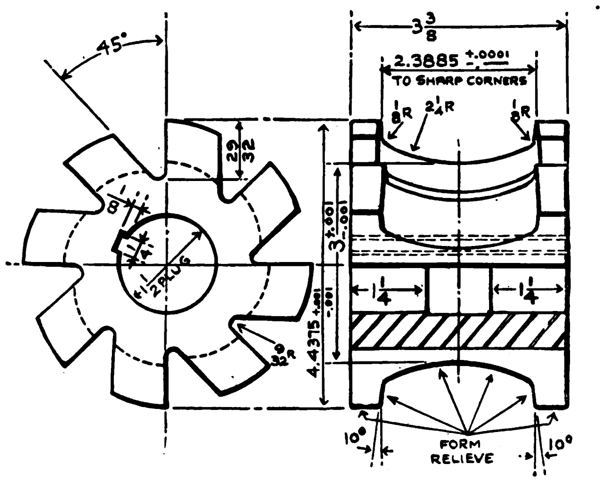


FIG. 108.—Form cutter.

work is at the correct height for giving the right depth of cut, a straight-edge placed on the 12-degree side will line up with the center

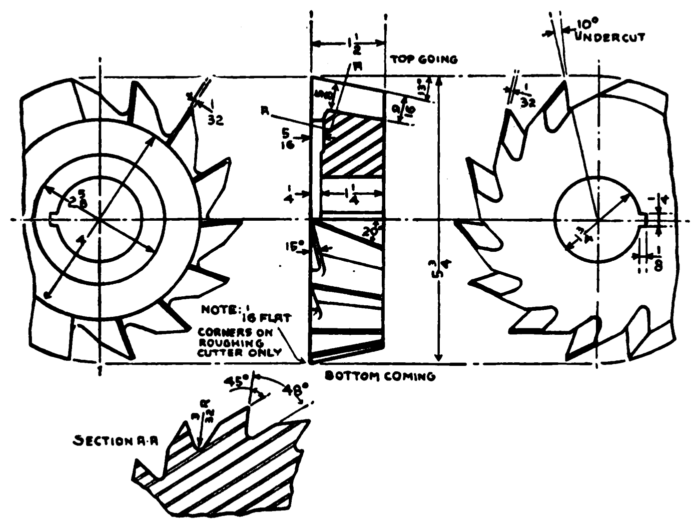


FIG. 110.—Angular cutter.

of the dividing head. The cutter is set before the table is swiveled to the angle of spiral to be cut. When milling the wide spaced cutter

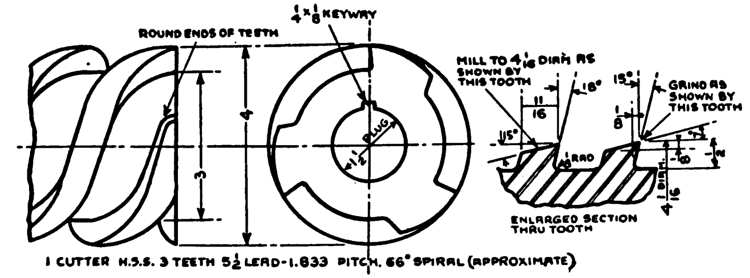


FIG. 111.—Helical mill.

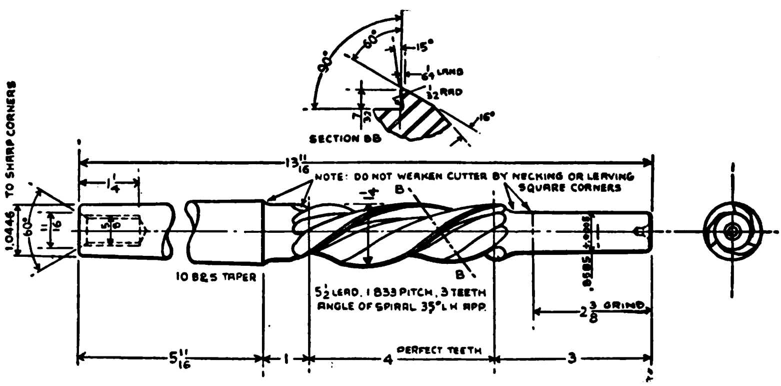


FIG. 112.—Helical mill for connecting rods.

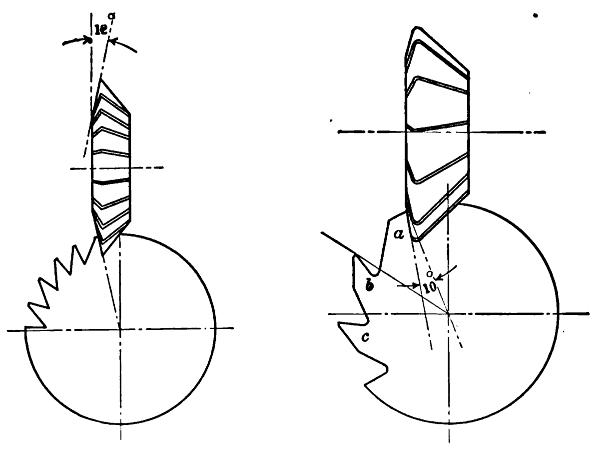


FIG. 113 FIG. 114

FIGS. 113–114.—Setting the cutter for making spiral mills.

with undercut face for the tooth two cuts are required as indicated in Fig. 114. The work is now offset more than in the case shown in Fig. 113. This offset is such that a straight-edge placed along the 12-degree side of the double angle cutter will form an angle with a line drawn from the outside diameter of the work to the center of the headstock of 10 degrees for an undercut face of 10 degrees, or of 15 degrees if the tooth face is to have an undercut of 15 degrees. This leaves the tooth tops too wide as already noted and as shown at *a*, Fig. 114, so a second cut must be taken in order to mill the teeth to correct form as at *b* and *c*, Fig. 114.

The table herewith will be found convenient in connection with the milling of spiral cutters, this giving the leads, change gears and angles for setting of table.

TABLE VI.—LEADS, CHANGE GEARS AND ANGLES FOR MAKING SPIRAL MILLING CUTTERS

(The Cincinnati Milling Machine Company.)

Diameter of Cutter, Inches	Lead in Inches	Gear on Worm	First Intermediate Gear	Second Intermediate Gear	Gear on Screw	Angle for Setting Milling Machine Table
1/2	3.24	28	48	40	72	25 3/4
5/8	4.17	40	64	48	72	25 1/4
3/4	4.68	40	64	56	72	25 3/4
7/8	6.12	56	40	28	64	24 1/4
1	6.67	64	56	28	48	25 1/4
1 1/4	8.33	48	32	40	72	25 1/2
1 1/2	10.29	72	40	32	56	24 3/4
1 3/4	11.66	56	32	48	72	25 1/4
2	13.33	64	32	48	72	25 1/2
2 1/4	15.24	64	28	48	72	25
2 1/2	16.87	72	32	48	64	25
2 3/4	18.75	72	32	40	48	25
3	19.69	72	32	56	64	25 1/2
3 1/4	21.43	72	28	40	48	25 1/2
3 1/2	23.33	64	48	56	32	25 1/4
3 1/4	25.57	100	64	72	44	24 3/4
4	26.67	64	28	56	48	25 1/4
4 1/4	28.67	86	48	64	40	25
4 1/2	30.71	86	32	64	56	24 3/4
4 3/4	32.73	72	32	64	44	24 1/2
5	32.73	72	32	64	44	25 3/4
5 1/4	34.72	100	24	40	48	25 1/2
5 1/2	37.04	100	24	64	72	25
5 3/4	39.29	100	28	44	40	24 3/4
6	39.29	100	28	44	40	25 1/2

LEADS, CHANGE GEARS AND ANGLES FOR MAKING SPIRAL END MILLS

Diameter of Mill, Inches	Lead in Inches	Gear on Worm	First Intermediate Gear	Second Intermediate Gear	Gear for Screw	Angle for Setting Milling Machine Table
1/4	2.08	24	64	40	72	20 1/2
3/8	3.24	28	48	40	72	19 3/4
1/2	4.17	40	64	48	72	20 1/2
5/8	5.44	56	40	28	72	20
3/4	6.48	40	48	56	72	20
7/8	7.41	40	48	64	72	20 1/4
1	8.33	48	32	40	72	20 1/2
1 1/8	9.70	64	48	32	44	20
1 1/4	10.94	56	32	40	64	20
1 3/8	11.84	64	24	32	72	20
1 1/2	13.12	56	32	48	64	20
1 3/4	15.24	64	28	48	72	20
2	17.14	72	56	64	48	20 1/4
2 1/4	19.59	64	28	48	56	20
2 1/2	21.43	72	28	40	48	20 1/4
2 3/4	23.33	64	48	56	32	20 1/4
3	26.25	72	48	56	32	19 3/4
3 1/4	28.00	64	40	56	32	20
3 1/2	30.86	72	28	48	40	19 1/2
3 3/4	31.50	72	40	56	32	20 1/2
4	34.55	86	56	72	32	20

DRIVING LARGE CUTTERS

The method of securing large face mills to the miller spindle varies with different designs of machines. The cutter drive for the Cincinnati High Power millers, large size cone driven machines and certain other

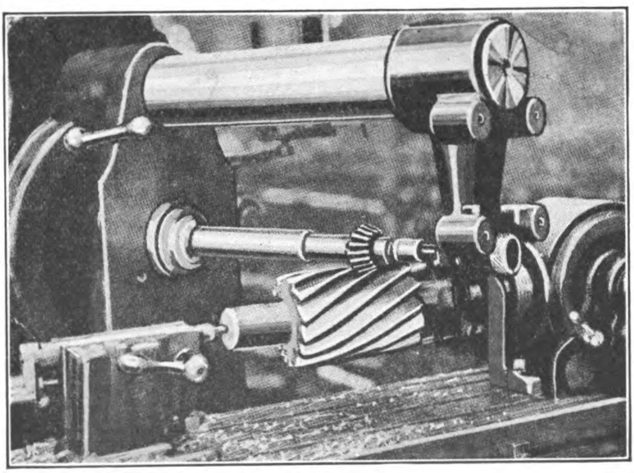


FIG. 115.—Milling a spiral cutter.

types of the same make is arranged as in Fig. 116. These machines have flanged spindles which are fitted with hardened cross keys and the regular cutter arbors are of solid forgings provided with similar flanges for driving. Face mills are driven in the same manner. These are counterbored to fit over the flanges in order to center them and they are provided with recesses to suit the driving keys, as indicated in the engraving referred to.

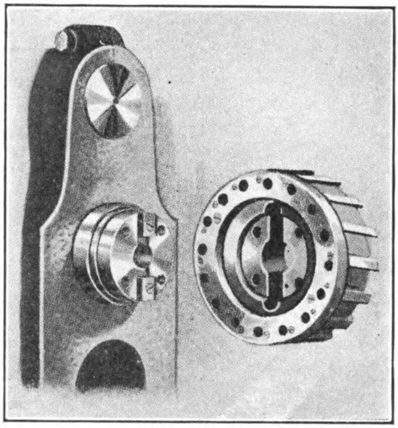


FIG. 116.—Cincinnati arbor and cutter drive.

Another form of drive is the Brown & Sharpe, Fig. 117, where a large face mill is shown with taper opening for fitting over the large spindle nose, while a rectangular cutter driver fits a cross slot in the cutter and a recess in the end of the spindle; the driver being held in place by a drawing-in bolt and serving as a clutch to form a positive drive.

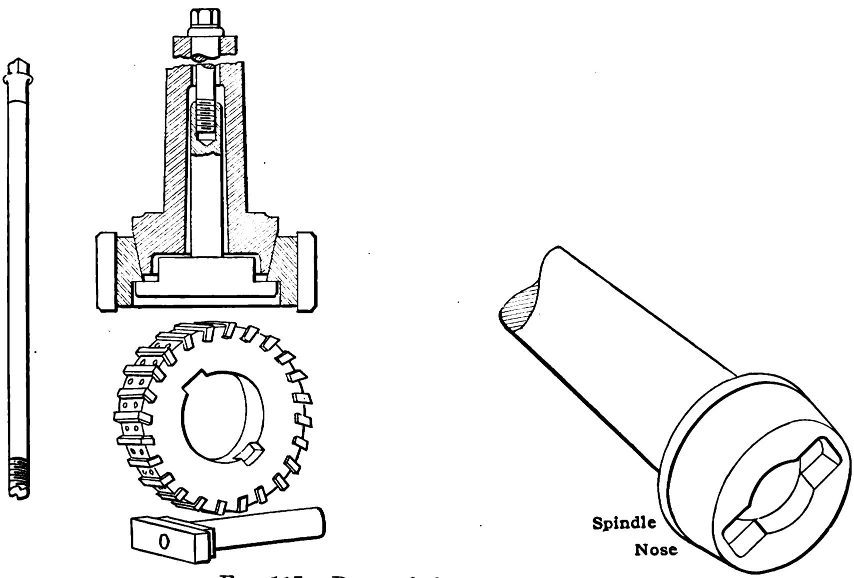


FIG. 117.—Brown & Sharpe cutter drive.

Methods of mounting cutters on their arbors and setting them properly for the work in hand are discussed in another chapter.

CHAPTER VII

SETTING CUTTERS AND WORK

There are certain fundamental details which must be given attention when work is to be set up on the milling machine. It is of first importance that the cutters be mounted as rigidly as possible which means that they be carried on their arbor as closely to the spindle nose as the work will allow, or if it is necessary to place them at some distance out on the arbor then the outer supports should be set as near the cutter as feasible. Similarly, the work itself should be secured in the vise, in a fixture, or to the table in such manner that spring and vibration of the work will be reduced to a minimum and the surface of the piece finished flat and true. The spindle of the machine and the table, saddle and knee gibs should be kept properly adjusted, the spindle taper hole and the cutter arbor cleaned thoroughly, the arbor should be true and the cutter true when running on its arbor.

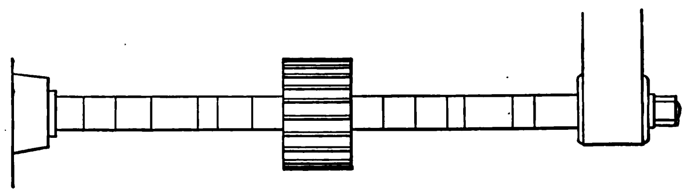


FIG. 118.—Improper method of supporting cutter.

If the cutter runs out one or two teeth on one side will form a high cutting point and the inequality of the action of the various teeth will lead to chatter and unsatisfactory results. The condition of the cutter both as to sharpness, clearance angle and truth of rotation, and the adjustments of the various supporting members, spindle, etc., have much to do with the output of the machine and the quality of the work irrespective of the matter of speeds and feeds; for without suitable conditions of the nature indicated adequate speeds and feeds are not applicable and even with low speeds and slow rates of feed satisfactory results cannot be expected.

In the illustrations which follow, various methods of supporting cutters and work are shown, the views in the half tones representing several small and medium classes of parts under operation.

The sketch in Fig. 118 shows an improperly supported cutter carried as indicated at the middle of the length of a long arbor where spring and chatter are developed to a marked degree. Sometimes

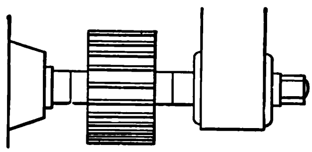


FIG. 119.—Use of short arbor with support close to cutter.

because of the width or shape of the work a fully satisfactory position of cutter and arbor supports is impossible and long arbors are then necessary. But ordinarily it is practicable to set the cutter near the

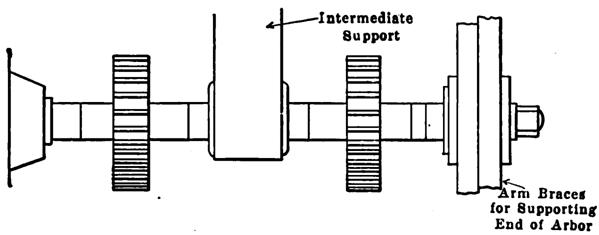


FIG. 120.—Support between cutters.

end of the arbor and support the latter rigidly. Thus in Fig. 119 a short arbor is represented with the same form of cutter as seen in Fig. 118. Here maximum conditions of rigidity are obtained, with

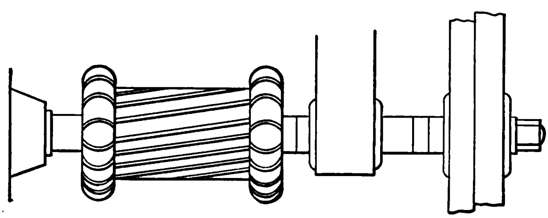


FIG. 121.—Cutters well supported on long arbor.

the arbor support and its properly adjusted bushing close up to the cutter. The pair of cutters in Fig. 120 are similarly well supported with the outer end of the arbor carried in its bushing in the outer support which is secured to rigid braces that tie the overhanging arm firmly to the knee of the miller. Between the cutters is located the intermediate support and its bushing so that both ends of the arbor and the center are carried under rigid conditions of operation.

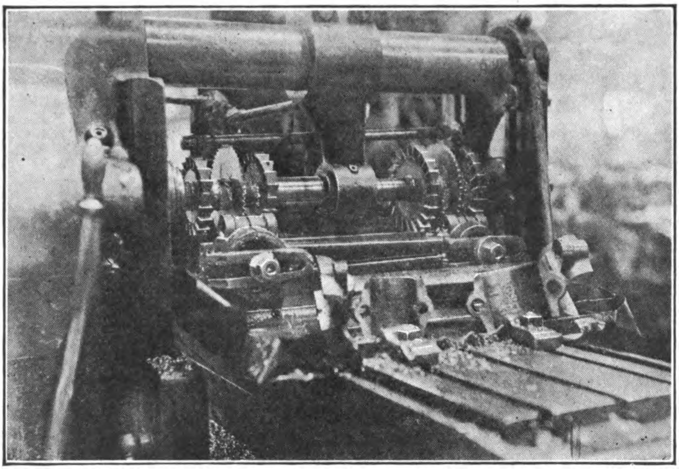


Fig. 122.—Gang cutters on connecting-rod work.

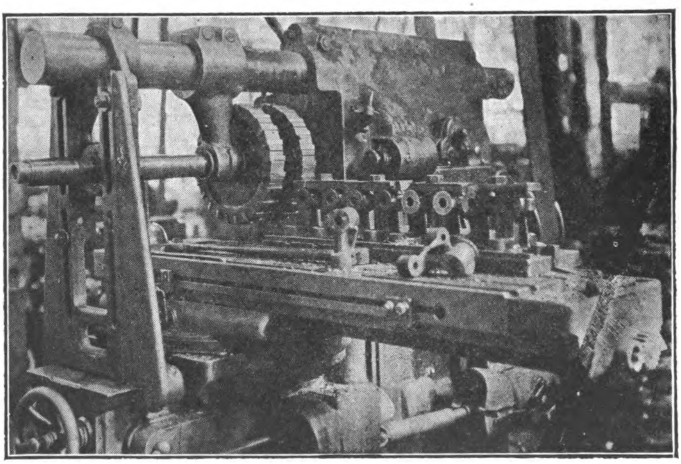


Fig. 123.—Milling a string of brackets

A set up of this kind is shown in the photograph Fig. 122, the method of support being a characteristic one for gangs of cutters where there happens to be sufficient space at the center of the arbor for a support at this point. The view illustrates a method of facing the bosses on connecting rods and splitting through for the caps. Two pairs of straddle mills are used for the facing of the bosses and two large saws for the splitting cuts. The work itself is secured to the vertical face of a simple fixture on which there are two locating plugs for positioning the connecting rod while two clamps are employed for holding the rod in place.

With a single gang of cutters or with two or three mills closely spaced it is often possible to locate the cutters near the end of the arbor and use two arbor supports at the outer side as in Fig. 121. Thus Fig. 123 shows a pair of large inserted tooth mills employed

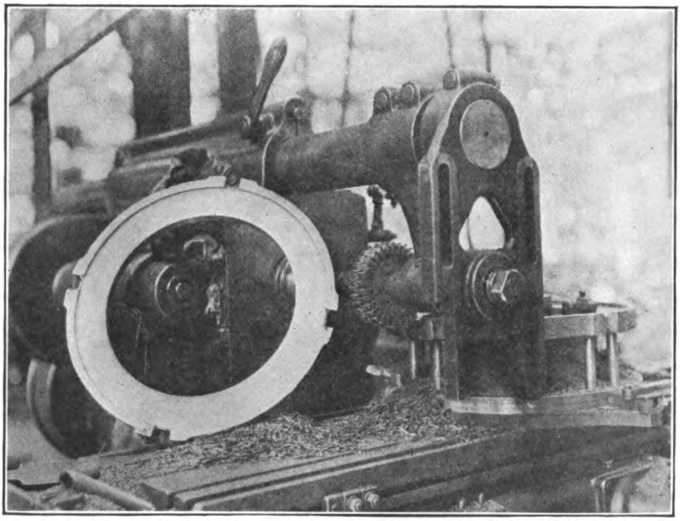


FIG. 124.—Notching a large ring.

in facing both ends of a series of brackets. The cutters are as close to the machine column as possible and the long arbor is rigidly carried outside of the cutters by the two supports. In addition to the stiffness of the cutter drive here obtained there is a further advantage due to the fact that the work is carried as far back on the table as possible and the latter with its saddle is close to the column in the most desirable position for rigidity of machine operation. The work, it will be noticed, is carried on what is known as a string milling fixture, a number of parts being placed in a line on the holding device and fed between the cutters just as a long single piece would be machined.

With larger work it is necessary to set the cutters further out on their arbor in order to clear the face of the column with the inner surface of the work. Such a case is illustrated by Fig. 124 which shows a large ring requiring the milling of a set of notches in its periphery. The work is placed horizontally on an upright indexing

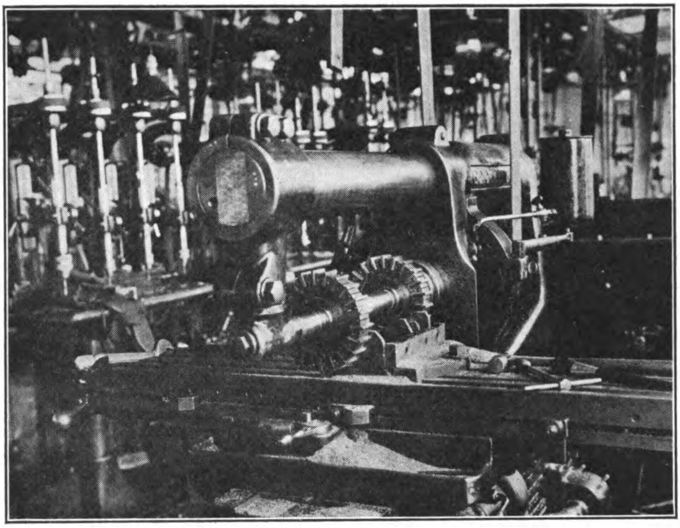


FIG. 125.—Straddle-milling the ends of a piece to length.

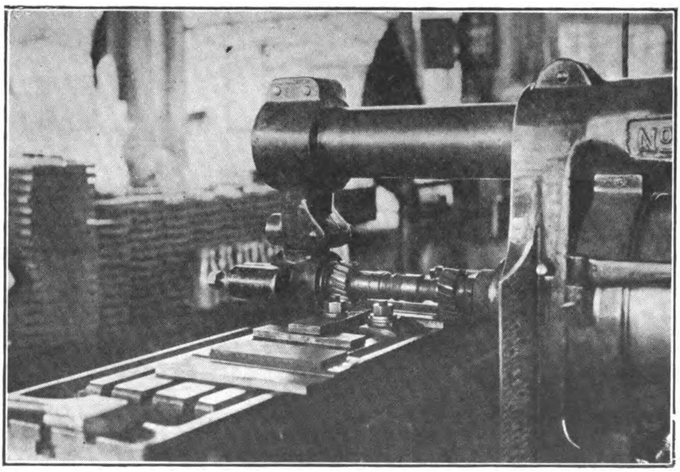


FIG. 126.—Milling the ends of thin work.

fixture and the cut taken by using the vertical feed to carry the table and work up past the cutters. A pair of interlocking mills are used as these are readily spaced outwardly in respect to each other to maintain accuracy in the width of opening milled in the ring.

Where work of considerable width requires facing at both ends this can be done with a pair of straddle mills as in Fig. 125 with the casting placed crosswise of the table and the cutters spaced at the necessary distance apart for the length of the work. This job like the one in Fig. 126 is accomplished with the cutters located as far in on the arbor as possible. The latter illustration is of a thin piece of work held directly to the table and finished by the use of a pair of small cutters which form narrow guide surfaces at the ends of the work.

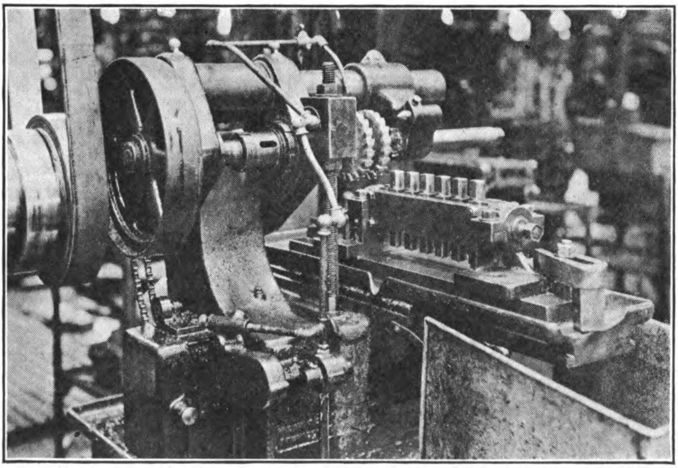


FIG. 127.—String milling on an indexing fixture.

A string milling job with an indexing fixture is shown by Fig. 127. The studs milled in this are flatted on each end by a pair of straddle mills and these are carried close up to the inner end of the arbor with the support close to the face of the outer cutter. After the first pass of the work between the cutters, the table is run back and the fixture indexed half way over to bring the other ends of the work upward into position for the straddle milling cut.

CLAMPS, BLOCKS, ETC.

Work which is to be milled in quantities is usually held in fixtures that are tongued and bolted to the table of the machine but in the general shop there are many pieces to be milled where the work must be secured in the vise or directly to the table or to an angle plate fastened to the table. Various types of straps and clamps are used for different classes of work and several types of jacks and step blocks are employed. A number of clamps plain and offset are shown in Fig. 128, a jack in Fig. 129, a step block in Fig. 130. The use of the

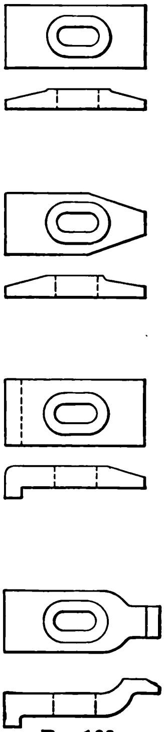


Fig. 128

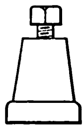


Fig. 129

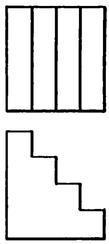


Fig. 130

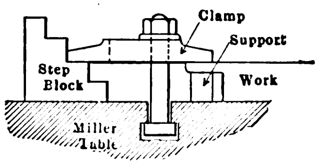


Fig. 131

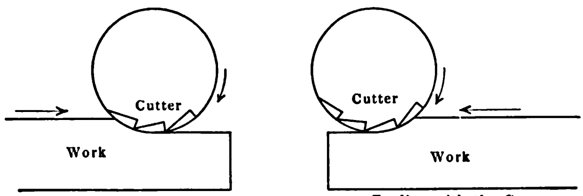
Figs. 128–131.—Clamps and step blocks.

latter is indicated in Fig. 131. As with planer work, supports required under the work should be placed directly beneath the point where the clamp is applied, or rather the clamp should be applied directly over the point of support. The bolt should be set forward in the clamp slot and as close to the work as possible as indicated in the sketch Fig. 131. The clamp should rest squarely across its end on work and step block. Where it is possible to place the clamp over a portion of the work which rests directly on the table this should be done.

No attempt will be made here to describe in detail the various types of fixtures used for different classes of milling machine operations. These fixtures are usually designed specially for the work in hand and a number of tools of this kind are shown in the next chapter which shows a variety of milling operations in different shops. A great deal of work, particularly of a light character, is held in the regular vise which is readily set either parallel to or crosswise of the arbor. Where the vise has a swivel base it is set directly from the graduations; with the plain vise the jaws are set to an arbor placed in the spindle when it is desired to have them crosswise of the table, or where the jaws are required to be at right angles to the cutter arbor a square may be placed between their faces and the blade brought into contact with the side of the arbor.

DIRECTION OF FEED IN RELATION TO CUTTER

It is customary in milling to feed the work in the opposite direction to the rotation of the cutter, that is the work is fed against the cut as in Fig. 132. There are exceptions to this practice but it is advantageous in most cases to feed the work as stated. The cutter runs



Feeding Against the Cut
FIG. 132

Feeding with the Cut
FIG. 133

FIGS. 132–133.—Direction of cutter and work travel.

under the work and has a clean surface free from scale for each tooth and there is no danger of the cutter drawing the work into the teeth as is likely to be the case where the work is fed in the same direction as the cutter rotates as in Fig. 133. There are instances however where it is preferable to run the cutter on top and feed with the direction of the cutter Fig. 133, such for example as when cutting very narrow slots where there is a tendency for the cutter to run off to one side if it is run under or opposite to the feed of the work. With the cutter cutting down, that is on top of the work as in Fig. 133 each tooth comes in contact with a fresh portion of the work surface and the result is that the teeth cut themselves free and have no tendency to bind and run sidewise as in the former instance. It is desirable when feeding with the direction of the cutter to keep out all back lash so far as possible by means of the table gibs so that the cutter will not pull the work into its teeth, and often when feeding in this direction some form of counter weight is applied to the table to hold it back against freedom in the parts and to prevent the cutter from drawing the work and table in with the liability of breaking the teeth of the cutter.

In milling cast iron, compressed air is often employed to clear the chips and cool the cutters and work. For steel, wrought iron and tough bronze, oil or soda water mixture should be used.

SPEEDS AND FEEDS IN MILLING

The question of speeds and feeds is one in which many factors are involved and no absolute rule can be given for speed and feed rates to cover all conditions. Some of the important factors are the condition of the miller itself as to power and rigidity, the size of the work and the amount of metal to be removed, the character of the material whether cast iron, malleable, machine steel, tool steel, etc., the relative degree of hardness of the metal to be cut, the quality of finish and accuracy desired, the shape of the cut whether broad slabbing, narrow channeling, side facing or other, the strength of the work itself toward resisting springing and giving under the action of the cutter. With precisely the same kind of material work of heavy section can naturally be machined under much heavier rates of feed than small slender parts which may admit of rapid cutter speeds but require relatively slow feeds in order to avoid deformation. When machining material which requires lubricant the manner in which the oil or other cooling medium is applied to work and cutter has an important bearing upon the rate at which the cutter may be operated and the work fed to the cut.

The surface speeds given below for cutters have been recommended as a guide although these necessarily must be varied appreciably under circumstances peculiar to different classes of work. With carbon steel cutters milling cast iron, 40 to 60 feet surface speed per minute; for machine steel, 30 to 40 feet per minute; for annealed tool steel, 20 to 30 feet per minute; for brass 80 to 100 feet per minute. With high speed steel cutters milling cast iron, 80 to 100 feet per minute; for machine steel, 80 to 100 feet per minute; for annealed tool steel, 60 to 80 feet per minute; for brass, 150 to 200 feet per minute.

In this connection, a table compiled by the Cincinnati Milling Machine Company includes important data pertaining to both roughing and finishing cuts in milling. The speeds given below, this company has found can be used safely in general practice with modern cutters and an ample supply of lubricant or coolant for the cutter on such work as requires coolant.

Milling cast iron with spiral mills.		
Rough Milling	65 to 75	feet per minute
Finish Milling	80 to 120	" " "
Milling cast iron with face mills.		
Rough Milling	65	" " "
Finish Milling	80 to 110	" " "
Milling machine steel with spiral mills.		
Rough Milling	70 to 75	" " "
Finish Milling	100 to 140	" " "
Milling machine steel with face mills.		
Rough Milling	60 to 85	" " "
Finish Milling	90 to 110	" " "
Milling tool steel (annealed) with spiral mills.		
Rough Milling	50	" " "
Finish Milling	70 to 80	" " "
Milling Tobin bronze with spiral mills and lubricant.		
Rough Milling	90	" " "
Finish Milling	125 to 150	" " "
Milling brass	200	" " "
Milling aluminum	600 to 1000	" " "

FEEDS FOR ROUGHING AND FINISHING CUTS

Oftentimes a piece of work is milled in a single cut while with other jobs two cuts are required so that the question of quality of finish does not have to be considered in connection with the roughing operation, and this cut can then be taken at the maximum rate that the machine and cutter and strength of the work will permit. But with a single cut only the matter of finish and character of surface desired enter into the question, and the rate of feed must be adjusted accordingly. The above company state that with spiral mills, end mills or formed mills, a very satisfactory commercial finish is produced with a feed of from 0.035 to 0.050 inch per revolution of cutter. Such a feed and often even higher feeds may be used for surfaces which are bolted together and do not require to be oil tight. For a great variety of work a finer feed is necessary. Work which must be scraped or which is finish ground will readily stand a feed of 0.030 inch per revolution of cutter while work requiring a high finish without subsequent operation may require a feed as low as 0.020 inch per revolution.

Before concluding this chapter reference should be made to the speeds and feeds obtained by the above company in the application of their system of "stream lubrication." The following data pertain to the milling of machinery steel .20 carbon, 55,000 to 65,000 lbs. tensile strength.

Cutting speed 458 ft. per min. 3½-inch diameter spiral mill 500 rev. per minute, 30½ inches feed per minute, cut 5 inches wide, ⅛ inch deep.

Cutting speed 835 feet per min. $6^{5}/_{16}$-inch slotting cutter, 510 rev. per min. 30½ inches feed per min. cut 1 inch wide, $^{3}/_{16}$ inch deep.

Cutting speed 200 ft. per min. 7-P gear cutter 218 rev. per min. 112 inches feed per min. cut full depth of tooth.

A number of examples of work in operation, some with rates of feed and cutter speed specified, will be found in the following chapter.

The table of cutting speeds included here will be of service as it will enable one to determine at once the number of revolutions for a cutter of given diameter which is to be run at a certain peripheral speed. Thus if it desired say to run a 4-inch mill at 100 feet per minute, we find opposite 4 (in the first column) and under 100 in the eighth column the quantity 95.5 which is the number of revolutions per minute for this cutter for the surface speed required.

The sharpening of cutters is an important operation in connection with the satisfactory performance of the milling process. Various details pertaining to this work are given in the volume on Grinding in this Library and need not be reproduced here.

TABLE VIII.—TABLE OF CUTTING SPEEDS

Feet per Minute	15	17.5	20	22.5	25	27.5	30	35
Diameter	Revolutions per Minute							
1/16	917	1070	1222	1375	1528	1681	1833	2139
1/8	458	535	611	688	764	840	917	1070
3/16	306	357	407	458	509	560	611	713
1/4	229	267	306	344	382	420	458	535
5/16	183	214	244	275	306	336	367	428
3/8	153	178	204	229	255	280	306	357
7/16	131	153	175	196	218	240	262	306
1/2	115	134	153	172	191	210	229	267
5/8	91.7	107	122	138	153	168	183	214
3/4	76.4	89.1	102	115	127	140	153	178
7/8	65.5	76.4	87.3	98.2	109	120	131	153
1	57.3	66.8	76.4	85.9	95.5	105	115	134
1 1/8	50.9	59.4	67.9	76.4	84.9	93.4	102	119
1 1/4	45.8	53.5	61.1	68.8	76.4	84.0	91.7	107
1 3/8	41.7	48.6	55.6	62.5	69.5	76.4	83.3	97.2
1 1/2	38.2	44.6	50.9	57.3	63.7	70.0	76.4	89.1
1 5/8	35.3	41.1	47.0	52.9	58.8	64.6	70.5	82.3
1 3/4	32.7	38.2	43.7	49.1	54.6	60.0	65.5	76.4
1 7/8	30.6	35.7	40.7	45.8	50.9	56.0	61.1	71.3
2	28.7	33.4	38.2	43.0	47.7	52.5	57.3	66.8
2 1/4	25.5	29.7	34.0	38.2	42.4	46.7	50.9	59.4
2 1/2	22.9	26.7	30.6	34.4	38.2	42.0	45.8	53.5
2 3/4	20.8	24.3	27.8	31.3	34.7	38.2	41.7	48.6
3	19.1	22.3	25.5	28.6	31.8	35.0	38.2	44.6
3 1/4	17.6	20.6	23.5	26.4	29.4	32.3	35.3	41.1
3 1/2	16.4	19.1	21.8	24.5	27.3	30.0	32.7	38.2
3 3/4	15.3	17.8	20.4	22.9	25.5	28.0	30.6	35.7
4	14.3	16.7	19.1	21.5	23.9	26.3	28.7	33.4
4 1/2	12.7	14.9	17.0	19.1	21.2	23.3	25.5	29.7
5	11.5	13.4	15.3	17.2	19.1	21.0	22.9	26.7
5 1/2	10.4	12.2	13.9	15.6	17.4	19.1	20.8	24.3
6	9.5	11.1	12.7	14.3	15.9	17.5	19.1	22.3
6 1/2	8.8	10.3	11.8	13.2	14.7	16.2	17.6	20.6
7	8.2	9.5	10.9	12.3	13.6	15.0	16.4	19.1
7 1/2	7.6	8.9	10.2	11.5	12.7	14.0	15.3	17.8
8	7.2	8.4	9.5	10.7	11.9	13.1	14.3	16.7
8 1/2	6.7	7.9	9.0	10.1	11.2	12.4	13.5	15.7
9	6.4	7.4	8.5	9.5	10.6	11.7	12.7	14.9
9 1/2	6.0	7.0	8.0	9.1	10.1	11.1	12.1	14.1
10	5.7	6.7	7.6	8.6	9.5	10.5	11.5	13.4
11	5.2	6.1	6.9	7.8	8.7	9.5	10.4	12.2
12	4.8	5.6	6.4	7.2	8.0	8.8	9.5	11.1
13	4.4	5.1	5.9	6.6	7.3	8.1	8.8	10.3
14	4.1	4.8	5.5	6.1	6.8	7.5	8.2	9.5
15	3.8	4.5	5.1	5.7	6.4	7.0	7.6	8.9
16	3.6	4.2	4.8	5.4	6.0	6.6	7.2	8.4
17	3.4	3.9	4.5	5.1	5.6	6.2	6.7	7.9
18	3.2	3.7	4.2	4.8	5.3	5.8	6.4	7.4
	15	17.5	20	22.5	25	27.5	30	35

TABLE VIII.—TABLE OF CUTTING SPEEDS—*Continued*

Feet per Minute	40	45	50	55	60	65	70	75
Diameter	Revolutions per minute							
1/16	2445	2750	3056	3361	3667	3973	4278	4584
1/8	1222	1375	1528	1681	1833	1986	2139	2292
3/16	815	917	1019	1120	1222	1324	1426	1528
1/4	611	688	764	840	917	993	1070	1146
5/16	489	550	611	672	733	794	856	917
3/8	407	458	509	560	611	662	713	764
7/16	349	393	437	480	524	568	611	655
1/2	306	344	382	420	458	497	535	573
5/8	244	275	306	336	367	397	428	458
3/4	204	229	255	280	306	331	357	382
7/8	175	196	218	240	262	284	306	327
1	153	172	191	210	229	248	267	287
1 1/8	136	153	170	187	204	221	238	255
1 1/4	122	138	153	168	183	199	214	229
1 3/8	111	125	139	153	167	181	194	208
1 1/2	102	115	127	140	153	166	178	191
1 5/8	94.0	106	118	129	141	153	165	176
1 3/4	87.3	98.2	109	120	131	142	153	164
1 7/8	81.5	91.7	102	112	122	132	143	153
2	76.4	85.9	95.5	105	115	124	134	143
2 1/4	67.9	76.4	84.9	93.4	102	110	119	127
2 1/2	61.1	68.8	76.4	84.0	91.7	99.3	107	115
2 3/4	55.6	62.5	69.5	76.4	83.3	90.3	97.2	104
3	50.9	57.3	63.7	70.0	76.4	82.8	89.1	95.5
3 1/4	47.0	52.9	58.8	64.6	70.5	76.4	82.3	88.2
3 1/2	43.7	49.1	54.6	60.0	65.5	70.9	76.4	81.9
3 3/4	40.7	45.8	50.9	56.0	61.1	66.2	71.3	76.4
4	38.2	43.0	47.7	52.5	57.3	62.1	66.8	71.6
4 1/2	34.0	38.2	42.4	46.7	50.9	55.2	59.4	63.6
5	30.6	34.4	38.2	42.0	45.8	49.7	53.5	57.3
5 1/2	27.8	31.3	34.7	38.2	41.7	45.1	48.6	52.1
6	25.5	28.6	31.8	35.0	38.2	41.4	44.6	47.8
6 1/2	23.5	26.4	29.4	32.3	35.3	38.2	41.1	44.1
7	21.8	24.5	27.3	30.0	32.7	35.5	38.2	40.9
7 1/2	20.4	22.9	25.5	28.0	30.6	33.1	35.7	38.2
8	19.1	21.5	23.9	26.3	28.7	31.0	33.4	35.8
8 1/2	18.0	20.2	22.5	24.7	27.0	29.2	31.5	33.7
9	17.0	19.1	21.2	23.3	25.5	27.6	29.7	31.8
9 1/2	16.1	18.1	20.1	22.1	24.1	26.1	28.2	30.2
10	15.3	17.2	19.1	21.0	22.9	24.8	26.7	28.7
11	13.9	15.6	17.4	19.1	20.8	22.6	24.3	26.0
12	12.7	14.3	15.9	17.5	19.1	20.7	22.3	23.9
13	11.8	13.2	14.7	16.2	17.6	19.1	20.6	22.0
14	10.9	12.3	13.6	15.0	16.4	17.7	19.1	20.5
15	10.2	11.5	12.7	14.0	15.3	16.6	17.8	19.1
16	9.5	10.7	11.9	13.1	14.3	15.5	16.7	17.9
17	9.0	10.1	11.2	12.4	13.5	14.6	15.7	16.9
18	8.5	9.5	10.6	11.7	12.7	13.8	14.9	15.9
	40	45	50	55	60	65	70	75

TABLE VIII.—TABLE OF CUTTING SPEEDS—*Continued*

Feet per Minute	80	90	100	110	120	130	140	150
Diameter	Revolutions per Minute							
1/16	4889							
1/8	2445	2750	3056	3361	3667	3973	4278	4584
3/16	1630	1833	2037	2241	2445	2648	2852	3056
1/4	1222	1375	1528	1681	1833	1986	2139	2292
5/16	978	1100	1222	1345	1467	1589	1711	1833
3/8	815	917	1019	1120	1222	1324	1426	1528
7/16	698	786	873	960	1048	1135	1222	1310
1/2	611	688	764	840	917	993	1070	1146
5/8	489	550	611	672	733	794	856	917
3/4	407	458	509	560	611	662	713	764
7/8	349	393	437	480	524	568	611	655
1	306	344	382	420	458	497	535	573
1 1/8	272	306	340	373	407	441	475	509
1 1/4	244	275	306	336	367	397	428	458
1 3/8	222	250	278	306	333	361	389	417
1 1/2	204	229	255	280	306	331	357	382
1 5/8	188	212	235	259	282	306	329	353
1 3/4	175	196	218	240	262	284	306	327
1 7/8	163	183	204	224	244	265	285	306
2	153	172	191	210	229	248	267	287
2 1/4	136	153	170	187	204	221	238	255
2 1/2	122	138	153	168	183	199	214	229
2 3/4	111	125	139	153	167	181	194	208
3	102	115	127	140	153	166	178	191
3 1/4	94.0	106	118	129	141	153	165	176
3 1/2	87.3	98.2	109	120	131	142	153	164
3 3/4	81.5	91.7	102	112	122	132	143	153
4	76.4	85.9	95.5	105	115	124	134	143
4 1/2	67.9	76.4	84.9	93.4	102	110	119	127
5	61.1	68.8	76.4	84.0	91.7	99.3	107	115
5 1/2	55.6	62.5	69.5	76.4	83.3	90.3	97.2	104
6	50.9	57.3	63.7	70.0	76.4	82.8	89.1	95.5
6 1/2	47.0	52.9	58.8	64.6	70.5	76.4	82.3	88.2
7	43.7	49.1	54.6	60.0	65.5	70.9	76.4	81.9
7 1/2	40.7	45.8	50.9	56.0	61.1	66.2	71.3	76.4
8	38.2	43.0	47.7	52.5	57.3	62.1	66.8	71.6
8 1/2	36.0	40.4	44.9	49.4	53.9	58.4	62.9	67.4
9	34.0	38.2	42.4	46.7	50.9	55.2	59.4	63.6
9 1/2	32.2	36.2	40.2	44.2	48.3	52.3	56.3	60.3
10	30.6	34.4	38.2	42.0	45.8	49.7	53.5	57.3
11	27.8	31.3	34.7	38.2	41.7	45.1	48.6	52.1
12	25.5	28.6	31.8	35.0	38.2	41.4	44.6	47.8
13	23.5	26.4	29.4	32.3	35.3	38.2	41.1	44.1
14	21.8	24.5	27.3	30.0	32.7	35.5	38.2	40.9
15	20.4	22.9	25.5	28.0	30.6	33.1	35.7	38.2
16	19.1	21.5	23.9	26.3	28.7	31.0	33.4	35.8
17	18.0	20.2	22.5	24.7	27.0	29.2	31.5	33.7
18	17.0	19.1	21.2	23.3	25.5	27.6	29.7	31.8
	80	90	100	110	120	130	140	150

CHAPTER VIII

TYPICAL MILLING OPERATIONS

The operations illustrated herewith are examples secured from shops handling various classes of work on the milling machine.

The view in Fig. 134 illustrates the milling with four inserted tooth cutters, of cast iron shoes and wedges for locomotives. The total width

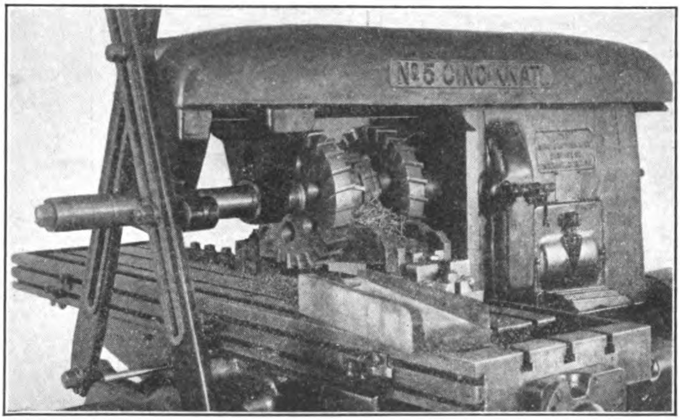


FIG. 134.—Milling cast-iron shoes and wedges.

of the cut in this operation is 17 inches and the amount of metal removed from $^1/_4$ inch to $^5/_{16}$ inch. The table travel is at the rate of 9 inches per minute and one of these shoes is milled in approximately 4 minutes.

Some further operations on locomotive parts are seen below. Figure 135 represents the slab milling of the face of a side rod with a large inserted tooth mill on a horizontal machine. The cutter is driven at 22 revolutions per minute and fed at the rate of $1\frac{1}{2}$ inch per minute. The depth of metal removed in the one cut is $\frac{3}{8}$ inch on each side of the steel forging. This cutter has a five-inch bore, which conveys some idea of the dimensions of the carrying and supporting members.

The milling of the edges of these rods is accomplished with the same type of cutter operating on two rods at once, or with a pair of similar cutters machining the edges of four rods simultaneously.

The depth of cut along the edge will average from 3/8 to 1/2 inch and at the large end this cut runs up to about 2 1/2 inches for a short

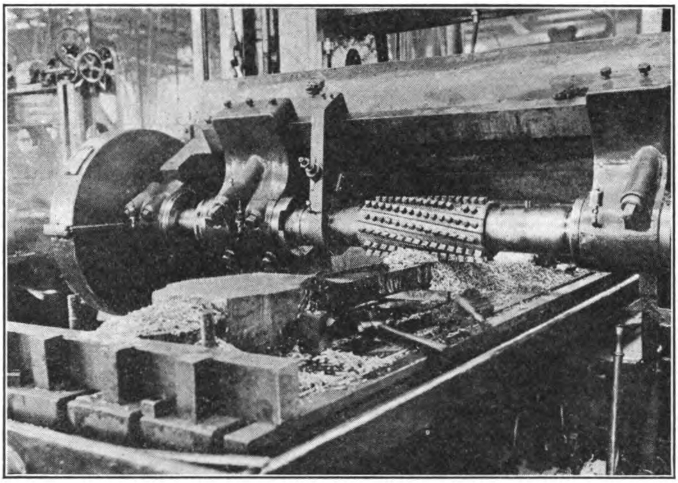


FIG. 135.—Slabbing the face of a locomotive side rod.

distance. The cutter speed is 22 revolutions per minute or a surface speed of 60 feet. The rate of feed is 2 inches per minute.

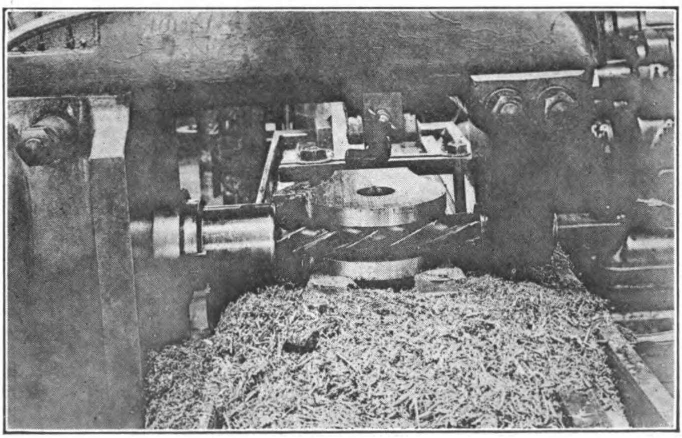


FIG. 136.—Slot-milling the side rod.

Milling out of the slot in the large end of the rods is accomplished with the cutter shown in operation in Fig. 136. This slot is milled from the solid metal, the width of the end being about 9 inches. The cutter detail, Fig. 137, shows all important dimensions of this tool. It is a spiral mill with five teeth cut at an angle of 30½ degrees or for

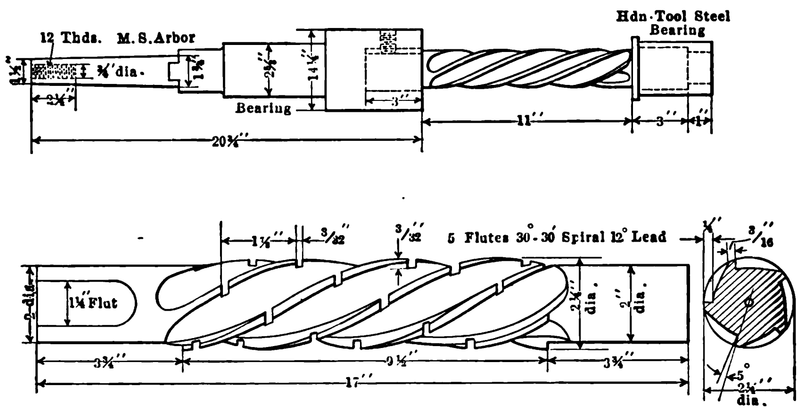


FIG. 137.—Details of cutter.

this size of mill 12-inch lead. The cutter is of high-speed steel and one cut is sufficient for the slot milling operation. The cutter is run

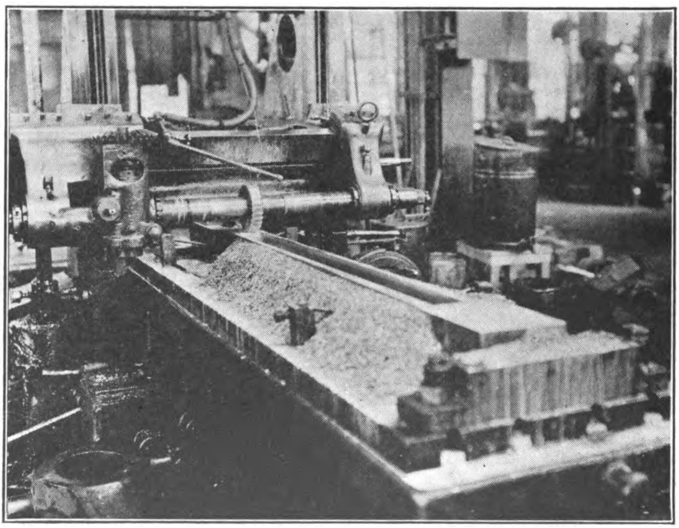


FIG. 138.—Milling channel in connecting rod.

at 148 revolutions per minute or 80 feet per minute surface speed. The feed is ¾ inch per minute.

Figure 138 is a channeling operation in a connecting rod in which a 7-inch side cutter is used on the horizontal miller, the cutter having a face of 2 inches and two cuts being taken from end to end to bring the channel to desired width. Each cut is made full depth or 1¾

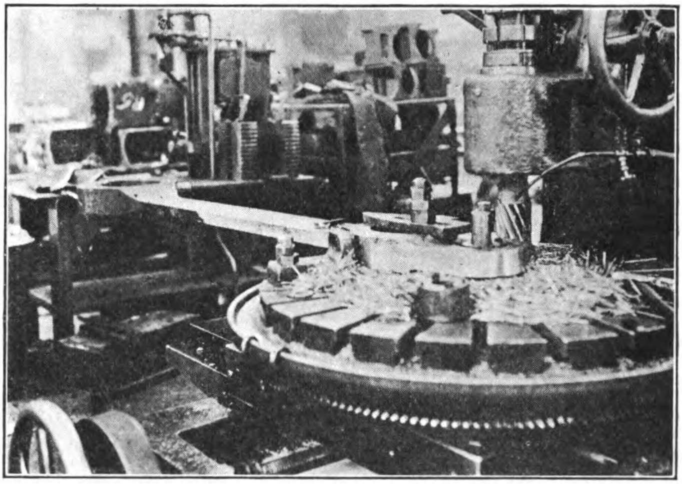


FIG. 139.—Milling the end of the rod.

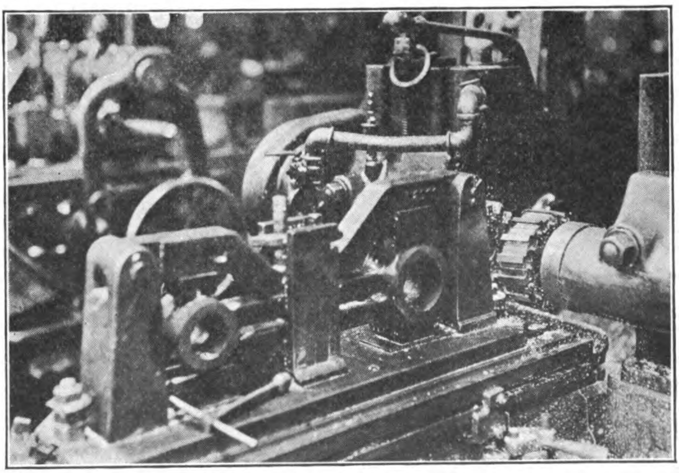


FIG. 140.—Straddle milling small connecting-rod ends.

inches. The length of cut is 65 inches. The feed is 2 inches per minute. The cutter speed is 50 revolutions per minute or 85 feet surface speed.

The operation in Fig. 139 is the milling of the edge of a side rod at the rounded end where the forging is about 4 inches in thickness at the broadest part and the amount of metal removed varies from 3/8 to 5/8 inch on a side. The work is done on the vertical miller with the cutter running at 45 feet per minute surface speed. The

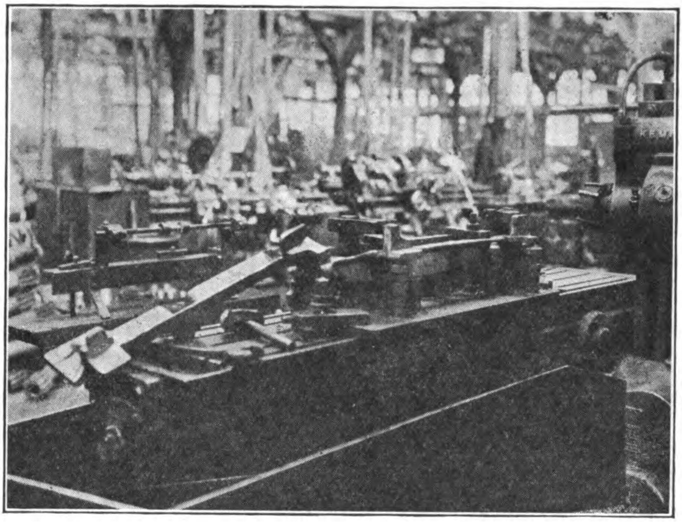


FIG. 141.—Milling a bracket.

work is fed around by the rotary table at 2 inches per minute while the round end is being milled, the straight portions permitting of a higher rate of feed. The surface is finished at the one cut. All of

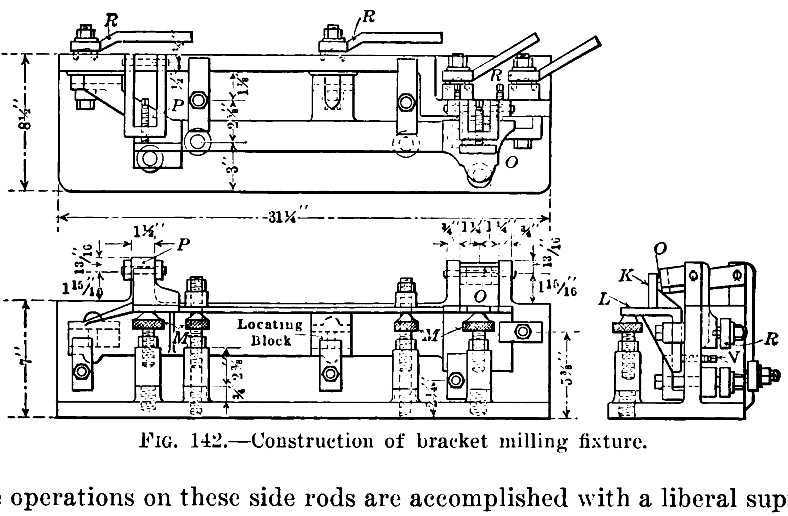


FIG. 142.—Construction of bracket milling fixture.

the operations on these side rods are accomplished with a liberal supply of lubricant on cutter and work.

Some operations on Holt Caterpillar Parts are seen in the views immediately below. Figure 140 is a straddle milling operation on connecting rods where both sides are undergoing facing at one time. The fixture for this operation is shown distinctly in the view. As indicated, the rod rests in V supports under the end and is held in position by two pivoted clamps over the top which swing down from opposite ends of the fixture and which carry a pair of V blocks for gripping the rod tightly when the swinging arms are forced down by two screws in the locking strap. This strap is slipped into grooves in the brackets shown at the center of the fixture.

Figure 141 shows a fixture for carrying a magneto bracket on the

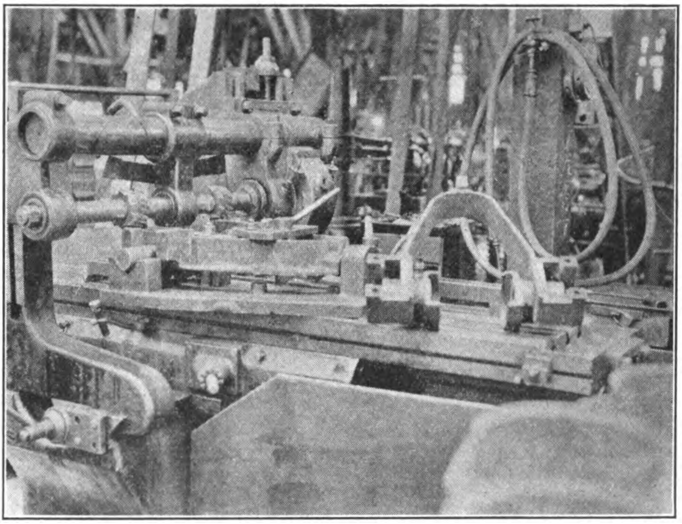


FIG. 143.—Milling a V-shaped bracket.

table of a miller. This bracket has various lugs and projections and requires special supporting devices in the fixture for holding the part properly. The fixture is shown clearly in Fig. 142 with the work in place. The operation is the milling of the bearing surfaces *K* and *L*, Fig. 142, the latter surface being at an angle of 2 degrees from a true right angle relation with surface *K*. So the cut in milling out the two seats at the ends of the bracket is taken with a mill which is tapered to the above angle and a single cut finishes both surfaces.

The work rests upon four stop screws *M*, Fig. 142, which are located under the points to be milled. Behind the work and at the bottom are stop screws *N* and at the top there are other stops carried in the swinging arms *O* and *P*, which are so pivoted as to be hung up out of the way for the removal of the work. A series of binder handles at the back

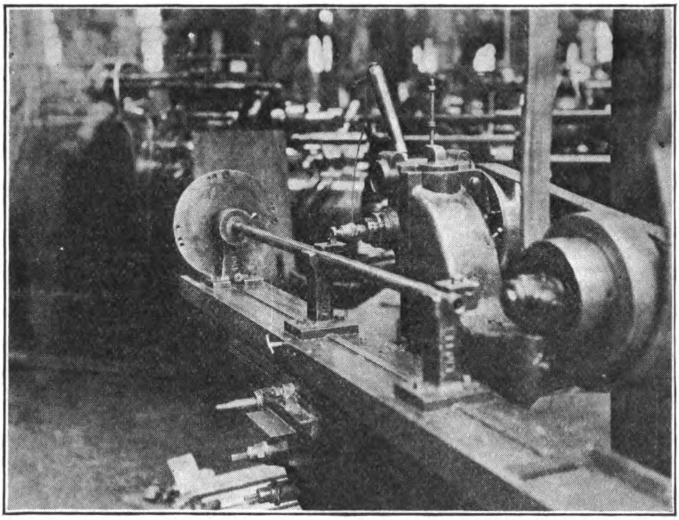


FIG. 144.—Hand miller with fixture for cam-shaft keyways.

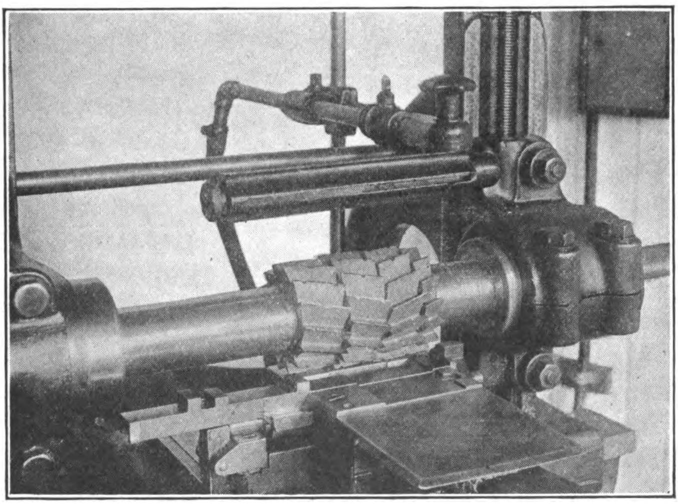


FIG. 145.—Finish milling bottom front section of rifle receiver.

operate the clamps on the face of the work and draw it back against the stops noted. These binders are in the nature of a face cam and are short enough to prevent undue stress being imposed upon the work.

Another bracket milling job is illustrated by Fig. 143. This casting is bored crosswise to form bearing surfaces and the holes are used here for carrying plugs which hold the work correctly in V blocks which form part of the milling fixture. There is a third hole at the closed end of the work and this provides an opening for a third locating plug which is fitted into a head on the fixture. Quick acting clamps lock the work in place. Two pairs of cutters are used to mill the bearing faces at the side of the bracket. A long arbor is necessary here to clear the wide work and fixture and the arbor is carried in a support at the middle as well as at the end.

A hand miller fixture is seen in Fig 144. This holds a cam shaft

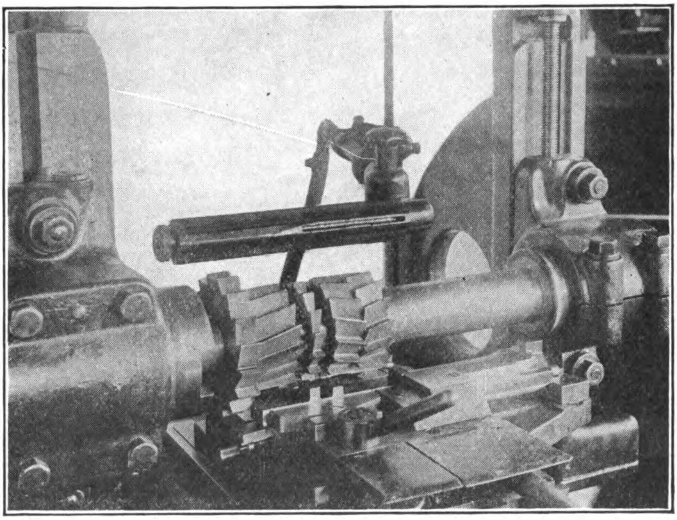


FIG. 146.—Finish milling of receiver bottom, rear end.

while the keyways are cut for the inlet and exhaust cams. There are eight keyways thus cut for Woodruff keys. The hand miller is fitted with a special table and fixture for locating all keyways in exact position in respect to one another and also in relation to the keyways for the timing gear which is cut in a previous operation. The upper slide on the fixture carries an index head and two supports for the long shaft. The work is slipped into a sleeve chuck where it is located by its main keyway. The angular positions of the cam keyways are then obtained by the index head which is provided with suitably spaced holes and index pin. The longitudinal position of the work for the series of keyways is obtained by a set of index lines and holes and by a locking plug seen at the front which enters the holes. The

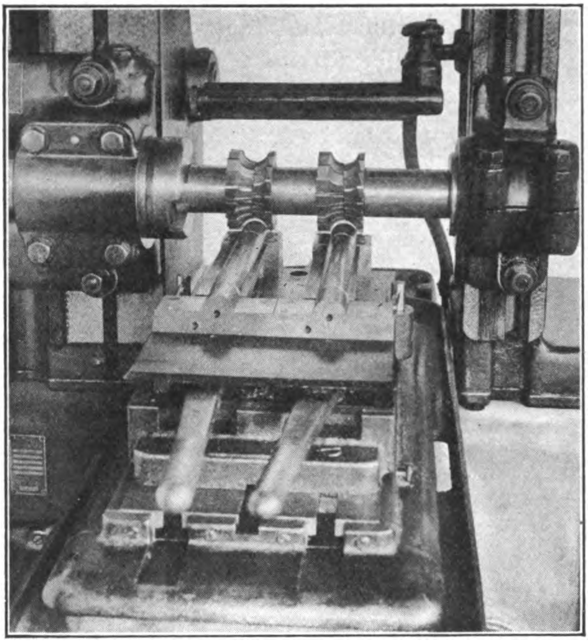


FIG. 147.—Finish milling of receiver top.

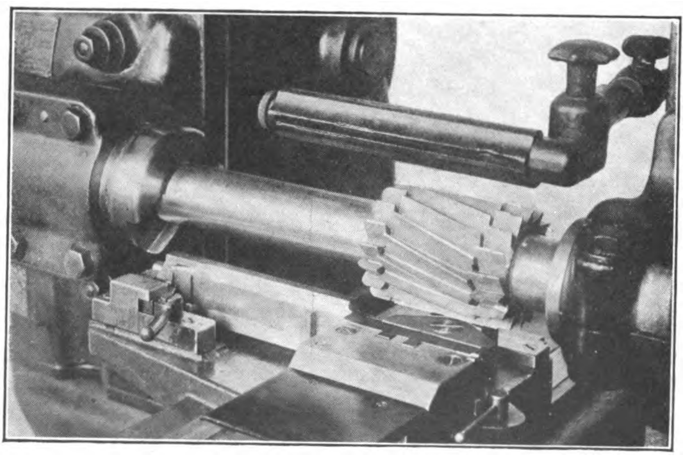


FIG. 148.—Finish milling of side of tang.

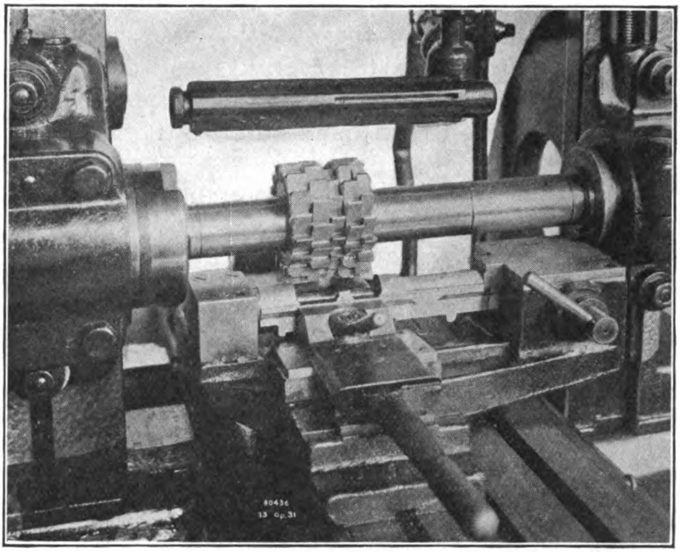


FIG. 149.—Milling top opening over magazine.

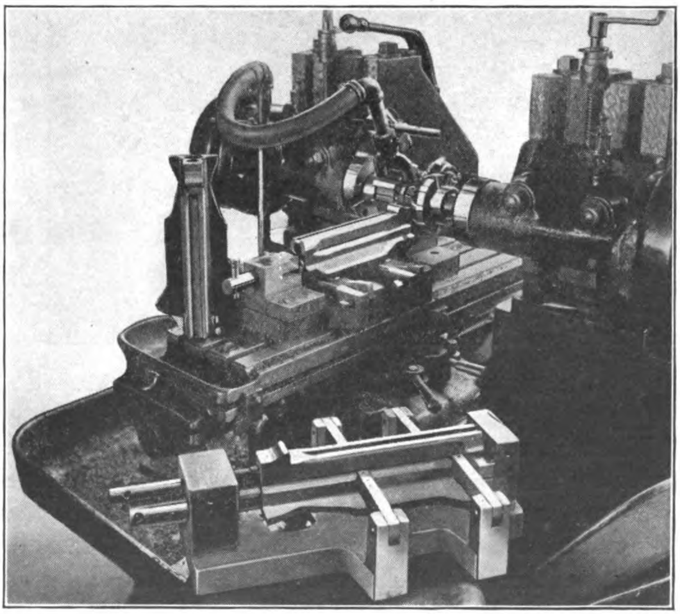


FIG. 150.—Milling a machine gun receiver.

machine once set for a given size of shaft, the operation of the apparatus consists in sinking the mill into the shaft for the first keyway, advancing the table to the next longitudinal station and locking it by the pin, then indexing the head spindle and work by means of the index plate on the spindle and cutting the next keyway.

GUN SHOP OPERATIONS

A few illustrations are here included to show typical milling operations on gun parts. Figures 145 to 149 show various cuts taken on the

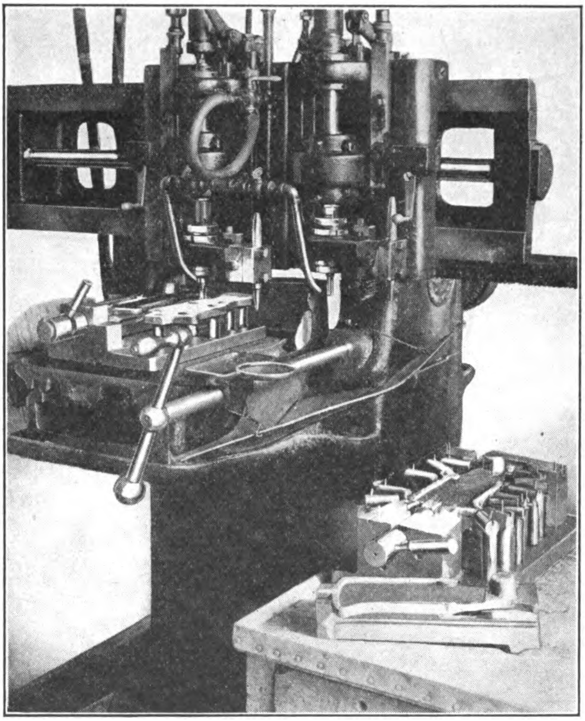


Fig. 151.—Profiling machine on machine-gun work.

Pratt & Whitney manufacturing miller in machining rifle receivers. These parts are made in large quantities and very accurately. The holding fixtures are rapid in operation and their general character is seen in the different views. Figure 145 shows the finish milling of the bottom front section of the receiver; Fig. 146 the finish milling of the bottom rear end; Fig. 147 finish milling of the top; Fig. 148 finish milling left-hand side of tang; Fig. 149 milling of top opening over magazine. Another interesting feature of these illustrations is the showing of the manner in which the cutters are ganged to take the different cuts over the surfaces indicated.

A milling operation on the receiver for a machine gun is shown by Fig. 150. The gage at the side is a flush pin device in which the milled part is located in the same way as in its milling fixture while the accuracy of the cuts is tested by series of flush pins which are

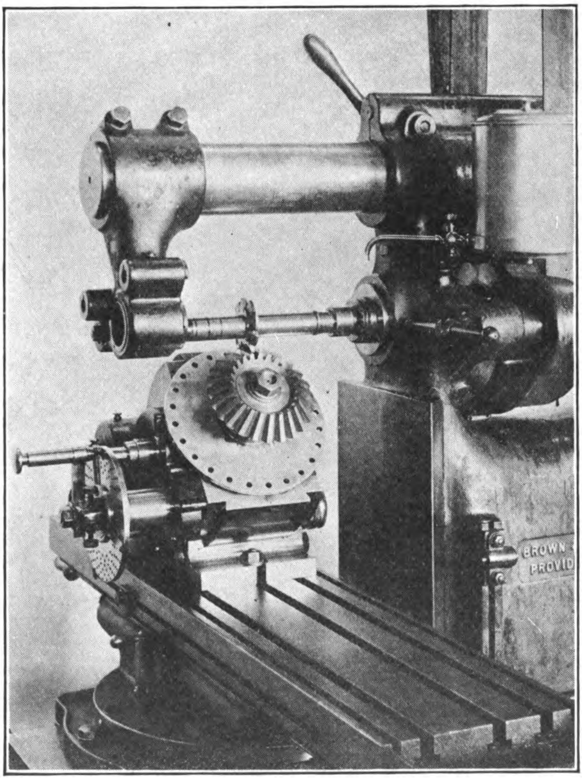


FIG. 152.—Cutting bevel-gear teeth.

pressed against the milled surface and must then come flush at their tops with the arms in which they are mounted. The operation illustrated is but one of a great number required to mill and otherwise machine such a part as a receiver for a machine gun.

Another type of machine used extensively on such work is the profiler which is a special form of milling machine in that it operates a small cutter in the same way as a regular vertical spindle miller except that the work is kept to the right path for the profiling cut by means of a former plate and guide pin. One illustration is included of this form of machine. See Fig. 151. The gage at the side is a device for testing the accuracy of the profiling cut taken around the edge of the receiver.

GEAR CUTTING

Gear cutting is one of the most important operations performed on the miller. It comprises in its branches a complete line of work

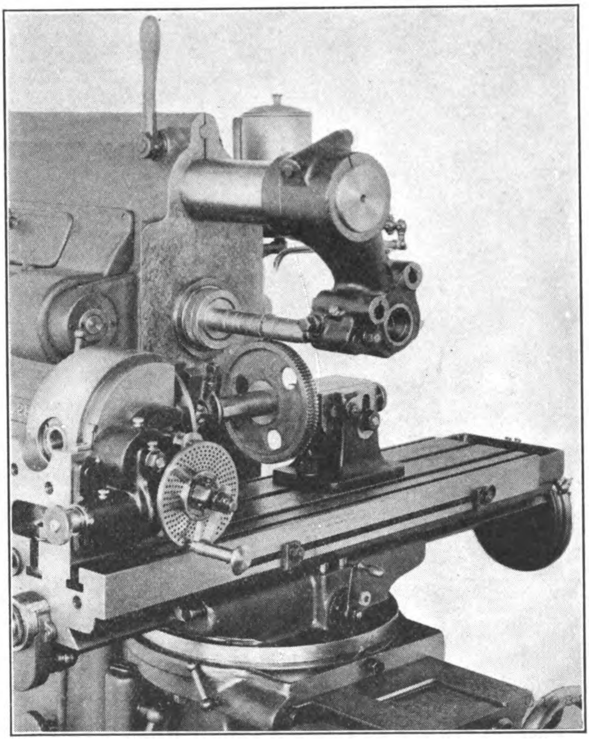


FIG. 153.—Cutting a worm wheel.

for the universal milling machine and an extensive treatise could be written on this subject alone. The present section gives little space to the subject as it is covered in other volumes in this Library. Two views are however presented herewith showing the universal miller set up for cutting a bevel gear, Fig. 152 and for cutting a worm wheel, Fig. 153.

GEARING FOR CUTTING WORM AND SPIRAL GEARS

Leads from .670" to 3.143"

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d x Worm}}{\text{1st x Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)
.670	24	86	24	100	1.714	40	56	24	100	2.442	28	64	48	86
.781	24	86	28	100	1.744	24	64	40	86	2.444	40	72	44	100
.800	24	72	24	100	1.750	28	64	40	100	2.450	56	64	28	100
.893	24	86	32	100	1.778	32	72	40	100	2.456	44	86	48	100
.900	24	64	24	100	1.786	32	86	48	100	2.481	32	72	48	86
.930	24	72	24	86	1.809	28	72	40	86	2.489	32	100	56	72
.933	24	72	28	100	1.823	28	100	56	86	2.500	24	64	48	72
1.029	24	56	24	100	1.860	24	72	48	86	2.514	44	56	32	100
1.042	28	86	32	100	1.867	28	72	48	100	2.532	28	72	56	86
1.047	24	64	24	86	1.886	44	56	24	100	2.537	24	44	40	86
1.050	24	64	28	100	1.919	24	64	44	86	2.558	32	64	44	86
1.067	24	72	32	100	1.925	28	64	44	100	2.567	44	48	28	100
1.085	24	72	28	86	1.944	28	64	32	72	2.605	28	40	32	86
1.116	24	86	40	100	1.956	32	72	44	100	2.619	24	56	44	72
1.196	24	56	24	86	1.990	28	72	44	86	2.658	32	56	40	86
1.200	24	64	32	100	1.993	24	56	40	86	2.667	40	72	48	100
1.221	24	64	28	86	2.000	32	64	40	100	2.674	28	64	44	72
1.228	24	86	44	100	2.030	24	44	32	86	2.713	28	48	40	86
1.240	24	72	32	86	2.035	28	64	40	86	2.743	48	56	32	100
1.244	28	72	32	100	2.047	40	86	44	100	2.750	40	64	44	100
1.302	28	86	40	100	2.057	48	56	24	100	2.778	32	64	40	72
1.333	24	72	40	100	2.067	32	72	40	86	2.791	32	64	48	86
1.340	24	86	48	100	2.083	24	64	40	72	2.800	56	64	32	100
1.371	32	56	24	100	2.093	24	64	48	86	2.842	40	72	44	86
1.395	24	64	32	86	2.100	28	64	48	100	2.849	28	64	56	86
1.400	28	64	32	100	2.133	32	72	48	100	2.857	24	56	48	72
1.433	28	86	44	100	2.171	28	72	48	86	2.865	44	100	56	86
1.447	28	72	32	86	2.178	28	100	56	72	2.880	48	40	24	100
1.458	24	64	28	72	2.182	40	44	24	100	2.894	32	72	56	86
1.467	24	72	44	100	2.193	24	56	44	86	2.917	28	64	48	72
1.488	32	86	40	100	2.200	32	64	44	100	2.924	32	56	44	86
1.500	40	64	24	100	2.222	28	56	32	72	2.933	44	72	48	100
1.550	24	72	40	86	2.233	40	86	48	100	2.946	44	56	24	64
1.556	28	72	40	100	2.238	28	64	44	86	2.960	28	44	40	86
1.563	28	86	48	100	2.274	32	72	44	86	2.984	28	48	44	86
1.595	24	56	32	86	2.286	32	56	40	100	3.000	40	64	48	100
1.600	24	72	48	100	2.292	24	64	44	72	3.044	24	44	48	86
1.628	28	64	32	86	2.326	32	64	40	86	3.056	32	64	44	72
1.637	32	86	44	100	2.368	28	44	32	86	3.070	24	40	44	86
1.650	44	64	24	100	2.381	24	56	40	72	3.101	40	72	48	86
1.667	24	64	32	72	2.392	24	56	48	86	3.111	40	100	56	72
1.705	24	72	44	86	2.400	32	64	48	100	3.126	48	100	56	86
1.711	28	72	44	100	2.431	28	64	40	72	3.143	40	56	44	100

FIG. 153A.—For leads up to 3.143 in.

Gearing for Cutting Worm and Spiral Gears

Leads from 3.175" to 6.667"

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d x Worm}}{\text{1st x Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)
3.175	32	56	40	72	4.040	32	44	40	72	5.185	32	48	56	72
3.189	32	56	48	86	4.059	32	44	48	86	5.209	56	40	32	86
3.198	40	64	44	86	4.070	40	64	56	86	5.226	86	64	28	72
3.241	28	48	40	72	4.074	32	48	44	72	5.238	44	56	48	72
3.256	32	64	56	86	4.093	32	40	44	86	5.316	40	56	64	86
3.267	56	48	28	100	4.134	40	72	64	86	5.333	32	40	48	72
3.300	44	64	48	100	4.144	56	44	28	86	5.347	44	64	56	72
3.307	32	72	64	86	4.167	40	64	48	72	5 357	48	64	40	56
3.333	32	64	48	72	4.200	48	100	56	64	5.412	64	44	32	86
3.349	24	40	48	86	4.242	28	44	48	72	5.426	40	48	56	86
3.360	48	40	28	100	4.252	32	56	64	86	5.444	56	40	28	72
3.383	32	44	40	86	4.264	40	48	44	86	5.568	56	44	28	64
3.403	28	64	56	72	4.286	48	64	32	56	5.625	72	48	24	64
3.411	44	72	48	86	4.341	48	72	56	86	5.657	32	44	56	72
3.422	44	100	56	72	4.364	48	44	40	100	5.714	64	48	24	56
3.429	40	56	48	100	4.365	40	56	44	72	5.759	86	56	24	64
3.488	40	64	48	86	4.375	56	48	24	64	5.788	56	72	64	86
3.492	32	56	44	72	4.385	44	56	48	86	5.833	48	64	56	72
3.500	40	100	56	64	4.444	28	56	64	72	5.847	44	56	64	86
3.520	44	40	32	100	4.465	32	40	48	86	5.893	48	64	44	56
3.551	28	44	48	86	4.477	44	64	56	86	5.920	40	44	56	86
3.565	28	48	44	72	4.480	56	40	32	100	5.926	64	48	32	72
3.581	28	40	44	86	4.537	28	48	56	72	5.954	64	40	32	86
3.618	40	72	56	86	4.548	44	72	64	86	5.969	44	48	56	86
3.636	24	44	48	72	4.558	56	40	28	86	5.972	86	48	24	72
3.654	40	56	44	86	4.583	44	64	48	72	6.061	40	44	48	72
3.667	44	48	40	100	4.667	28	40	48	72	6.109	56	44	48	100
3.704	32	48	40	72	4.736	32	44	56	86	6.125	56	40	28	64
3.721	28	56	64	86	4.762	40	56	48	72	6.136	72	44	24	64
3.733	48	100	56	72	4.773	56	44	24	64	6.140	44	40	48	86
3.750	48	64	28	56	4.821	72	56	24	64	6.160	56	40	44	100
3.771	44	56	48	100	4.848	32	44	48	72	6.202	40	48	64	86
3.798	28	48	56	86	4.861	40	64	56	72	6.222	64	40	28	72
3.810	32	56	48	72	4.884	48	64	56	86	6.234	64	44	24	56
3.819	40	64	44	72	4.889	32	40	44	72	6.349	40	56	64	72
3.837	44	64	48	86	4.949	56	44	28	72	6.364	56	44	32	64
3.840	48	40	32	100	4.961	48	72	64	86	6.379	48	56	64	86
3.850	44	100	56	64	5.074	40	44	48	86	6.429	72	56	32	64
3.889	32	64	56	72	5.080	32	56	64	72	6.465	64	44	32	72
3.907	28	40	48	86	5.093	40	48	44	72	6.481	40	48	56	72
3.920	56	40	28	100	5.104	56	48	28	64	6.515	86	44	24	72
3.979	44	72	56	86	5.119	86	56	24	72	6.563	72	48	28	64
3.986	40	56	48	86	5.133	56	48	44	100	6.667	64	56	28	48

FIG. 153B.—For leads up to 6.667 in.

GEARING FOR CUTTING WORM AND SPIRAL GEARS

Leads from 6.720" to 12.444"

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d x Worm}}{\text{1st x Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)
6.720	56	40	48	100	8.212	86	64	44	72	10.238	86	56	48	72
6.750	72	40	24	64	8.250	48	64	44	40	10.286	72	40	32	56
6.765	40	44	64	86	8.312	64	56	32	44	10.313	72	64	44	48
6.806	56	32	28	72	8.333	48	32	40	72	10 370	56	48	64	72
6.822	44	48	64	86	8.361	86	40	28	72	10.390	64	56	40	44
6.825	86	56	32	72	8.377	86	44	24	56	10.419	56	40	64	86
6.968	86	48	28	72	8.485	48	44	56	72	10.451	86	64	56	72
6.984	44	56	64	72	8.532	86	56	40	72	10.476	64	56	44	48
7.000	56	40	32	64	8.551	86	44	28	64	10.500	56	64	48	40
7.013	72	44	24	56	8.555	44	40	56	72	10.558	86	64	44	56
7.071	40	44	56	72	8.571	72	56	32	48	10.667	48	40	64	72
7.104	48	44	56	86	8.682	64	48	56	86	10.694	56	32	44	72
7.111	64	40	32	72	8.687	86	44	32	72	10.714	72	56	40	48
7.130	44	48	56	72	8.839	72	64	44	56	10.750	86	40	32	64
7.159	72	44	28	64	8.889	56	28	32	72	10.859	86	44	40	72
7.163	44	40	56	86	8.930	48	40	64	86	10.909	72	48	32	44
7.167	86	40	24	72	8.958	86	56	28	48	10.938	56	32	40	64
7.273	64	44	28	56	9.000	72	40	28	56	10.949	86	48	44	72
7.292	56	64	40	48	9.143	64	40	32	56	11.111	64	32	40	72
7.330	86	44	24	64	9.166	48	32	44	72	11.168	86	44	32	56
7.333	44	40	48	72	9.214	86	40	24	56	11.169	72	48	64	86
7.407	40	48	64	72	9.333	48	40	56	72	11.198	86	64	40	48
7.465	86	64	40	72	9.351	72	56	32	44	11.250	72	32	28	56
7.500	72	48	32	64	9.375	72	64	40	48	11.313	56	44	64	72
7.601	86	44	28	72	9.385	86	56	44	72	11.402	86	44	28	48
7.619	48	56	64	72	9.406	86	40	28	64	11.518	86	64	48	56
7.679	86	64	32	56	9.429	48	56	44	40	11.667	56	32	48	72
7.714	72	40	24	56	9.471	56	44	64	86	11.688	72	56	40	44
7.778	64	32	28	72	9.524	64	56	40	48	11.758	86	32	28	64
7.814	48	40	56	86	9.545	72	48	28	44	11.786	72	56	44	48
7.839	86	48	28	64	9.556	86	40	32	72	11.852	64	24	32	72
7.875	72	40	28	64	9.568	72	56	64	86	12.000	72	40	32	48
7.955	56	64	40	44	9.598	86	64	40	56	12.031	56	32	44	64
7.963	86	48	32	72	9.625	56	64	44	40	12.040	86	56	64	72
8.000	64	40	28	56	9.643	72	64	48	56	12 121	64	48	40	44
8.021	56	64	44	48	9.697	64	48	32	44	12.178	72	44	64	86
8.036	72	64	40	56	9.722	56	32	40	72	12.216	86	64	40	44
8.063	86	40	24	64	9.773	86	44	32	64	12.222	48	24	44	72
8.081	40	44	64	72	9.778	44	40	64	72	12.273	72	64	48	44
8.118	48	44	64	86	9.844	72	32	28	64	12.286	86	40	32	56
8.148	44	48	64	72	9.954	86	48	40	72	12.318	86	64	44	48
8.182	72	44	28	56	10 159	64	28	32	72	12.375	72	40	44	64
8.186	44	40	64	86	10 227	72	64	40	44	12.444	56	40	64	72

FIG. 153C.—For leads up to 12.444 in.

Gearing for Cutting Worm and Spiral Gears

Leads from 12.468" to 24.635"

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d x Worm}}{\text{1st x Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)
12.468	64	56	48	44	15.429	72	56	48	40	19.196	86	32	40	56
12.500	56	28	40	64	15.469	72	32	44	64	19.286	72	32	48	56
12.542	86	40	28	48	15.556	64	32	56	72	19.592	64	28	48	56
12.571	64	56	44	40	15.636	86	40	32	44	19.636	72	44	48	40
12.698	64	28	40	72	15.677	86	64	56	48	19 688	72	32	56	64
12.798	86	56	40	48	15 714	64	32	44	56	19.708	86	48	44	40
12.833	56	48	44	40	15.750	72	64	56	40	19.907	86	24	40	72
12.857	72	28	32	64	15 926	86	48	64	72	20.156	86	64	72	48
12.963	56	24	40	72	16.071	72	32	40	56	20.204	72	28	44	56
13.030	86	48	32	44	16.125	86	64	48	40	20.364	64	44	56	40
13.091	72	40	32	44	16.288	86	48	40	44	20.455	72	32	40	44
13.125	56	32	48	64	16.296	64	24	44	72	20.476	86	56	64	48
13.139	86	40	44	72	16.424	86	32	44	72	20.571	72	56	64	40
13.333	64	32	48	72	16.500	72	48	44	40	20.625	72	48	44	32
13.395	72	40	64	86	16.722	86	40	56	72	20.741	64	24	56	72
13.438	86	32	28	56	16.753	86	56	48	44	20.903	86	32	56	72
13.500	72	64	48	40	16.797	86	32	40	64	20.952	64	24	44	56
13.636	72	48	40	44	16.875	72	32	48	64	21.000	72	48	56	40
13.651	86	28	32	72	16.893	86	56	44	40	21.116	86	32	44	56
13 714	64	56	48	40	16.970	64	48	56	44	21.429	72	28	40	48
13.750	56	28	44	64	17.063	86	28	40	72	21.818	72	48	64	44
13.935	86	24	28	72	17.102	86	64	56	44	21.939	86	28	40	56
13.961	86	56	40	44	17.143	72	56	64	48	21.989	86	64	72	44
13 968	64	28	44	72	17.277	86	64	72	56	22.041	72	28	48	56
14.026	72	56	48	44	17.374	86	44	64	72	22.338	86	56	64	44
14.063	72	32	40	64	17.455	64	44	48	40	22.396	86	32	40	48
14.077	86	56	44	48	17.500	56	24	48	64	22.500	72	28	56	64
14.143	72	56	44	40	17.551	86	28	32	56	22.803	86	48	56	44
14.259	56	24	44	72	17 679	72	56	44	32	22.857	64	24	48	56
14.286	64	32	40	56	17.777	64	28	56	72	22.909	72	44	56	40
14.318	72	64	56	44	17.917	86	32	48	72	23.036	86	56	72	48
14.333	86	40	48	72	17.959	64	28	44	56	23.333	64	48	56	32
14.659	86	64	48	44	18.333	64	48	44	32	23.455	86	44	48	40
14.667	64	48	44	40	18.367	72	28	40	56	23.516	86	64	56	32
14.694	72	28	32	56	18 429	86	56	48	40	23.571	72	28	44	48
14 781	86	64	44	40	18.477	86	32	44	64	23.889	86	32	64	72
14.815	64	24	40	72	18.667	64	48	56	40	24.000	72	48	64	40
14.931	86	32	40	72	18.701	72	56	64	44	24.133	86	28	44	56
15 000	56	28	48	64	18.750	72	32	40	48	24.188	86	64	72	40
15.202	86	44	56	72	18.770	86	28	44	72	24.432	86	32	40	44
15.238	64	28	48	72	18.813	86	64	56	40	24.545	72	44	48	32
15.273	56	44	48	40	19.091	72	48	56	44	24.571	86	56	64	40
15 357	86	28	32	64	19 111	86	40	64	72	24.635	86	48	44	32

Fig. 153d.—For leads up to 24.635 in.

Gearing for Cutting Worm and Spiral Gears

Leads from 24.750″ to 80.625″

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d x Worm}}{\text{1st x Screw}}$$

Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)	Lead of Spiral in Inches	Gear on Worm (Driven)	1st Intermediate Gear (Driver)	2d Intermediate Gear (Driven)	Gear for Screw (Driver)
24.750	72	40	44	32	30.857	72	28	48	40	40.952	86	28	64	48
25.083	86	48	56	40	31.111	64	24	56	48	41.143	72	28	64	40
25.130	86	56	72	44	31.273	86	44	64	40	41.806	86	24	56	48
25.455	64	44	56	32	31.354	86	48	56	32	42.232	86	28	44	32
25 595	86	28	40	48	31.500	72	40	56	32	43.000	86	40	64	32
25 714	72	56	64	32	31.852	86	24	64	72	43.636	72	24	64	44
26.061	86	48	64	44	32.000	64	28	56	40	43.977	86	44	72	32
26 182	72	44	64	40	32.250	86	48	72	40	44.675	86	28	64	44
26.250	72	48	56	32	32.576	86	24	40	44	45.000	72	28	56	32
26.327	86	28	48	56	32.727	72	44	64	32	45.606	86	24	56	44
26.667	64	28	56	48	32.847	86	24	44	48	46.071	86	28	72	48
26.875	86	28	56	64	33.507	86	28	48	44	47.778	86	24	64	48
27.000	72	40	48	32	33.786	86	28	44	40	48.000	72	24	64	40
27 302	86	28	64	72	33.939	64	24	56	44	48.375	86	40	72	32
27 364	86	44	56	40	34.205	86	44	56	32	49.143	86	28	64	40
27 500	72	24	44	48	34.286	72	28	64	48	50.167	86	24	56	40
27.643	86	56	72	40	34.554	86	56	72	32	50.260	86	28	72	44
27 922	86	28	40	44	35.000	72	24	56	48	51.429	72	28	64	32
28.000	64	40	56	32	35.102	86	28	64	56	52.121	86	24	64	44
28.052	72	28	48	44	35.182	86	44	72	40	53.750	86	28	56	32
28.155	86	28	44	48	35.833	86	48	64	32	55.286	86	28	72	40
28.636	72	44	56	32	36.000	72	40	64	32	57.333	86	24	64	40
28.667	86	48	64	40	36.857	86	28	48	40	58.636	86	24	72	44
29 091	64	28	56	44	37.403	72	28	64	44	60.000	72	24	64	32
29.318	86	48	72	44	37.625	86	40	56	32	61.429	86	28	64	32
29.388	72	28	64	56	38.182	72	24	56	44	62.708	86	24	56	32
29 563	86	40	44	32	39.091	86	44	64	32	64.500	86	24	72	40
29.861	86	24	40	48	39.417	86	24	44	40	69.107	86	28	72	32
30.000	72	48	64	32	39.490	86	28	72	56	71.667	86	24	64	32
30.234	86	64	72	32	40.000	72	24	64	48	80.625	86	24	72	32
30.714	86	56	64	32	40.313	86	48	72	32					

FIG. 153E.—For leads up to 80.625 in.

Table of Change Gears, Approximate Angles and Leads for Cutting Spirals

Twelve Change Gears are furnished with each Universal Miller as follows: 24, 24, 28, 32, 40, 44, 48, 56, 64, 72, 86 and 100 teeth.

1st Intermediate Gear Drives the Gear on Worm.
2d Intermediate Gear drives the Gear for Screw.

Lead of Spiral, Inches	Gear on Worm	1st Intermediate Gear	2d Intermediate Gear	Gear for Screw	DIAMETER OF WORK																							
					1/8 In.	1/4 In.	3/8 In.	1/2 In.	5/8 In.	3/4 In.	7/8 In.	1 In.	1¼ In.	1½ In.	1¾ In.	2 In.	2¼ In.	2½ In.	2¾ In.	3 In.	3¼ In.	3½ In.	3¾ In.	4 In.	4½ In.	5 In.	5½ In.	6 In.
	Driven	Driver	Driven	Driver																								
67	24	86	24	100	30¼																							
.78	24	86	28	100	26	44½																						
.89	24	86	32	100	23½	41																						
1.12	24	86	40	100	19	34½																						
1.34	24	86	48	100	16	30¼	41½																					
1.46	24	64	28	72	14¾	28	38½																					
1.56	28	86	48	100	13¾	26½	37																					
1.67	24	64	32	72	12¾	25	34¾	43¼																				
1.94	28	64	32	72	11¼	21¾	31	39	45																			
2 08	24	64	40	72	10¼	20½	29½	37	43¼																			
2.22	32	56	28	72	9¾	19¼	27½	35	41¼																			
2.50	24	64	48	72	8¾	17	25	32	38	43¼																		
2.78	32	64	40	72	8	15½	23	29½	35¼	40½	44¾																	
2.92	32	56	44	86	7½	15	21¾	28¼	34	39	43¼																	
3.24	28	48	40	72	6¾	13¼	19¾	25¾	31¼	36	40½	44¼																
3.70	32	48	40	72	6	11¾	17½	23	28	32½	36½	40½																
3.89	32	64	56	72	5½	11¼	16¾	22	26¾	31¼	35¼	39																
4.17	40	64	48	72	5¼	10½	15¾	20½	25¼	29½	33½	37	43¼															
4.46	32	40	48	86	4¾	9¾	14¾	19¼	23¾	27¾	31½	35	41½															
4.86	40	64	56	72	4½	9	13½	17¾	22	25¾	29½	33	39	44¼														
5.33	32	40	48	72	4	8¼	12¼	16½	20¼	23¾	27¼	30½	36½	41½														
5.44	56	40	28	72	4	8	12	16	20	23½	26¾	30	36	41														
6.12	56	40	28	64	3½	7¼	11	14½	17¾	21	24¼	27	33	37¾	42													
6.22	64	40	28	72	3½	7	10¾	14¼	17½	20¾	23¾	26¾	32½	37¼	41½													
6.48	40	48	56	72	3¼	6¾	10¼	13½	16¾	20	23	25¾	31½	36¼	40¼	44¼												
6.67	64	56	28	48	3¼	6½	10	13¼	16½	19½	22½	25¼	30¾	35¼	39½	43½												
7 29	56	64	40	48	3	6¼	9¼	12¼	15	18	20½	23½	28½	33	37	41	44¼											
7 41	40	48	64	72	3	6	9	12	14¾	17¾	20¼	22¾	28¼	32½	36½	40¼	43¾											

Approximate Angle in Degrees for Setting Milling Machine Table.

These tables are of especial convenience for quickly setting the machine with proper change gears when the angle of spiral and the diameter of a piece of work are known. For example: To cut a spiral mill 4" diameter, 25° angle: Follow down the 4" column to the nearest angle, 25¼, and the change gears are 64, 28, 56 and 48.

$$\frac{\text{Lead}}{10} = \frac{\text{Driven}}{\text{Drivers}} = \frac{\text{2d} \times \text{Worm}}{\text{1st} \times \text{Screw}}$$

FIG. 153F.—For leads up to 7.41 in.

7.62	48	56	64	72	2¾	5½	8¾	11½	14½	17¼	19¾	22¼	27½	32	36	39½	43											
8.33	48	32	40	72	2½	5¼	8	10½	13¼	15¾	18¼	20½	25½	29½	33½	37	40½	43½										
8.95	86	48.	28	56	2½	5	7½	10	12½	14¾	17	19½	24	28	31¾	35¼	38½	41¼	44									
9.33	48	40	56	72	2¼	4¾	7¼	9½	11¾	14	16¼	18½	23	27	30½	34	37½	40¼	43									
9.52	64	56	40	48	2¼	4½	7	9¼	11½	13¾	16	18¼	22½	26½	30	33½	36½	39½	42¼	45								
10.29	72	40	32	56	2	4¼	6½	8¾	10¾	12¾	15	17¼	21	24¾	28¼	31½	34½	37½	40	42¼	45							
10.37	56	48	64	72	2	4¼	6½	8½	10½	12¾	14¾	17	20¾	24½	28	31¼	34¼	37¼	39¾	42¼	44¾							
10.50	56	64	48	40	2	4¼	6¼	8½	10½	12½	14½	16¾	20½	24¼	27¾	31	34	36¾	39½	42	44¼							
10.67	48	40	64	72	2	4	6¼	8¼	10¼	12¼	14¼	16½	20¼	24	27¼	30½	33½	36½	39	41½	43¾							
10.94	56	32	40	64	2	4	6	8¼	10¼	12	14	16¼	20	23½	26¾	30	33	35¾	38¼	43¾	43							
11.11	64	32	40	72	2	4	6	8	10	11¾	13¾	16	19¾	23	26½	29½	32½	35¼	38	40¼	42½	44¾						
11.66	56	32	48	72	1¾	3¾	5¾	7½	9½	11¼	13¼	15¾	18¾	22	25¼	28½	31¼	34	36½	39	41¼	43½						
12.00	72	40	32	48	1¾	3¾	5½	7¼	9¼	11	12¾	15	18¼	21½	24¾	27¾	30½	33¼	35¾	38	40¼	42½	44¾					
13.12	56	32	48	64	1½	3½	5¼	6¾	8½	10¼	11¾	13½	16¾	20	22¾	25¾	28¼	31	33¼	35¾	37¾	40	42	43¾				
13.33	64	32	48	72	1½	3¼	5	6½	8¼	10	11½	13¼	16½	19½	22½	25½	28	30½	33	35¼	37½	39½	41½	43¼	46¾	49¼	52¼	
13.71	64	56	48	40	1½	3¼	4¾	6½	8	9¾	11¼	13	16	19	22	24¾	27¼	30	32¼	34½	36½	38¾	40¾	42½	45¾	49	51½	
15.24	64	28	48	72	1½	3	4½	5¾	7¼	8¾	10¼	11¾	14½	17¼	20	22½	25	27¼	29½	31¾	34	35¾	37¾	39½	42¾	46	48½	51
15.56	64	32	56	72	1¼	2¾	4¼	5¾	7¼	8¾	10	11½	14¼	17	19½	22	24½	27	29	31¼	33¼	35¼	37	39	42¼	45¼	48	50½
15.75	72	64	56	40	1¼	2¾	4¼	5½	7	8½	9¾	11¼	14	16¾	19¼	21¾	24¼	26½	28¾	31	33	35	36¾	38½	42	45	47½	50
16.87	72	32	48	64	1¼	2½	4	5¼	6¾	7¾	9¼	10½	13¼	15¾	18¼	20½	22¾	25	27	29¼	31¼	33¼	35	36½	39¾	43	45¾	48¼
17.14	72	56	64	48	1¼	2½	4	5¼	6½	7¾	9	10¼	13	15½	17¾	20¼	22¼	24¾	26¾	29	30¾	32¾	34½	36	39½	42½	45¼	47¾
18.75	72	32	40	48	1	2¼	3½	4¾	6	7¼	8¼	9½	12	14¼	16¼	18½	20¾	22¾	25	26¾	28½	30¼	32	33¾	37	39¾	42¾	45
19.29	72	32	48	56	1	2¼	3½	4½	5¾	7	8	9¼	11½	13¾	16	18¼	20¼	22¼	24	26	28	29¾	31½	33	36¼	38¾	42	44½
19.59	64	28	48	56	1	2¼	3¼	4½	5¾	6¾	8	9¼	11½	13½	15¾	18	20	22	23¾	25¾	27½	29¼	31	32¾	35½	38¾	41½	44
19.69	72	32	56	64	1	2¼	3¼	4½	5¾	6¾	8	9	11½	13½	15¾	17¾	20	21¾	23¾	25½	27½	29¼	31	32½	35¾	38½	41¼	43¾
21.43	72	28	40	48	1	2	3¼	4¼	5¼	6¼	7½	8½	10½	12½	14½	16½	18½	20¼	22	23¾	25½	27¼	29	30¼	33½	36¼	38¾	41¼
22.50	72	28	56	64	1	2	3	4	5	6	7	8	10	12	13¾	15¾	17½	19¼	21	22¾	24½	27	27¾	29¼	32¼	35	37½	40
23.33	64	48	56	32	1	2	3	4	5	5¾	6¾	7¾	9¾	11½	13¼	15¼	17	18¾	20¼	22	23½	25¼	27	28¼	31¼	34	36¾	39
26.25	72	48	56	32	1	1¾	2¾	3½	4¼	5	6	7	8½	10¼	12	13½	15	16¾	18¼	19¾	21¼	22¾	24¼	25½	28¼	31	33¼	35¾
26.67	64	28	56	48	¾	1¾	2¾	3½	4¼	5	6	6¾	8½	10	11¾	13¼	14¾	16½	18	19½	21	22¼	23¾	25¼	28	30½	31¼	35¼
28.00	64	40	56	32	¾	1¾	2½	3¼	4	4¾	5¾	6½	8	9½	11¼	12¾	14¼	15¾	17¼	18¾	20	21½	22¾	24	26¾	29¼	31¾	34
30.86	72	28	48	40	¾	1½	2¼	3	3¾	4½	5	5¾	7¼	8¾	10	11½	13	14¼	15½	17	18½	19½	21	22	26	27	29¼	31½
31.50	72	40	56	32	¾	1½	2¼	3	3½	4¼	5	5¾	7¼	8½	10	11¼	12¾	14	15¼	16½	18	19¼	20½	21¾	24¼	26¾	28¾	31
36.00	72	40	64	32	½	1¼	2	2½	3¼	3¾	4½	5	6¼	7½	8¾	10	11	12¼	13½	14¾	16	17	18¼	19¼	21½	23½	25¾	27¾
41.14	72	28	64	40	½	1	1¾	2¼	2¾	3¼	4	4½	5½	6½	7¾	8¾	9¾	10¾	11¾	13	14	15	16	17	19	21	22¾	24¾
45.00	72	28	56	32	½	1	1½	2	2½	3	3½	4	5	6	7	8	9	10	11	11¾	12¾	13¾	14¾	15½	17½	19¼	21	22¾
48.00	72	24	64	40	½	1	1½	2	2½	3	3¼	3¾	4¾	5½	6½	7½	8½	9¼	10¼	11¼	12	13	13¾	14½	16½	18	19¾	21½
51.43	72	28	64	32	½	¾	1½	1¾	2¼	2¾	3	3½	4½	5¼	6	7	7¾	8¾	9½	10½	11¼	12	12¾	13¾	14¾	17	18½	20
60.00	72	24	64	32	½	¾	1¼	1½	2	2¼	2½	3	3¾	4½	5¼	6	6¾	7½	8¼	9	9½	10¼	11	11¾	13¼	14¾	16	17½

FIG. 153G.—For leads up to 60 in.

SECTION VI

GEAR CUTTING

CHAPTER I

METHODS OF GEAR CUTTING

There are two methods of cutting gears, by milling and by the planing processes. The first includes the older method of using a formed milling cutter which cuts a single tooth as well as the newer method of hobbing or continuous milling. The second includes the Fellows gear shaper for spur gears and the Gleason and Bilgram gear planers for bevel gears. The milling methods use cutters having teeth formed to the desired shape and the process is that of simple milling, using an indexing head to move the gear blank the correct amount to secure the required number of teeth.

There are also other spur gear planing machines, including the Sunderland and the Maag, but neither are as yet in common use.

In most of the planing processes the tooth is generated, or formed by the rolling action of the gear blank and the cutting tool, giving a theoretically perfect tooth. A perfect cutter, ground after hardening so as to remove the slight distortion due to the heating and cooling of the cutter, will give practically perfect results by either method.

While the actual cutting of gears can be done with no knowledge of tooth forms it is well to be somewhat familiar with the theory of gears and the way in which the teeth are laid out. This can be found in detail in the "American Machinists' Gear Book," by Logue, which forms one of the volumes of this set. It should be referred to frequently even by those who do not expect or desire to design gears.

In cutting gears with the formed milling cutter great care must be taken to have the cutter set exactly in the center of the blank. This is particularly true with small pinions. If the cutter is exactly true to form it is enough to center cutting point with the mandrel carrying the gear blank. But if the cutter is not exactly symmetrical it is necessary to use the cut and try method until the best results possible are secured.

One of the first essentials of gear cutting is to have the gear blanks turned the right size before commencing to cut the teeth. The following tables give the correct diameters. The correct cutters to

TABLE I. B. & S. INVOLUTE GEAR TOOTH CUTTERS

No.	1	will cut gear wheels from			135 teeth	to a	rack
"	1½	"	"	"	80	"	134 teeth
"	2	"	"	"	55	"	134 "
"	2½	"	"	"	42	"	54 "
"	3	"	"	"	35	"	54 "
"	3½	"	"	"	30	"	34 "
"	4	"	"	"	26	"	34 "
"	4½	"	"	"	23	"	25 "
"	5	"	"	"	21	"	25 "
"	5½	"	"	"	19	"	20 "
"	6	"	"	"	17	"	20 "
"	6½	"	"	"	15	"	16 "
"	7	"	"	"	14	"	16 "
"	7½	"	"	"	13	"	14 "
"	8	"	"	"	12	"	13 "

TABLE II. TABLE SHOWING DEPTH OF SPACE AND THICKNESS OF TOOTH IN SPUR WHEELS, WHEN CUT WITH THESE CUTTERS

Pitch of Cutter	Depth to be Cut in Gear, Inches	Thickness of Tooth at Pitch Line, Inches	Pitch of Cutter	Depth to be Cut in Gear, Inches	Thickness of Tooth at Pitch Line, Inches
1¼	1.726	1.257	11	.196	.143
1½	1.438	1.047	12	.180	.131
1¾	1.233	.898	14	.154	.112
2	1.078	.785	16	.135	.098
2¼	.958	.697	18	.120	.087
2½	.863	.628	20	.108	.079
2¾	.784	.570	22	.098	.071
3	.719	.523	24	.090	.065
3½	.616	.448	26	.083	.060
4	.539	.393	28	.077	.056
5	.431	.314	30	.072	.052
6	.359	.262	32	.067	.049
7	.308	.224	36	.060	.044
8	.270	.196	40	.054	.039
9	.240	.175	48	.045	.033
10	.216	.157			

TABLE III. TABLE FOR TURNING AND CUTTING GEAR BLANKS FOR STANDARD LENGTH TOOTH

Pitch	16	12	10	8	Pitch	16	12	10	8
Depth of Tooth	.135	.180	.216	.270	Depth of Tooth	.135	.180	.216	.270
No. of Teeth	Outside Diameter				No. of Teeth	Outside Diameter			
10	3/4	1	1 2/10	1 1/2	51	3 5/16	4 5/12	5 3/10	6 5/8
11	13/16	1 1/12	1 3/10	1 5/8	52	3 3/8	4 6/12	5 4/10	6 3/4
12	7/8	1 2/12	1 4/10	1 3/4	53	3 7/16	4 7/12	5 5/10	6 7/8
13	15/16	1 3/12	1 5/10	1 7/8	54	3 1/2	4 8/12	5 6/10	7
14	1	1 4/12	1 6/10	2	55	3 9/16	4 9/12	5 7/10	7 1/8
15	1 1/16	1 5/12	1 7/10	2 1/8	56	3 5/8	4 10/12	5 8/10	7 1/4
16	1 1/8	1 6/12	1 8/10	2 1/4	57	3 11/16	4 11/12	5 9/10	7 3/8
17	1 3/16	1 7/12	1 9/10	2 3/8	58	3 3/4	5	6	7 1/2
18	1 1/4	1 8/12	2	2 1/2	59	3 13/16	5 1/12	6 1/10	7 5/8
19	1 5/16	1 9/12	2 1/10	2 5/8	60	3 7/8	5 2/12	6 2/10	7 3/4
20	1 3/8	1 10/12	2 2/10	2 3/4	61	3 15/16	5 3/12	6 3/10	7 7/8
21	1 7/16	1 11/12	2 3/10	2 7/8	62	4	5 4/12	6 4/10	8
22	1 1/2	2	2 4/10	3	63	4 1/16	5 5/12	6 5/10	8 1/8
23	1 9/16	2 1/12	2 5/10	3 1/8	64	4 1/8	5 6/12	6 6/10	8 1/4
24	1 5/8	2 2/12	2 6/10	3 1/4	65	4 3/16	5 7/12	6 7/10	8 3/8
25	1 11/16	2 3/12	2 7/10	3 3/8	66	4 1/4	5 8/12	6 8/10	8 1/2
26	1 3/4	2 4/12	2 8/10	3 1/2	67	4 5/16	5 9/12	6 9/10	8 5/8
27	1 13/16	2 5/12	2 9/10	3 5/8	68	4 3/8	5 10/12	7	8 3/4
28	1 7/8	2 6/12	3	3 3/4	69	4 7/16	5 11/12	7 1/10	8 7/8
29	1 15/16	2 7/12	3 1/10	3 7/8	70	4 1/2	6	7 2/10	9
30	2	2 8/12	3 2/10	4	71	4 9/16	6 1/12	7 3/10	9 1/8
31	2 1/16	2 9/12	3 3/10	4 1/8	72	4 5/8	6 2/12	7 4/10	9 1/4
32	2 1/8	2 10/12	3 4/10	4 1/4	73	4 11/16	6 3/12	7 5/10	9 3/8
33	2 3/16	2 11/12	3 5/10	4 3/8	74	4 3/4	6 4/12	7 6/10	9 1/2
34	2 1/4	3	3 6/10	4 1/2	75	4 13/16	6 5/12	7 7/10	9 5/8
35	2 5/16	3 1/12	3 7/10	4 5/8	76	4 7/8	6 6/12	7 8/10	9 3/4
36	2 3/8	3 2/12	3 8/10	4 3/4	77	4 15/16	6 7/12	7 9/10	9 7/8
37	2 7/16	3 3/12	3 9/10	4 7/8	78	5	6 8/12	8	10
38	2 1/2	3 4/12	4	5	79	5 1/16	6 9/12	8 1/10	10 1/8
39	2 9/16	3 5/12	4 1/10	5 1/8	80	5 1/8	6 10/12	8 2/10	10 1/4
40	2 5/8	3 6/12	4 2/10	5 1/4	81	5 3/16	6 11/12	8 3/10	10 3/8
41	2 11/16	3 7/12	4 3/10	5 3/8	82	5 1/4	7	8 4/10	10 1/2
42	2 3/4	3 8/12	4 4/10	5 1/2	83	5 5/16	7 1/12	8 5/10	10 5/8
43	2 13/16	3 9/12	4 5/10	5 5/8	84	5 3/8	7 2/12	8 6/10	10 3/4
44	2 7/8	3 10/12	4 6/10	5 3/4	85	5 7/16	7 3/12	8 7/10	10 7/8
45	2 15/16	3 11/12	4 7/10	5 7/8	86	5 1/2	7 4/12	8 8/10	11
46	3	4	4 8/10	6	87	5 9/16	7 5/12	8 9/10	11 1/8
47	3 1/16	4 1/12	4 9/10	6 1/8	88	5 5/8	7 6/12	9	11 1/4
48	3 1/8	4 2/12	5	6 1/4	89	5 11/16	7 7/12	9 1/10	11 3/8
49	3 3/16	4 3/12	5 1/10	6 3/8	90	5 3/4	7 8/12	9 2/10	11 1/2
50	3 1/4	4 4/12	5 2/10	6 1/2	91	5 13/16	7 9/12	9 3/10	11 5/8

Table III. Table for Turning and Cutting Gear Blanks for Standard Length Tooth—*Continued*

Pitch	16	12	10	8	Pitch	16	12	10	8
Depth of Tooth	.135	.180	.216	.270	Depth of Tooth	.135	.180	.216	.270
No. of Teeth	Outside Diameter				No. of Teeth	Outside Diameter			
92	5 7/8	7 10/12	9 4/10	11 3/4	133	8 7/16	11 3/12	13 5/10	16 7/8
93	5 15/16	7 11/12	9 5/10	11 7/8	134	8 1/2	11 4/12	13 6/10	17
94	6	8	9 6/10	12	135	8 9/16	11 5/12	13 7/10	17 1/8
95	6 1/16	8 1/12	9 7/10	12 1/8	136	8 5/8	11 6/12	13 8/10	17 1/4
96	6 1/8	8 2/12	9 8/10	12 1/4	137	8 11/16	11 7/12	13 9/10	17 3/8
97	6 3/16	8 3/12	9 9/10	12 3/8	138	8 3/4	11 8/12	14	17 1/2
98	6 1/4	8 4/12	10	12 1/2	139	8 13/16	11 9/12	14 1/10	17 5/8
99	6 5/16	8 5/12	10 1/10	12 5/8	140	8 7/8	11 10/12	14 2/10	17 3/4
100	6 3/8	8 6/12	10 2/10	12 3/4	141	8 15/16	11 11/12	14 3/10	17 7/8
101	6 7/16	8 7/12	10 3/10	12 7/8	142	9	12	14 4/10	18
102	6 1/2	8 8/12	10 4/10	13	143	9 1/16	12 1/12	14 5/10	18 1/8
103	6 9/16	8 9/12	10 5/10	13 1/8	144	9 1/8	12 2/12	14 6/10	18 1/4
104	6 5/8	8 10/12	10 6/10	13 1/4	145	9 3/16	12 3/12	14 7/10	18 3/8
105	6 11/16	8 11/12	10 7/10	13 3/8	146	9 1/4	12 4/12	14 8/10	18 1/2
106	6 3/4	9	10 8/10	13 1/2	147	9 5/16	12 5/12	14 9/10	18 5/8
107	6 13/16	9 1/12	10 9/10	13 5/8	148	9 3/8	12 6/12	15	18 3/4
108	6 7/8	9 2/12	11	13 3/4	149	9 7/16	12 7/12	15 1/10	18 7/8
109	6 15/16	9 3/12	11 1/10	13 7/8	150	9 1/2	12 8/12	15 2/10	19
110	7	9 4/12	11 2/10	14	151	9 9/16	12 9/12	15 3/10	19 1/8
111	7 1/16	9 5/12	11 3/10	14 1/8	152	9 5/8	12 10/12	15 4/10	19 1/4
112	7 1/8	9 6/12	11 4/10	14 1/4	153	9 11/16	12 11/12	15 5/10	19 3/8
113	7 3/16	9 7/12	11 5/10	14 3/8	154	9 3/4	13	15 6/10	19 1/2
114	7 1/4	8 8/12	11 6/10	14 1/2	155	9 13/16	13 1/12	15 7/10	19 5/8
115	7 5/16	9 9/12	11 7/10	14 5/8	156	9 7/8	13 2/12	15 8/10	19 3/4
116	7 3/8	9 10/12	11 8/10	14 3/4	157	9 15/16	13 3/12	15 9/10	19 7/8
117	7 7/16	9 11/12	11 9/10	14 7/8	158	10	13 4/12	16	20
118	7 1/2	10	12	15	159	10 1/16	13 5/12	16 1/10	20 1/8
119	7 9/16	10 1/12	12 1/10	15 1/8	160	10 1/8	13 6/12	16 2/10	20 1/4
120	7 5/8	10 2/12	12 2/10	15 1/4	161	10 3/16	13 7/12	16 3/10	20 3/8
121	7 11/16	10 3/12	12 3/10	15 3/8	162	10 1/4	13 8/12	16 4/10	20 1/2
122	7 3/4	10 4/12	12 4/10	15 1/2	163	10 5/16	13 9/12	16 5/10	20 5/8
123	7 13/16	10 5/12	12 5/10	15 5/8	164	10 3/8	13 10/12	16 6/10	20 3/4
124	7 7/8	10 6/12	12 6/10	15 3/4	165	10 7/16	13 11/12	16 7/10	20 7/8
125	7 15/16	10 7/12	10 7/10	15 7/8	166	10 1/2	14	16 8/10	21
126	8	10 8/12	12 8/10	16	167	10 9/16	14 1/12	16 9/10	21 1/8
127	8 1/16	10 9/12	12 9/10	16 1/8	168	10 5/8	14 2/12	17	21 1/4
128	8 1/8	10 10/12	13	16 1/4	169	10 11/16	14 3/12	17 1/10	21 3/8
129	8 3/16	10 11/12	13 1/10	16 3/8	170	10 3/4	14 4/12	17 2/10	21 1/2
130	8 1/4	11	13 2/10	16 1/2	171	10 13/16	14 5/12	17 3/10	21 5/8
131	8 5/16	11 1/12	13 3/10	16 5/8	172	10 7/8	14 6/12	17 4/10	21 3/4
132	8 3/8	11 2/12	13 4/10	16 3/4	173	10 15/16	14 7/12	17 5/10	21 7/8

Table IV. Index Table for Spacing in Blocks of the Brown and Sharpe Gear Cutter

Teeth to be Cut	No. Indexed at Once	First Driver	First Follower	Second Driver	Second Follower	Turns of Locking Disc	Teeth to be Cut	No. Indexed at Once	First Driver	First Follower	Second Driver	Second Follower	Turns of Locking Disc
25	4	100	50	72	30	4	63	5	100	30	80	56	2
26	3	100	50	90	52	4	64	5	100	30	90	64	2
27	2	100	50	60	54	4	65	4	100	50	96	52	2
28	3	100	50	90	56	4	66	5	100	44	80	40	2
29	3	100	50	90	58	4	67	5	100	30	90	67	2
30	1	100	50	60	60	2	68	5	100	30	90	68	3
31	3	100	50	90	62	4	69	5	100	46	80	40	2
32	3	100	50	90	64	4	70	3	100	50	90	70	2
33	4	100	50	80	44	4	72	5	100	30	90	72	2
34	3	100	50	90	68	4	74	5	100	30	90	74	2
35	4	100	50	96	56	4	75	7	100	30	84	50	2
36	5	100	48	80	40	4	76	5	100	30	90	76	2
37	5	100	30	90	74	4	77	4	100	70	96	44	2
38	5	100	30	90	76	4	78	5	100	30	90	78	2
39	5	100	30	90	78	4	80	3	100	50	90	80	2
40	3	100	50	90	80	4	81	7	100	30	84	52	2
41	5	100	30	90	82	4	82	5	100	30	90	82	2
42	5	100	30	90	84	4	84	5	100	30	90	84	2
43	5	100	30	90	86	4	85	4	100	50	96	68	2
44	5	100	30	90	88	4	86	5	100	30	90	86	2
45	7	100	50	70	30	4	87	7	100	30	84	58	2
46	5	100	30	90	92	4	88	5	100	30	90	88	2
47	5	100	30	90	94	4	90	7	100	30	70	50	2
48	5	100	30	90	96	4	91	3	100	70	72	52	2
49	5	100	30	90	98	4	92	5	100	30	90	92	2
50	7	100	50	84	40	4	93	7	100	30	84	62	2
51	4	100	30	96	68	2	94	5	100	30	90	94	2
52	5	100	30	90	52	2	95	4	100	50	96	76	2
54	5	100	30	90	54	2	96	5	100	30	90	96	2
55	4	100	30	96	44	2	98	5	100	30	90	98	2
56	5	100	30	90	56	2	99	10	100	30	80	44	2
57	4	100	30	96	76	2	100	7	100	50	84	40	2
58	5	100	30	90	58	2	102	5	100	30	60	68	2
60	7	100	30	84	40	2	104	5	100	60	90	52	2
62	5	100	30	90	62	2	105	4	100	70	96	60	2

Table IV. Index Table for Spacing in Blocks on the Brown and Sharpe Gear Cutter—*Continued*

Teeth to be Cut	No. Indexed at Once	First Driver	First Follower	Second Driver	Second Follower	Turns of Locking Disc	Teeth to be Cut	No. Indexed at Once	First Driver	First Follower	Second Driver	Second Follower	Turns of Locking Disc
108	7	100	30	70	60	2	152	5	100	60	90	76	2
110	7	100	50	84	44	2	153	5	100	68	80	60	2
111	5	100	74	80	40	2	154	5	100	56	72	66	2
112	5	100	60	90	56	2	155	6	100	50	72	62	2
114	7	100	30	84	76	2	156	5	100	60	90	78	2
115	8	100	50	96	46	2	160	7	100	50	84	64	2
116	5	100	60	90	58	2	161	5	100	70	60	46	2
117	8	100	30	96	78	2	162	7	100	60	84	52	2
119	3	100	70	72	68	2	164	5	100	60	90	82	2
120	7	100	50	70	40	2	165	7	100	50	84	66	2
121	4	60	66	96	44	2	168	5	100	60	90	84	2
123	7	100	30	84	82	2	169	6	96	52	90	78	2
124	5	100	60	90	62	2	170	7	100	50	84	68	2
125	7	100	50	84	50	2	171	5	70	42	80	76	2
126	5	100	50	50	42	2	172	5	100	60	90	86	2
128	5	100	60	90	64	2	174	7	100	60	84	58	2
129	7	100	30	84	86	2	175	8	100	50	96	70	2
130	7	100	50	84	52	2	176	5	100	60	90	88	2
132	5	100	88	80	40	2	180	7	100	60	70	50	2
133	4	100	70	96	76	2	182	9	90	56	96	52	2
134	5	100	60	90	67	2	184	5	100	60	90	92	2
135	7	100	50	84	54	2	185	6	100	50	72	74	2
136	5	100	60	90	68	2	186	7	100	60	84	62	2
138	5	100	92	80	40	2	187	5	100	44	48	68	2
140	3	50	50	90	70	2	188	5	100	60	90	94	2
141	5	100	94	80	40	2	189	5	100	60	80	84	2
143	6	90	66	96	52	2	190	7	100	50	84	76	2
144	5	100	60	90	72	2	192	5	100	60	90	96	2
145	6	100	50	72	58	2	195	7	100	50	84	78	2
147	5	100	98	80	40	2	196	5	100	60	90	98	2
148	5	100	60	90	74	2	198	7	100	50	70	66	2
150	7	100	60	84	50	2	200	7	60	60	84	40	2

use for different numbers of teeth are also given as a matter of ready reference.

BLOCK INDEXING IN CUTTING GEAR TEETH

Block or intermittent indexing is a method to increase the output of gear cutters by allowing the feed and cutting speed to be increased without unduly heating the work. This is done by jumping from the tooth just cut to a tooth far enough away to escape the local heating and on the following rounds to cut the intermediate teeth. While the indexing takes a trifle more time, the heat is distributed so that faster cutting can be done without heating and dulling the cutter.

The preceding table gives the indexing of gears from 25 to 200 teeth and is worked out for the Brown & Sharpe gear cutter but can be modified to suit other machines.

CHAPTER II

HELICAL AND SPIRAL GEARS

In order to secure quiet running it has become rather common practice to cut angular or helical teeth on gears which run on parallel shafts. This requires that the cutter be set at the proper angle with the gear blank and that the blank revolve as it is fed under the cutter. This is exactly the same as milling a spiral on a reamer and the same tables for gearing up the milling machine table will answer in this case.

Spiral gearing is the term applied when gears have angular or spiral teeth and run on shafts at different angles to each other. Spiral gears take the place of bevel gears in many instances and are in reality a form of worm in gearing in which the worm and worm gear are approximately the same size. They are really helical however.

As the twisting of the teeth affects the width of cut made by the cutter it is necessary to find the proper cutter to use by considering the spiral angle and the number of teeth. This can be easily done by means of the chart shown on page 235; the explanation as to its use is on page 232.

To find the lead of spiral consult Table XI on page 236, and also the explanation which follows it. For the real pitches of circular pitch spiral gears see Table X and the explanation with it.

WORM THREADS AND GEARS

The gear wheels used with worm gearing, usually called worm gears, are usually cut with a hob or continuous tap, run between centers in a milling or hobbing machine. The roughing out or gashing of the wheel is frequently done with a single milling cutter. This necessitates setting the cutter at an angle with the blank the same as in helical gearing but the cutter is simply fed down into the work instead of across the face as in the case of helical gearing.

A little data about worms and worm wheels, showing the width of face and depth of thread and teeth will be of value, and is given in the tables which follow.

THREADS OF WORMS

Worms are cut with threads having a total angle of 29 degrees, similar to the Acme thread. Some use the same proportions as for the

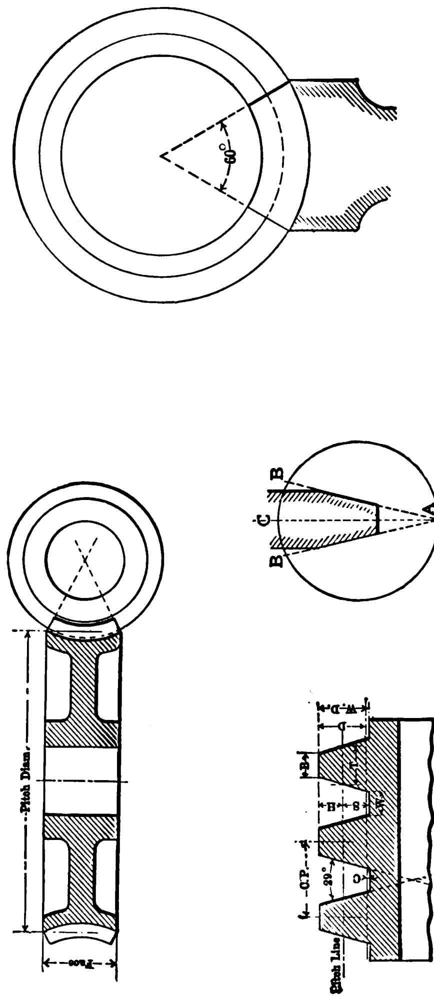


FIG. 1

FIG. 2

To Find the Pitch Diameter. (Given pitch and number of teeth.)

Rule.—Multiply the number of teeth by the circular pitch and divide by 3.1416.

Example.—Number of teeth 96; Circular pitch, $\frac{1}{4}$. Then $96 \times \frac{1}{4} = 24$. $24 \div 3.1416 = 7.639$ = pitch diameter.

Note.—Diameter of Hob equals diameter of Worm plus twice the clearance "C."

Figs. 1-2.—Proportions of worm threads and gears.

Acme, but most use a deeper thread such as the Brown & Sharpe, which is .6866 deep instead of .51 for a one-inch pitch as in the Acme. Fig. 1 shows the proportions used. It is not easy to cut odd fractional pitches in most lathes, so regular pitches are cut and the circular pitch of the worm wheel is allowed to come in fractional measurements for pitch diameters and center distances. Having determined on the reduction as 40 to 1, the relative proportions can be considered as follows:

Assume a thread of 4 to the inch for the worm or a lead of ¼ inch. Then as the reduction of 40 to 1 there must be 40 teeth in the worm gear, ¼ inch from center to center of teeth or 10 inches in circumference on the pitch line or 3.18 inches. If a reduction of 20 to 1 is wanted we can use the same gear but cut a double thread of 2 per inch, which will give the same distance between teeth, but the worm gear will be moved two teeth every revolution of the worm.

Some of the commonly used proportions are:

$$\text{Pitch diam. of worm gear} = \frac{\text{No. of teeth} \times \text{pitch in inches}}{3.1416}$$

$$\text{Diametral pitch} = \frac{3.1416}{\text{Linear pitch}}$$

$$\text{Throat diam. of worm gear} = \frac{\text{Pitch diam.} + 2}{\text{Diametral Pitch}}$$

Outside diam. of gear for 60° sides = Throat diam. + 2 (.13397 Throat Radius).

Whole depth of tooth of worm or worm gear = .6866 × linear pitch.

Width at top of tooth of worm = .335 × linear pitch.

Width of bottom of tooth of worm = .31 × linear pitch.

Outside diam. of worm — single thread = 4 × linear pitch.

Outside diam. of worm — double thread = 5 × linear pitch.

Outside diam. of worm — triple thread = 6 × linear pitch.

Face of worm gear = ½ to ¾ outside diameter of worm.

WIDTH OF FACE

A common practice for determining the width of face or thickness of worm wheels is shown in Fig. 2. Draw the diameter of the worm and lay off 60 degrees as shown; this gives the width of working face, the sides being made straight from the bottom of the teeth. Others make the face equal to ¾ the outside diameter of worm, but ½ the diameter of the worm is more common.

To Find the Pitch Diameter (Given pitch and number of teeth).

Rule.—Multiply the number of teeth by the circular pitch and divide by 3.1416.

Example.—Number of teeth 96; Circular pitch, ¼. Then 96×¼=24. 24÷3.1416=7.639=pitch diameter.

Note.—Diameter of Hob equals diameter of Worm plus twice the clearance "C."

TABLE V.—TABLE OF PROPORTIONS OF WORM THREADS TO RUN IN WORM WHEELS

C.P. Circular Pitch	π Threads per Inch	D.P. Diametrical Pitch	H. Tooth Above Pitch Line	D. Working Depth of Tooth	C. Clearance	S. Depth of Space Below Pitch Line	W.D. Whole Depth of Tooth	T. Thickness of Tooth on Pitch Line	W. Width of Threads Tool at End	B. Width of Thread at Top
C.P. Inches	$\pi=\frac{1}{C.P.}$	$D.P.=\frac{\pi}{C.P.}$	$H.=\frac{1}{D.P.}$	$D.=2\times\frac{1}{D.P.}$	$C.=\frac{T}{10}$	S.=H+C.	W.D.= D.+C.	$T.=\frac{C.P.}{2}$	W.= .31×C.P.	B.=.335 ×C.P.
2	½	1.5708	.6366	1.2732	.1000	.7366	1.3732	1.0000	.6200	.6708
1¾	4/7	1.7952	.5570	1.1141	.0875	.6445	1.2016	.8750	.5425	.5862
1½	⅔	2.0944	.4775	.9549	.0750	.5525	1.0299	.7500	.4650	.5025
1¼	⅘	2.5133	.3979	.7958	.0625	.4604	.8583	.6250	.3875	.4187
1	1	3.1416	.3183	.6366	.0500	.3683	.6866	.5000	.3100	.3350
¾	1⅓	4.1888	.2387	.4775	.0375	.2762	.5150	.3750	.2325	.2512
⅔	1½	4.7124	.2122	.4244	.0333	.2455	.4577	.3333	.2066	.2233
½	2	6.2832	.1592	.3183	.0250	.1842	.3433	.2500	.1550	.1675
⅖	2½	7.8540	.1273	.2546	.0200	.1473	.2746	.2000	.1240	.1340
⅓	3	9.4248	.1061	.2122	.0166	.1227	.2288	.1666	.1033	.1117
2/7	3½	10.9956	.0909	.1819	.0143	.1052	.1962	.1429	.0886	.0957
¼	4	12.5664	.0796	.1591	.0125	.0921	.1716	.1250	.0775	.0838
2/9	4½	14.1372	.0707	.1415	.0111	.0818	.1526	.1111	.0689	.0744
⅕	5	15.7080	.0637	.1273	.0100	.0737	.1373	.1000	.0620	.0670
⅙	6	18.8496	.0531	.1061	.0083	.0614	.1144	.0833	.0517	.0558
1/7	7	21.9911	.0455	.0910	.0071	.0526	.0981	.0714	.0443	.0479
⅛	8	25.1327	.0398	.0796	.0062	.0460	.0858	.0625	.0388	.0419
1/9	9	28.2743	.0354	.0707	.0055	.0409	.0763	.0555	.0344	.0372
1/10	10	31.4159	.0318	.0637	.0050	.0368	.0687	.0500	.0310	.0335
1/12	12	37.6992	.0265	.0530	.0042	.0307	.0572	.0416	.0258	.0279
1/14	14	43.9824	.0227	.0454	.0036	.0263	.0490	.0357	.0221	.0239
1/16	16	50.2655	.0199	.0398	.0031	.0230	.0429	.0312	.0194	.0209
1/18	18	56.5488	.0176	.0352	.0025	.0201	.0377	.0255	.0172	.0186

Note.—The above table refers to single threads only. For Multiple threads, divide the sizes given in the table for the same pitch, by 2 for double, 3 for triple, 4 for quadruple threads, etc.

To find the Pitch Diameter (given pitch and number of teeth).

Rule.—Multiply the number of teeth by the circular pitch and divide by 3.1416.

Example.—Number of teeth, 96; Circular pitch, ¼. Then 96×¼=24. 24÷3.1416=7.639=pitch diameter. *Note.*—Diameter of Hob equals diameter of Worm plus twice the clearance "C."

SPEEDS AND FEEDS FOR GEAR CUTTING

Knowing how to set up the machine and the cutters to use it is also necessary to know the correct speeds and feeds at which the cutters should be run and the work fed to the cutters. The following data are from the experience of the Cincinnati Gear Cutting Machine Company and represent good average practice.

TABLE VI.—SPEEDS AND FEEDS FOR GEAR CUTTING

(Cincinnati Gear Cutting Machine Co.)

Range of different sizes of machines as follows:

No. 3. Up to and including 4 diametral pitch.
No. 4. Up to and including 3 diametral pitch.
No. 5. Up to and including 2 diametral pitch.
No. 6. Up to and including $1\frac{3}{4}$ diametral pitch.
No. 7. Up to and including 1 diametral pitch.

FOR CARBON STEEL CUTTERS RUNNING AT A PERIPHERAL SPEED OF 35 FEET PER MINUTE ON CAST IRON AND 30 FEET PER MINUTE ON STEEL

Diametral Pitch of Gear	Feed in In. per Min. Finishing in One Cut				Feed in In. per Min. for Roughing Cut .010 to .030 In. Left for Finishing Cut				Feed in In. per Min. for Finishing Cut			
	Cast Iron	Soft Steel	High Carbon Steel	Nickel Steel	Cast Iron	Soft Steel	High Carbon Steel	Nickel Steel	Cast Iron	Soft Steel	High Carbon Steel	Nickel Steel
1					$1\frac{5}{8}$	$1\frac{1}{4}$	1	1	$2\frac{1}{16}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{1}{4}$
$1\frac{1}{4}$					$1\frac{5}{8}$	$1\frac{1}{4}$	1	1	$2\frac{1}{16}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{1}{4}$
$1\frac{1}{2}$					$2\frac{1}{16}$	$1\frac{5}{8}$	$1\frac{1}{4}$	1	$2\frac{11}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$1\frac{5}{8}$
$1\frac{3}{4}$	$2\frac{1}{16}$	$1\frac{11}{16}$	$1\frac{5}{16}$	1	$3\frac{3}{8}$	$2\frac{11}{16}$	$2\frac{1}{16}$	$2\frac{11}{16}$	$4\frac{3}{8}$	$3\frac{3}{8}$	$2\frac{11}{16}$	$2\frac{1}{16}$
2	$2\frac{1}{2}$	2	$1\frac{11}{16}$	$1\frac{1}{4}$	$4\frac{1}{16}$	$3\frac{1}{8}$	$2\frac{1}{2}$	2	$4\frac{1}{16}$	$3\frac{1}{8}$	$2\frac{1}{2}$	2
$2\frac{1}{2}$	$2\frac{1}{2}$	2	$1\frac{11}{16}$	$1\frac{1}{4}$	$4\frac{1}{16}$	$3\frac{1}{8}$	$2\frac{1}{2}$	2	$4\frac{1}{16}$	$3\frac{1}{8}$	$2\frac{1}{2}$	2
3	$3\frac{7}{16}$	$2\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$4\frac{1}{16}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2
4	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$1\frac{5}{8}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2
5	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$1\frac{5}{8}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2
6	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$1\frac{5}{8}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2
7	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$1\frac{5}{8}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2
8	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$1\frac{5}{8}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$
9	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$5\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$
10	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	2	$5\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$2\frac{1}{2}$

(Continued on p. 215)

For High Speed Steel Cutters Running at a Peripheral Speed of 55 Feet per Minute on Cast Iron and 80 Feet per Minute on Steel

Diametral Pitch of Gear	Feed in In. per Min. Finishing in One Cut				Feed in In. per Min. for Roughing Cut .010 to 0.30 In. Left for Finishing Cut				Feed in In. per Min. for Finishing Cut			
	Cast Iron	Soft Steel	High Carbon Steel	Nickel Steel	Cast Iron	Soft Steel	High Carbon Steel	Nickel Steel	Cast Iron	Soft Steel	High Carbon Steel	Nickel Steel
1					2	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$2\frac{11}{16}$	$2\frac{11}{16}$	$2\frac{11}{16}$	$2\frac{1}{16}$
$1\frac{1}{4}$					$2\frac{1}{2}$	2	2	$1\frac{5}{8}$	$3\frac{5}{16}$	$3\frac{5}{16}$	$3\frac{5}{16}$	$2\frac{11}{16}$
$1\frac{1}{2}$					$3\frac{3}{8}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$4\frac{3}{8}$	$4\frac{3}{8}$	$4\frac{3}{8}$	$3\frac{3}{8}$
$1\frac{3}{4}$	$2\frac{11}{16}$	$2\frac{1}{16}$	$2\frac{1}{16}$	$1\frac{11}{16}$	$4\frac{3}{8}$	$3\frac{3}{8}$	$3\frac{3}{8}$	$2\frac{11}{16}$	$5\frac{9}{16}$	$5\frac{9}{16}$	$5\frac{9}{16}$	$4\frac{3}{8}$
2	$3\frac{1}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{15}{16}$	$5\frac{1}{8}$	4	4	$3\frac{1}{8}$	$6\frac{9}{16}$	$6\frac{9}{16}$	$6\frac{9}{16}$	$5\frac{1}{8}$
$2\frac{1}{2}$	$3\frac{1}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$	$1\frac{15}{16}$	$5\frac{1}{8}$	4	4	$3\frac{1}{8}$	$6\frac{9}{16}$	$6\frac{9}{16}$	$6\frac{9}{16}$	$5\frac{1}{8}$
3	$3\frac{7}{16}$	$2\frac{1}{2}$	$2\frac{1}{2}$	2	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$5\frac{7}{16}$
4	$3\frac{7}{16}$	$2\frac{1}{2}$	$2\frac{1}{2}$	2	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$
5	$3\frac{7}{16}$	$2\frac{1}{2}$	$2\frac{1}{2}$	2	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$
6	$4\frac{1}{4}$	$3\frac{7}{16}$	$3\frac{7}{16}$	$2\frac{1}{2}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$
7	$4\frac{1}{4}$	$3\frac{7}{16}$	$3\frac{7}{16}$	$2\frac{1}{2}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$
8	$4\frac{1}{4}$	$3\frac{7}{16}$	$3\frac{7}{16}$	$2\frac{1}{2}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$	$6\frac{13}{16}$
9	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$5\frac{7}{16}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$
10	$5\frac{7}{16}$	$4\frac{1}{4}$	$4\frac{1}{4}$	$3\frac{7}{16}$	$6\frac{13}{16}$	$5\frac{7}{16}$	$5\frac{7}{16}$	$4\frac{1}{4}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$	$8\frac{1}{2}$

Gould & Eberhardt recommend the following speed for gear cutters:

Table VII.—R.P.M. of Carbon Steel Cutters for Cutting Speeds Given Below

Diam. of Cutter	Cast Iron			Steel		
	Feet per Minute			Feet per Minute		
	Min. 35	Average 45	Max. 60	Min. 25	Average 30	Max. 40
2	67	86	114	48	57	76
$2\frac{1}{2}$	54	69	92	38	46	61
3	45	57	76	32	38	51
$3\frac{1}{2}$	38	49	65	27	33	44
4	33	44	58	24	29	38
$4\frac{1}{2}$	30	38	51	21	26	34
5	27	34	46	19	24	31
$5\frac{1}{2}$	24	31	42	17	21	27
6	22	27	38	16	19	25
$6\frac{1}{2}$	20	26	35	15	18	23
7	19	25	33	13	16	22
$7\frac{1}{2}$	18	23	30	12	15	20
8	17	21	29	10	14	19

TABLE VIII.—R.P.M. OF HIGH SPEED STEEL CUTTERS FOR CUTTING SPEEDS GIVEN BELOW

Diam. of Cutter	Cast Iron			Steel		
	Feet per Minute			Feet per Minute		
	Min. 50	Average 60	Max. 70	Min. 60	Average 80	Max. 100
2	96	114	134	114	152	193
2½	77	92	107	92	122	154
3	64	76	89	76	102	128
3½	55	65	76	65	87	110
4	48	58	67	58	76	97
4½	43	51	56	51	63	86
5	38	46	53	46	61	77
5½	34	42	49	42	56	70
6	32	38	45	38	51	64
6½	29	35	41	35	47	58
7	27	33	38	33	44	54
7½	25	30	36	30	41	50
8	24	29	34	29	38	48

These figures are of course only to be used as a guide, to be modified by judgment and experience. Use minimum speeds for finishing cuts.

CHAPTER III

THE GEAR SHAPER

The method of cutting gears used by the Fellows gear shaper is entirely different. This machine uses a cutter which is practically a hardened gear with properly relieved teeth, and which revolves with the gear blank at the same time it moves past the edge of it. The cutting gear (if we may call the cutter by that name) is fed

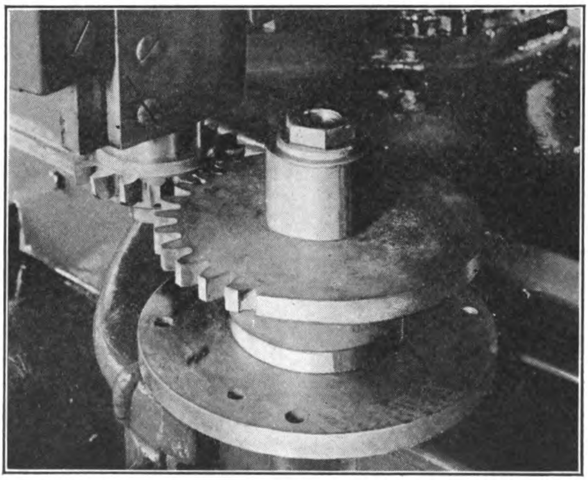


FIG. 3.—Fellows gear shaper at work.

straight into the blank until it reaches the full depth of the tooth. Then the two spindles, one carrying the cutter and the other the blank to be cut, start to revolve together like a pair of gears at the same time the cutter is moving back and forth, taking off a chip at every stroke. The way this works is shown in Fig. 3 where the cutter is a little over one-quarter way around the blank. It will be noticed that the first tooth is not to full depth, this being on the side of the first full depth tooth at the beginning. This will be finished to full depth as soon as the blank has made a complete revolution.

One advantage of this method is that one cutter of any pitch is perfectly adapted to cut any number of teeth of that pitch. With the circular cutter a set of 15 cutters is given and even these are compromises for all except one or two gears within their range. They are good enough for most purposes, but not for the finest work where utmost quietness is desired.

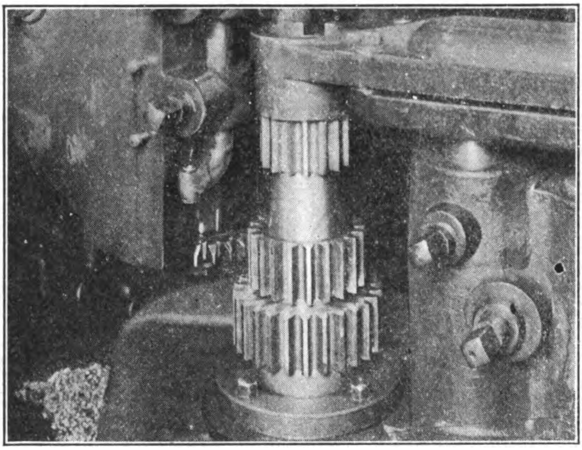


FIG. 4.—Gear cutting in close quarters.

The shaper cutter does not require the same accuracy in setting that is necessary in the milling cutter. Being as it is, simply one of a pair of gears, it is only necessary to put it in place on its spindle, just as we would one of a pair of gears.

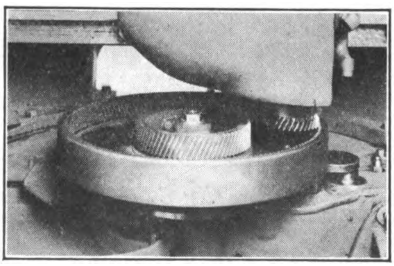


FIG. 5.—Cutting internal helical gear.

In order to become fairly familiar with this type of machine a special view is shown in which the various parts are named so as to be easily understandable. In this case the cutter is working on the up-stroke, the work support holding the edge of the blank against the upward thrust of the cutter. In many cases it is found more convenient to have the cutter operate on the down stroke as in Fig. 4, which shows incidentally, in what close quarters this type of machine can be operated. The three cluster gears shown are all solid on the shaft, the lower pair having just room between them for the cutter to clear as it passes out of the second gear.

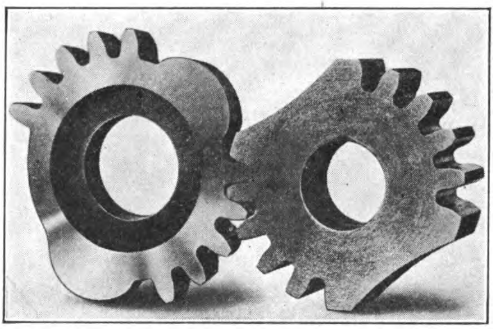


FIG. 6.—Intermittent gear with cutter.

Another good example of the close quarters in which this type of machine can work is given in Fig. 5 where it is cutting both an internal and external helical gear. The cutter is given the proper twisting motion by a very simple device which will be shown later.

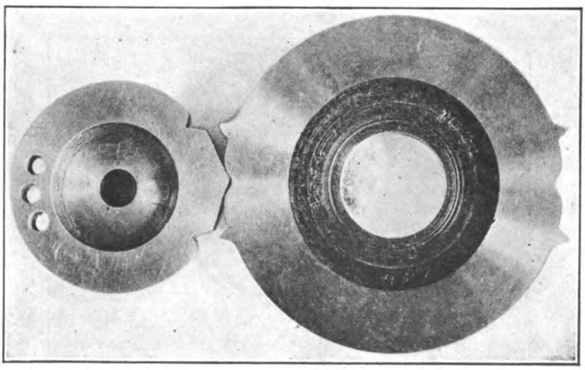


FIG. 7.—Generating a special, double-lobe cam.

When any deviation from the straight downward stroke is desired, a simple and rigid helical guide is fastened to the upper end of the cutter bar so that it must give a certain, definite twist as it moves up and down. These guides are made for only one angle and must be changed whenever a different angle tooth gear is to be cut.

This generating process makes it possible to do almost any sort of irregular cutting on these machines. Some of the unusual jobs which have been handled are shown in Figs. 6, 7 and 8, and in each

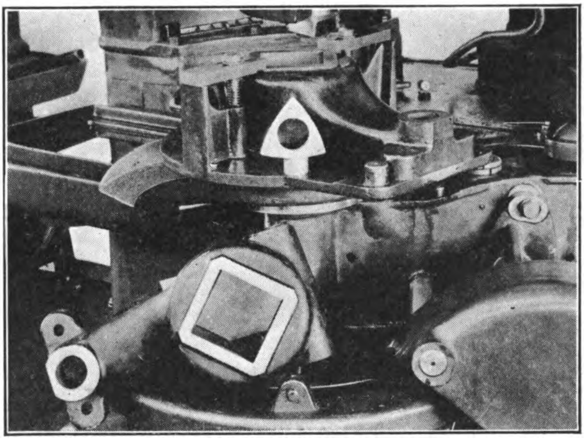


FIG. 8.—A square hole with a three-cornered cutter.

case the cutter which produces the work is also shown. Figure 8 shows that in some cases at least this machine is a real rival of the broaching machine as this is cutting a square hole.

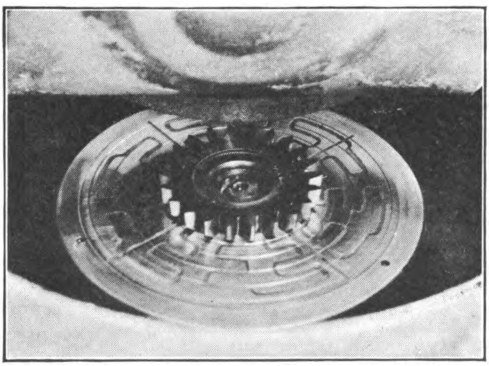


FIG. 9.—Sharpening the cutter.

At first glance it seems that the cutters used on these shapers were made tapered or from a coned blank. If this were true they would change shape with grinding and only be correct when new. In reality they are made from a cylinder and the teeth relieved in such a way that they retain their correct form until entirely used up, if they are ground on the face only, as they should be.

This is a very simple operation on a small vertical surface grinder, the correct handling of the cutters being shown in Fig. 9. A little care in sharpening these cutters, and they should be kept sharp as with all cutters if best results are to be secured, will keep them in good shape and secure a remarkably long life from them.

As with all machines, the instruction book of the builder should be always at hand and should be frequently consulted until one is thoroughly familiar with the machine.

CHAPTER IV

BEVEL GEARS

Bevel gears are used to transmit power when shafts are not parallel. They can be made for any angle, but are more often at right angles than any other. Right angle bevel gears are often called miter gears. The teeth are or should be radial so that they are longer at the outer

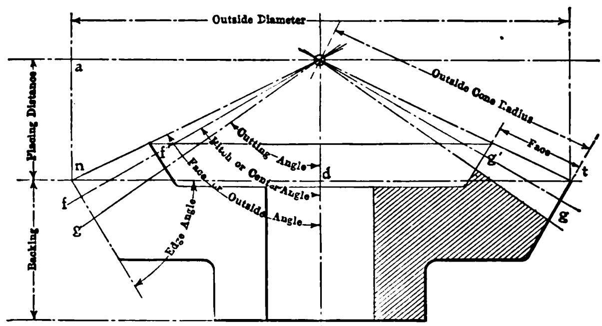


FIG. 10.—Parts of a bevel gear.

end. The names or parts are shown in Fig. 10. These should be noted carefully, particularly the face angles.

CUTTING BEVEL GEARS

Bevel gears are cut with rotary cutters as are spur gears; they are also planed to an enlarged form in some machines, and generated in others. The rotary method uses the regular gear cutting machine or the milling machine and the machine is set up in the regular way as in Fig. 11. The cutters must be selected according to the small end of the tooth, which makes it more difficult to cut gears with wide faces. We must also know the pitch of teeth at large end; number of teeth; whole depth of tooth space at both large and small ends of teeth; thickness of teeth at both ends; cutting angle for setting either the work slide or the cutter slide, as the case may be; height of teeth above pitch line at both ends.

In order to get the wide tooth space at the outer end we must roll the gear blank as much as necessary and also shift the cutter sideways a certain amount. The amount of these adjustments must generally be determined by trials on the first gear. A central cut should be taken from which the amount of roll can be determined. With a coarse pitch gear it may be best to take this central cut all the way around for while this necessitates three cuts in all, it leaves much less stock for the side cuts. On finer pitches only two cuts are necessary after we find the amount of roll necessary.

As the cutter can be no thicker than the tooth space at the small

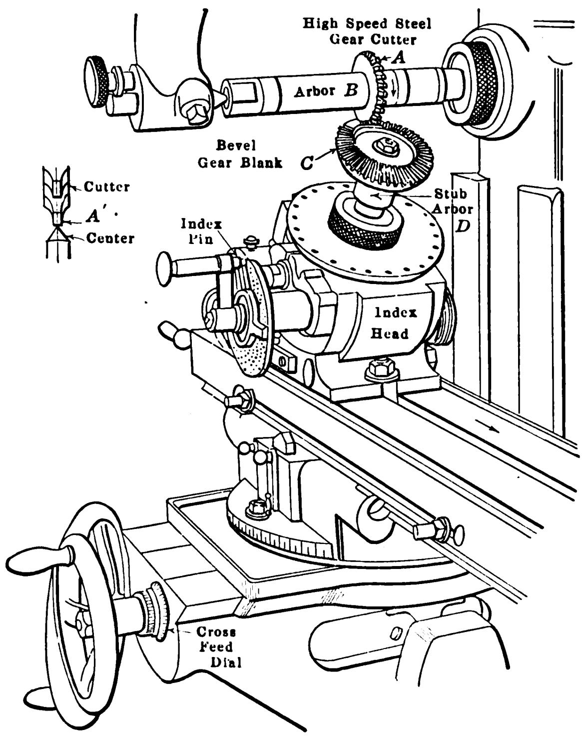


FIG. 11.—Cutting bevel-gears in a milling machine.

end, we must set it off center a little, as well as to roll the gear blank, in order to get the correct thickness of teeth at outer end. A few trials will show how much it is necessary to roll the gear and how much to set the cutter out of center. Make a note of these for use in completing the gear and be sure to use the same settings both sides of the center. Unless the gear is of coarse pitch, the teeth can be completed in two cuts, omitting the central cut.

Some machines are so made that the cutter slide swivels. When swiveling the slide to the right, shift the cutter sideways to the left so that the cutting edge will just graze the left side of the tooth space. Reverse this when swiveling to the left.

Accurate gear cutting requires sharp cutters. Should they dull on one side it tends to crowd to the other side, making uneven teeth. The rim of gear blanks should be well braced to prevent springing under the cut. Gear blanks sometimes become quite warm under continuous cutting.

Some use block or intermittent indexing to avoid this. Block indexing means to jump several spaces between teeth, moving far enough to escape the local heat generated by the last tooth. Then the intermediate teeth are cut in the same way. In case gear blanks do heat, however, it is better to go on cutting as there is less chance of serious distortion than if the blank is allowed to cool.

It is good practice to notch the front edge of large gears, perhaps ½ to ¾ of depth with the finishing cutter before starting to cut the gear. Any error in gearing can be detected by counting the notches and should the work slip you can detect it by noting whether the cutter enters each notch as it should. This may save spoiling valuable gears.

LAYING OUT BEVEL GEAR BLANKS

In laying out bevel gears, first decide upon the pitch, and draw the center lines *BB* and *CC*, intersecting at right angles at *A* as shown in

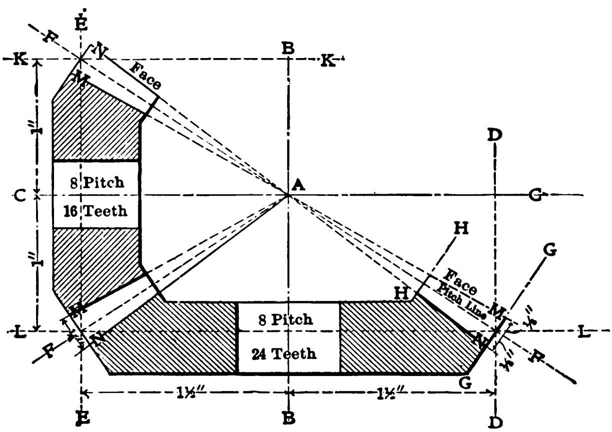


FIG. 12.—Laying out bevel gears.

Fig. 12. Then draw the lines *DD* to *EE* the same distance each side of *BB* and parallel to it; the distance from *DD* to *EE* being as many eighths of an inch—if it be 8 pitch—as there are to be teeth in the gear. In the example the number of teeth is 24; therefore the distance from

DD to *EE* will be $^{24}/_8$, or $1^1/_2$ inches each side of *BB*. *KK* and *LL* are similarly drawn, but there being only 16 teeth in the small gear, the distance from *KK* to *LL* will be $^{16}/_8$, or 1 inch each side of *CC*. Then through the intersections of *DD* and *LL*, *EE* and *LL*, and *EE* and *KK*, draw the diagonals *FA*. These are the pitch lines. Through the same point draw lines as *GG* at right angles to the pitch lines, forming the backs of the teeth. On these lines lay off ⅛ of an inch each side of the pitch lines, and draw *MA* and *NA*, forming the faces and bottoms of the teeth. The lines *HH* are drawn parallel to *GG*, the distance between them being the width of the face.

The face of the larger gear should be turned to the lines *MA*, and the small gear to *NA*. For other pitches the same rules apply. If 4 pitch, use 4ths instead of 8ths; if 3 pitch, 3ds, and so on.

Bevel gears should always be turned to the exact diameters and angles of the drawings and the teeth cut at the correct angle.

PROPORTIONS OF MITER AND BEVEL GEARS

To Find the Pitch or Center Angle:

Divide the number of teeth in the gear by the number of teeth in the pinion. This gives the tangent of the pitch angle of the gear. Or divide the number of teeth in the pinion by the teeth in the gear and get the tangent of the pitch angle of the pinion. Subtracting either pitch angle from 90 gives the pitch angle of the other.

To Find the Outside Diameter:

Multiply the cosine of the pitch angle by twice the addendum and add the pitch diameter.

To find the Outside Cone Radius or Apex Distance:

Multiply the secant of the pitch angle of the pinion by ½ the pitch diameter of the gear.

To Find the Face and Cutting Angles:

Divide the addendum by the outside cone radius or apex distance. This gives the tangent of the addendum or outside angle. Subtract this angle from the pitch angle of the pinion to obtain the cutting angle of the pinion, and the face angle of the gear. Subtract the same addendum angle from the center angle of the gear to obtain the cutting angle of the gear and the face angle of the pinion. This gives a uniform clearance and is especially for use with rotary cutters.

To Find Height of Addendum at Small End of Tooth:

Divide the addendum at the large end of the tooth by the outside cone radius. This gives the decrease in height of the addendum for each inch of gear face. Multiply this by the length of the gear face and subtract the result from the addendum of the large end of the tooth. The difference is the height of the addendum at the small end of the tooth.

CUTTERS FOR BEVEL GEARS

Lay out the bevel gears as in Fig. 13 and draw lines *A* and *B* at right angles to the center angle line. Extend this to the center lines and measure *A* and *B*. The distance *A* = the radius of a spur gear of the same pitch, and finding the number of teeth in such a gear we

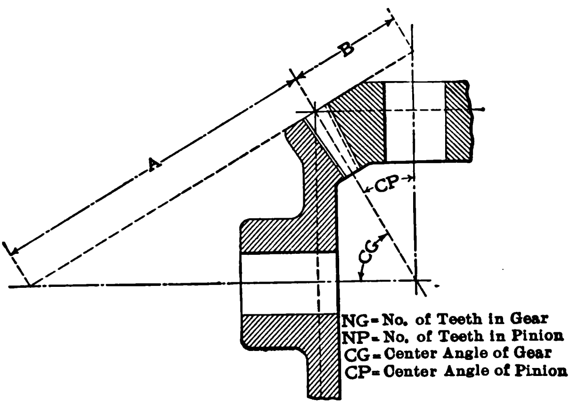


FIG. 13.—Finding the right cutter to use.

have the right cutter for the bevel gear in question. Calling the gears 8 pitch and the distance A = 4 inches. Then 2 × 4 × 8 = 64 teeth, so that a No. 2 cutter is the one to use. For the pinion, if *B* is 2 inches, then 2 × 2 × 8 = 32 or a No. 4 cutter is the one to use.

HOBBING MACHINES

Cutting gears by the hobbing method dates back many years, but it was the demand for great quantities of gears by the automobile builders which brought it into extensive use. The hob, which may be compared to a worm wheel hob, or special tap, is set so that the angle of its thread will make the desired angle with the gear blank to be cut. The hob revolves and at the same time is fed across the face of the gear blank. The blank also turns on its axis so that the tooth of the hob is always in the tooth space of the gear. In this way the hob tooth generates the tooth form.

Each maker of gear hobbing machines supplies a book of instructions for setting up and operating their machines and these should be carefully studied and followed. Great care must be taken in setting the machines but when one becomes accustomed to them, this is not difficult.

The accuracy of gears cut by this method depends largely on the accuracy of the hobs used. Where the greatest accuracy is desired, the teeth of the hobs are ground after hardening. Inaccuracy also comes from forcing the machine beyond a reasonable limit. This may cause variation in the shape of the tooth curve.

On average work the hobbing method will cut gears faster than the regular method. It is particularly adapted for helical and worm gears.

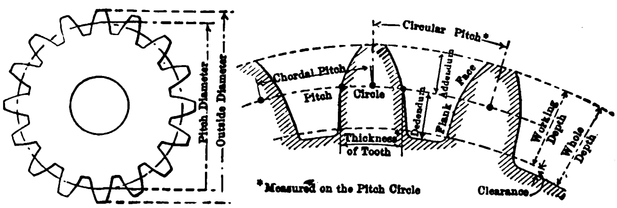


Fig. 14.—Names of parts of gear teeth.

The correct angle for setting the cutter head for cutting spur gears is stamped on the end of the hob in most cases. This setting should always bring the thread of the hob parallel to the axis of the work arbor, for spur gears. When cutting helical gears the cutter head is set at the angle of the gear to be cut, *minus* the angle of the thread stamped on the end of the cutter. When the angle of the gear tooth is more than 45 degrees, some machines provide for swinging the cutter head and also for reversing the rotation of the cutter arbor. By carefully following directions in instruction books, the handling of any make of machine will not be difficult after the principles are understood.

CHAPTER V

GEAR DATA AND TABLES

GEAR TEETH—SHAPES OF

Cycloidal or Epicycloidal.—A curved tooth generated by the point of a circle rolling away from the gear wheel or rack.

Involute.—A curved tooth generated by unwinding a tape or string from a cylinder. The rack tooth has straight sides.

Involute Standard.—The standard gear tooth has a 14½-degree pressure angle which means that the teeth of a standard rack have straight sides 14½ degrees from the vertical.

Involute—Stubbed.—A tooth shorter than the standard and usually with a 20-degree pressure angle.

GEARS—TEETH AND PARTS

Addendum.—Length from pitch line to outside.

Chordal Pitch.—Distance from center to center of teeth in a straight line.

Circular Pitch.—Distance from center to center of teeth measured on the pitch circle.

Clearance.—Extra depth of space between teeth.

Dedendum.—Length from pitch line to base of tooth.

Diametral Pitch.—Number of teeth divided by the pitch diameter or the teeth to each inch of diameter.

Face.—Working surface of tooth outside of pitch line.

Flank.—Working surface of tooth below pitch line.

Outside Diameter.—Total diameter over teeth.

Pitch Diameter.—Diameter at the pitch line.

Pitch Line.—Line of contact of two cylinders which would have the same speed ratios as the gears.

Linear Pitch.—Sometimes used in rack measurement. Same as circular pitch of a gear.

As it is natural to think of gear pitches as the distance between teeth the same as threads, it is well to fix in the mind the approximate center distances of the pitches most in use. Or it is easy to remember that if the diametral pitch be divided by $3^1/_7$ we have the teeth per

Table IX.—Gear Wheels

TABLE OF TOOTH PARTS—DIAMETRAL PITCH IN FIRST COLUMN

Diametral Pitch	Circular Pitch	Thickness of Tooth on Pitch Line	Addendum and $\frac{1''}{P}$	Working Depth of Tooth	Depth of Space below Pitch Line	Whole Depth of Tooth
P	P'	t	s	D''	$s+f$	$D''+f$
½	6.2832	3.1416	2.0000	4.0000	2.3142	4.3142
¾	4.1888	2.0944	1.3333	2.6666	1.5428	2.8761
1	3.1416	1.5708	1.0000	2.0000	1.1571	2.1571
1¼	2.5133	1.2566	.8000	1.6000	.9257	1.7257
1½	2.0944	1.0472	.6666	1.3333	.7714	1.4381
1¾	1.7952	.8976	.5714	1.1429	.6612	1.2326
2	1.5708	.7854	.5000	1.0000	.5785	1.0785
2¼	1.3963	.6981	.4444	.8888	.5143	.9587
2½	1.2566	.6283	.4000	.8000	.4628	.8628
2¾	1.1424	.5712	.3636	.7273	.4208	.7844
3	1.0472	.5236	.3333	.6666	.3857	.7190
3½	.8976	.4488	.2857	.5714	.3306	.6163
4	.7854	.3927	.2500	.5000	.2893	.5393
5	.6283	.3142	.2000	.4000	.2314	.4314
6	.5236	.2618	.1666	.3333	.1928	.3595
7	.4488	.2244	.1429	.2857	.1653	.3081
8	.3927	.1963	.1250	.2500	.1446	.2696
9	.3491	.1745	.1111	.2222	.1286	.2397
10	.3142	.1571	.1000	.2000	.1157	.2157
11	.2856	.1428	.0909	.1818	.1052	.1961
12	.2618	.1309	.0833	.1666	.0964	.1798
13	.2417	.1208	.0769	.1538	.0890	.1659
14	.2244	.1122	.0714	.1429	.0826	.1541
15	.2094	.1047	.0666	.1333	.0771	.1438
16	.1963	.0982	.0625	.1250	.0723	.1348
17	.1848	.0924	.0588	.1176	.0681	.1269
18	.1745	.0873	.0555	.1111	.0643	.1198
19	.1653	.0827	.0526	.1053	.0609	.1135
20	.1571	.0785	.0500	.1000	.0579	.1079
22	.1428	.0714	.0455	.0909	.0526	.0980
24	.1309	.0654	.0417	.0833	.0482	.0898
26	.1208	.0604	.0385	.0769	.0445	.0829
28	.1122	.0561	.0357	.0714	.0413	.0770
30	.1047	.0524	.0333	.0666	.0386	.0719
32	.0982	.0491	.0312	.0625	.0362	.0674
34	.0924	.0462	.0294	.0588	.0340	.0634
36	.0873	.0436	.0278	.0555	.0321	.0599
38	.0827	.0413	.0263	.0526	.0304	.0568
40	.0785	.0393	.0250	.0500	.0289	.0539
42	.0748	.0374	.0238	.0476	.0275	.0514
44	.0714	.0357	.0227	.0455	.0263	.0490
46	.0683	.0341	.0217	.0435	.0252	.0469
48	.0654	.0327	.0208	.0417	.0241	.0449
50	.0628	.0314	.0200	.0400	.0231	.0431
56	.0561	.0280	.0178	.0357	.0207	.0385
60	.0524	.0262	.0166	.0333	.0193	.0360

To obtain the size of any part of a diametral pitch not given in the table, divide the corresponding part of 1 diametral pitch by the pitch required.

inch on the pitch line. By this method we easily see that in a 10 diametral pitch gear there are approximately 3 teeth per inch while in a 22 diametral pitch there will be just 7 teeth to the inch.

SPUR-GEAR DIAGRAMS

The two diagrams shown in Figs. 15 and 16 are being used considerably in the shops and drafting room of the Wyman-Gordon Co., Worcester, Mass., and are much liked by the men.

Figure 15 gives the outside diameters, number of teeth and pitch of spur gears and was designed to be used mostly in the shop. For instance,

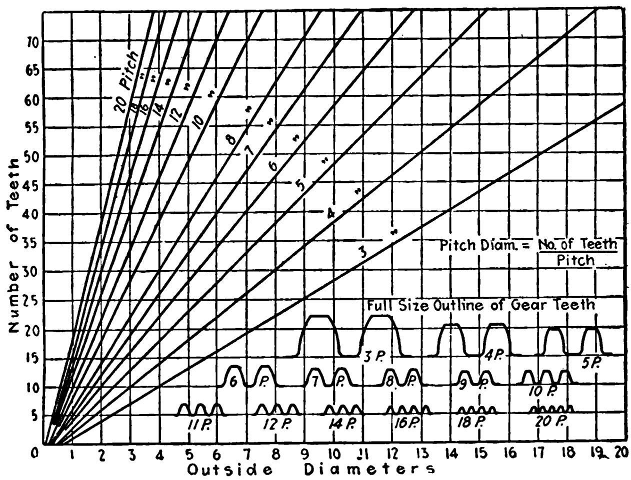


FIG. 15.—For finding gear dimensions.

when a gear is broken the machinist has simply to measure the outside diameter and count the teeth and the pitch is then derived from the chart. To find the pitch diameter he divides the number of teeth by the pitch, and he is all equipped to cut a duplicate gear. The actual tooth outlines are also shown and can be used as a check.

Figure 16 is for use in the drawing room. This chart gives us the number of teeth for different pitch diameters or vice versa, and also all other information in regard to spur gears. The chart is also used for checking.

REAL PITCHES FOR CIRCULAR PITCH SPIRAL GEARS

The accompanying table will be found convenient in figuring particulars for spiral gearing, as it eliminates much of the work by shortening the process, thus making it quite an easy and simple matter to find the dimensions for either helical gears with axes parallel to each other or for gears with right-angle drive.

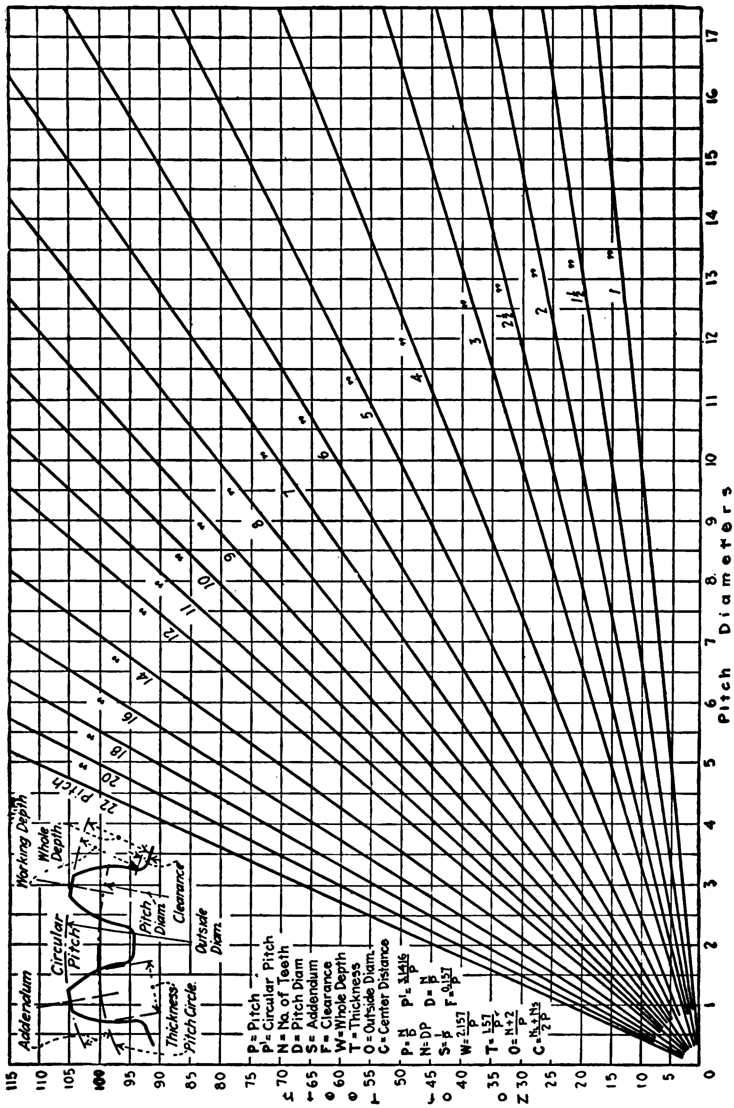


FIG. 16.—Convenient gear diagram for draftsmen and others.

Formulas for use with the table are as follows: Circumference on pitch line = real pitch multiplied by number of teeth.

Lead of Spiral = Circumference on pitch line divided by the tangent.

Pitch Diameter = Circumference divided by 3.1416.

For whole diameter add the same amount above pitch line as for spur wheels of the same pitch as the normal pitch.

The following is an example of the use of the table: A pair of wheels is required to be: Ratio, 6 to 1; normal pitch, 1 in.; driver, 6 teeth; follower, 36 teeth; angle for driver, 66 degrees; angle for follower, 24 degrees.

Referring to the table we find that the real pitch for the driver is 2.4585.

2.4585 × 6 (*teeth*) = 14.751 (*circumference on pitch line*).

Cir. 14.751 ÷ 2.246 (*tangent*) = 6.567 (*lead of spiral*).

Cir. 14.751 ÷ 3.1416 = 4.695 (*pitch diameter*).

For the follower the real pitch is 1.0946.

1.0946 × 36 = 39.4056 (*circumference*).

Cir. 39.4056 ÷ 0.4452 (*tangent*) = 88.512 (*lead of spiral*).

Cir. 39.4056 ÷ 3.1416 = 12.543 (*pitch diameter*).

Another method of finding the lead of spiral is to multiply the real pitch by the number of teeth, but for this purpose take the real pitch of the mating wheel.

In the above example we should have

Real pitch of follower, 1.0946 × 6 = 6.5676 (*lead of spiral*).

Real pitch of driver, 2.4585 × 36 = 88.506.

It will be noticed that there is a slight difference in the result but this is unimportant, as it is only brought about by the dropping of a few decimal points in the tangent.

SPUR-GEAR CUTTERS FOR SPIRAL GEARS

To find the number of a spur-gear cutter to be used in cutting a given spiral gear, locate the intersection of lines traced from the points representing the number of teeth and the spiral angle on the two scales. The number in the area on the chart within which the intersection falls is the cutter number of Brown & Sharpe's involute cutter system required. This is shown in Fig. 17.

SPIRAL GEAR TABLE

While it is better in every case to understand the principles involved before using a table as this tends to prevent errors, they can be used with good results by simply following directions carefully. The subject of spiral gears is so much more complicated than other gears that many will prefer to depend entirely on tables such as No. XI.

TABLE X.—TABLE OF REAL PITCHES FOR CIRCULAR PITCH SPIRAL GEARS

Angles from Axis		Normal Pitches													
		1/4″		5/16″		3/8″		7/16″		1/2″		5/8″		3/4″	
Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower
80°	10°	1.4396	0.2538	1.7996	0.3173	2.1595	0.3808	2.5194	0.4442	2.8793	0.5077	3.5992	0.6346	4.3190	0.7616
79°	11°	1.3102	0.2546	1.6377	0.3183	1.9653	0.3820	2.2928	0.4457	2.6304	0.5093	3.2755	0.6366	3.9306	0.7640
78°	12°	1.2024	0.2556	1.5030	0.3195	1.8036	0.3833	2.1042	0.4473	2.4049	0.5112	3.0060	0.6390	3.6072	0.7666
77°	13°	1.1113	0.2565	1.3892	0.3207	1.6669	0.3848	1.9449	0.4490	2.2226	0.5131	2.7784	0.6414	3.3338	0.7696
76°	14°	1.0334	0.2576	1.2917	0.3220	1.5500	0.3865	1.8084	0.4509	2.0668	0.5153	2.5834	0.6440	3.1000	0.7730
75°	15°	0.9659	0.2591	1.2074	0.3238	1.4489	0.3885	1.6903	0.4529	1.9318	0.5181	2.4148	0.6476	2.8978	0.7772
74°	16°	0.9069	0.2600	1.1337	0.3250	1.3605	0.3901	1.5872	0.4551	1.8139	0.5201	2.2674	0.6502	2.7210	0.7802
73°	17°	0.8550	0.2614	1.0688	0.3268	1.2826	0.3931	1.4964	0.4575	1.7101	0.5228	2.1377	0.6536	2.5652	0.7842
72°	18°	0.8090	0.2628	1.0112	0.3286	1.2135	0.3943	1.4157	0.4600	1.6180	0.5257	2.0225	0.6572	2.4270	0.7886
71°	19°	0.7678	0.2644	0.9598	0.3305	1.1518	0.3966	1.3438	0.4627	1.5357	0.5288	1.9196	0.6610	2.3036	0.7932
70°	20°	0.7309	0.2660	0.9137	0.3325	1.0964	0.3990	1.2791	0.4656	1.4619	0.5320	1.8274	0.6651	2.1928	0.7981
69°	21°	0.6976	0.2678	0.8720	0.3347	1.0464	0.4017	1.2208	0.4686	1.3952	0.5356	1.7440	0.6694	2.0928	0.8034
68°	22°	0.6673	0.2696	0.8342	0.3370	1.0010	0.4044	1.1679	0.4718	1.3346	0.5392	1.6684	0.6740	2.0020	0.8088
67°	23°	0.6398	0.2716	0.7998	0.3395	0.9597	0.4074	1.1120	0.4752	1.2796	0.5432	1.5996	0.6790	1.9194	0.8148
66°	24°	0.6146	0.2736	0.7683	0.3420	0.9220	0.4105	1.0756	0.4789	1.2292	0.5472	1.5366	0.6841	1.8440	0.8210
65°	25°	0.5915	0.2758	0.7394	0.3448	0.8873	0.4137	1.0352	0.4827	1.1830	0.5516	1.4788	0.6896	1.7746	0.8274
64°	26°	0.5702	0.2781	0.7129	0.3477	0.8554	0.4172	0.9980	0.4868	1.1406	0.5563	1.4258	0.6954	1.7108	0.8344
63°	27°	0.5507	0.2806	0.6883	0.3507	0.8260	0.4209	0.9636	0.4910	1.1014	0.5612	1.3766	0.7014	1.6520	0.8418
62°	28°	0.5325	0.2831	0.6656	0.3539	0.7988	0.4247	0.9319	0.4955	1.0650	0.5662	1.3312	0.7078	1.5976	0.8494
61°	29°	0.5157	0.2858	0.6446	0.3573	0.7735	0.4287	0.9024	0.5002	1.0314	0.5716	1.2892	0.7146	1.5470	0.8574
60°	30°	0.5000	0.2886	0.6250	0.3608	0.7500	0.4330	0.8750	0.5051	1.0000	0.5773	1.2500	0.7216	1.5000	0.8660
59°	31°	0.4853	0.2916	0.6067	0.3646	0.7281	0.4375	0.8494	0.5104	0.9708	0.5833	1.2134	0.7292	1.4562	0.8750
58°	32°	0.4717	0.2948	0.5897	0.3685	0.7076	0.4422	0.8256	0.5159	0.9435	0.5896	1.1794	0.7370	1.4152	0.8844
57°	33°	0.4590	0.2981	0.5738	0.3726	0.6885	0.4471	0.8033	0.5216	0.9180	0.5962	1.1476	0.7452	1.3770	0.8942
56°	34°	0.4470	0.3015	0.5588	0.3769	0.6706	0.4523	0.7824	0.5277	0.8941	0.6031	0.1176	0.7538	1.3412	0.9046
55°	35°	0.4358	0.3052	0.5448	0.3815	0.6538	0.4578	0.7627	0.5341	0.8717	0.6104	1.0896	0.7630	1.3076	0.9156
54°	36°	0.4253	0.3090	0.5316	0.3862	0.6380	0.4635	0.7443	0.5408	0.8506	0.6180	1.0632	0.7724	1.2760	0.9270
53°	37°	0.4154	0.3130	0.5192	0.3913	0.6231	0.4695	0.7269	0.5478	0.8308	0.6260	1.0384	0.7826	1.2462	0.9390
52°	38°	0.4060	0.3172	0.5076	0.3965	0.6091	0.4759	0.7161	0.5552	0.8121	0.6345	0.0152	0.7930	1.2182	0.9518
51°	39°	0.3972	0.3217	0.4965	0.4021	0.5959	0.4825	0.6952	0.5628	0.7945	0.6434	0.9930	0.8042	1.1918	0.9650
50°	40°	0.3889	0.3264	0.4861	0.4079	0.5834	0.4895	0.6806	0.5711	0.7778	0.6527	0.9722	0.8159	1.1668	0.9790
49°	41°	0.3810	0.3312	0.4763	0.4140	0.5716	0.4969	0.6668	0.5797	0.7621	0.6625	0.9526	0.8280	1.1432	0.9938
48°	42°	0.3736	0.3364	0.4670	0.4205	0.5604	0.5046	0.6538	0.5887	0.7472	0.6728	0.9340	0.8410	1.1208	1.0092
47°	43°	0.3665	0.3418	0.4582	0.4272	0.5498	0.5127	0.6415	0.5982	0.7331	0.6836	0.9164	0.8544	1.0996	1.0254
46°	44°	0.3598	0.3475	0.4498	0.4344	0.5398	0.5213	0.6298	0.6082	0.7197	0.6950	0.8996	0.8688	1.0796	1.0426
45°	45°	0.3536	0.3536	0.4419	0.4419	0.5303	0.5303	0.6187	0.6187	0.7071	0.7071	0.8839	0.8839	1.0606	1.0606

TABLE X.—TABLE OF REAL PITCHES FOR CIRCULAR PITCH SPIRAL GEARS—*Continued.*

Angles from Axis		Normal Pitches												Tangent of Angle	
		7/8″		1″		1 1/8″		1 1/4″		1 3/8″		1 1/2″			
Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower	Driver	Follower
80°	10°	5.0388	0.8884	5.7587	1.0154	6.4785	1.1423	7.1983	1.2692	7.8192	1.3962	8.6380	1.5230	5.6713	0.1763
79°	11°	4.5856	0.8914	5.2407	1.0187	5.8961	1.1460	6.5510	1.2732	7.2061	1.4007	7.8612	1.5280	5.1446	0.1944
78°	12°	4.2084	0.8946	4.8098	1.0223	5.4109	1.1501	6.0122	1.2780	6.6134	1.4057	7.2146	1.5335	4.7046	0.2126
77°	13°	3.8898	0.8980	4.4454	1.0263	5.0001	1.1546	5.5568	1.2828	6.1125	1.4111	6.6681	1.5394	4.3315	0.2309
76°	14°	3.6168	0.9018	4.1336	1.0306	4.6500	1.1594	5.1669	1.2882	5.6837	1.4171	6.2004	1.5459	4.0108	0.2493
75°	15°	3.3806	0.9058	3.8637	1.0353	4.3466	1.1658	4.8296	1.2952	5.3126	1.4248	5.7955	1.5543	3.7321	0.2679
74°	16°	3.1744	0.9102	3.6279	1.0403	4.0814	1.1703	4.5348	1.3004	4.9884	1.4304	5.4419	1.5604	3.4874	0.2867
73°	17°	2.9928	0.9150	3.4203	1.0457	3.8478	1.1764	4.2754	1.3071	4.7029	1.4378	5.1304	1.5685	3.2709	0.3057
72°	18°	2.8314	0.9200	3.2360	1.0515	3.6405	1.1829	4.0450	1.3143	4.4495	1.4457	4.8540	1.5771	3.0777	0.3249
71°	19°	2.6876	0.9254	3.0715	1.0576	3.4554	1.1898	3.8394	1.3220	4.2233	1.4542	4.6072	1.5864	2.9042	0.3443
70°	20°	2.5582	0.9312	2.9238	1.0641	3.2892	1.1972	3.6548	1.3302	4.0202	1.4632	4.3857	1.5962	2.7475	0.3640
69°	21°	2.4416	0.9372	2.7904	1.0711	3.1391	1.2050	3.4880	1.3389	3.8368	1.4728	4.1856	1.6067	2.6051	0.3839
68°	22°	2.3358	0.9436	2.6694	1.0785	3.0030	1.2133	3.3369	1.3480	3.6705	1.4829	4.0041	1.6178	2.4751	0.4040
67°	23°	2.2240	0.9504	2.5593	1.0863	2.8792	1.2221	3.1991	1.3580	3.5190	1.4937	3.8389	1.6295	2.3559	0.4245
66°	24°	2.1512	0.9578	2.4585	1.0946	2.7659	1.2314	3.0732	1.3682	3.3805	1.5051	3.6876	1.6418	2.2460	0.4452
65°	25°	2.0704	0.9654	2.3662	1.1033	2.6619	1.2412	2.9577	1.3792	3.2535	1.5171	3.5493	1.6550	2.1445	0.4663
64°	26°	1.9960	0.9736	2.2811	1.1127	2.5663	1.2517	2.8515	1.3908	3.1366	1.5298	3.4218	1.6689	2.0503	0.4877
63°	27°	1.9272	0.9820	2.2026	1.1223	2.4780	1.2626	2.7533	1.4029	3.0287	1.5431	3.3040	1.6835	1.9626	0.5095
62°	28°	1.8638	0.9910	2.1300	1.1326	2.3963	1.2741	2.6625	1.4157	2.9288	1.5572	3.1950	1.6988	1.8807	0.5317
61°	29°	1.8048	1.0004	2.0626	1.1433	2.3205	1.2862	2.5783	1.4292	2.8361	1.5721	3.0940	1.7150	1.8040	0.5543
60°	30°	1.7500	1.0102	2.0000	1.1548	2.2500	1.2990	2.5000	1.4433	2.7500	1.5877	3.0000	1.7320	1.7321	0.5774
59°	31°	1.6988	1.0208	1.9415	1.1667	2.1843	1.3125	2.4269	1.4583	2.6696	1.6042	2.9134	1.7499	1.6643	0.6009
58°	32°	1.6512	1.0318	1.8870	1.1790	2.1229	1.3266	2.3588	1.4740	2.5947	1.6213	2.8306	1.7687	1.6003	0.6249
57°	33°	1.6066	1.0432	1.8360	1.1923	2.0655	1.3414	2.2951	1.4904	2.5246	1.6395	2.7451	1.7885	1.5399	0.6494
56°	34°	1.5648	1.0554	1.7883	1.2062	2.0118	1.3569	2.2353	1.5077	2.4589	1.6585	2.6824	1.8093	1.4826	0.6745
55°	35°	1.5254	1.0682	1.7434	1.2207	1.9614	1.3734	2.1793	1.5260	2.3972	1.6786	2.6151	1.8311	1.4281	0.7002
54°	36°	1.4886	1.0816	1.7012	1.2360	1.9139	1.3905	2.1266	1.5449	2.3392	1.6997	2.5519	1.8541	1.3764	0.7265
53°	37°	1.4538	1.0956	1.6614	1.2521	1.8693	1.4086	2.0070	1.5652	2.2847	1.7217	2.4924	1.8781	1.3270	0.7536
52°	38°	1.4322	1.1104	1.6242	1.2690	1.8273	1.4276	2.0303	1.5862	2.2333	1.7449	2.4364	1.9035	1.2799	0.7813
51°	39°	1.3904	1.1256	1.5890	1.2867	1.7876	1.4476	1.9862	1.6084	2.1847	1.7693	2.3835	1.9301	1.2349	0.8098
50°	40°	1.3612	1.1422	1.5557	1.3054	1.7502	1.4686	1.9446	1.6317	2.1391	1.7949	2.3336	1.9581	1.1918	0.8391
49°	41°	1.3336	1.1594	1.5240	1.3250	1.7148	1.4906	1.9054	1.6562	2.0958	1.8219	2.2863	1.9875	1.1504	0.8693
48°	42°	1.3076	1.1774	1.4944	1.3456	1.6813	1.5138	1.8681	1.6820	2.0549	1.8502	2.2417	2.0184	1.1106	0.9004
47°	43°	1.2830	1.1964	1.4662	1.3673	1.6495	1.5382	1.8328	1.7089	2.0161	1.8001	2.1994	2.0510	1.0724	0.9325
46°	44°	1.2596	1.2164	1.4395	1.3901	1.6194	1.5639	1.7994	1.7377	1.9792	1.9114	2.1593	2.0852	1.0355	0.9657
45°	45°	1.2374	1.2374	1.4142	1.4142	1.5910	1.5910	1.7678	1.7678	1.9445	1.9445	2.1213	2.1213	1.0000	1.0000

This table gives the circular pitch and addendum or the diametral pitch and lead of spirals for one diametral pitch and with teeth having angles from 1 to 45 and 45 to 89 degrees. For other pitches divide the addendum given and the spiral number by the required pitch and multiply the results by the required number of teeth. This will

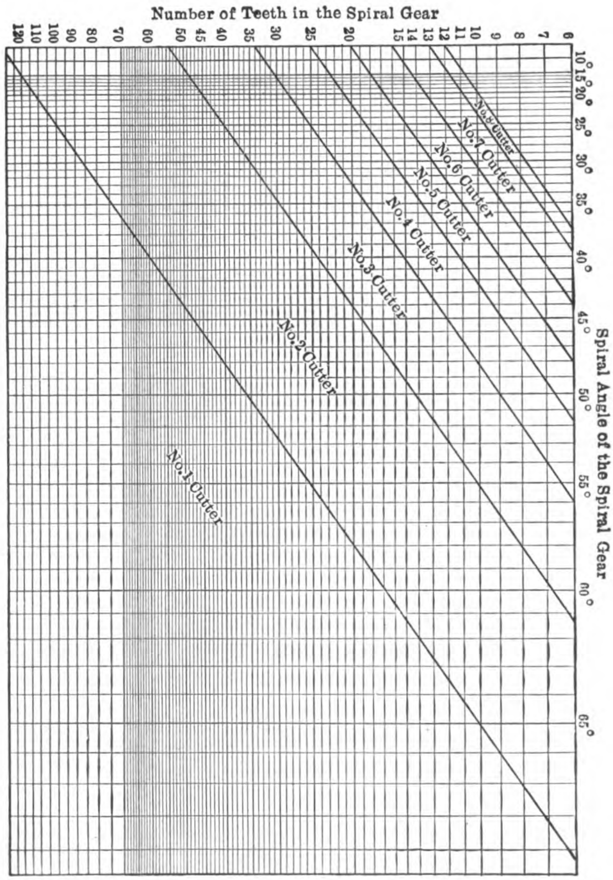


FIG. 17.—Spur-gear cutters for spiral gears.

give the pitch diameter and lead of spiral for each wheel. For the outside diameter add two diametral pitches as in spur gearing.

Suppose we want a pair of spiral gears with 10- and 80-degree angles, 8 diametral pitch cutter, with 16 teeth in the small gear, having 10-degree angle and 10 teeth in the larger gear with its 80-degree angle.

Find the 10-degree angle of spiral and in the third column find 1.0154. Divide by pitch, 8, and get .1269. Multiply this by number

Table XI.—Spiral Gear Table

SHAFT ANGLES 90° FOR ONE DIAMETRAL PITCH

Angle of Spiral in Degrees	To obtain the circular pitch for one tooth, divide by the required diametral pitch	To obtain the pitch diameter, divide by the required diametral pitch and multiply the quotient by the required number of teeth	To obtain the lead of spiral, divide by the required diametral pitch and multiply quotient by the required number of teeth		To obtain the pitch diameter, divide by the required diametral pitch and multiply the quotient by the required number of teeth	To obtain the circular pitch for one tooth, divide by the required diametral pitch	Angle of Spiral in Degrees
	Circular Pitch	One Tooth or Addendum	Lead of Spirals		One Tooth or Addendum	Circular Pitch	
Small Wheel	Small Wheel	Small Wheel	Small Wheel	Large Wheel	Large Wheel	Large Wheel	Large Wheel
1	3.1419	1.0001	180.05	3.1420	57.298	180.01	89
2	3.1435	1.0006	90.020	3.1435	28.653	90.016	88
3	3.1457	1.0013	60.032	3.1458	19.107	60.026	87
4	3.1491	1.0024	45.038	3.1492	14.335	45.035	86
5	3.1535	1.0038	37.077	3.1527	11.473	36.044	85
6	3.1589	1.0055	30.056	3.1589	9.5667	30.055	84
7	3.1652	1.0075	25.728	3.1651	8.2055	25.778	83
8	3.1724	1.0098	22.573	3.1724	7.1852	22.573	82
9	3.1806	1.0124	20.082	3.1807	6.3924	20.082	81
10	3.1900	1.0154	18.092	3.1901	5.7587	18.092	80
11	3.2003	1.0187	16.464	3.2003	5.2408	16.464	79
12	3.2145	1.0232	15.076	3.2105	4.8097	15.104	78
13	3.2242	1.0263	13.966	3.2294	4.4454	13.988	77
14	3.2377	1.0306	12.986	3.2378	4.1335	12.986	76
15	3.2522	1.0352	12.138	3.2524	3.8637	12.138	75
16	3.2679	1.0402	11.393	3.2678	3.6279	11.397	74
17	3.2848	1.0456	10.417	3.2821	3.4203	10.745	73
18	3.3116	1.0514	10.192	3.3032	3.2360	10.166	72
19	3.3225	1.0576	9.6494	3.3225	3.0715	9.6494	71
20	3.3430	1.0641	9.1848	3.3433	2.9238	9.1854	70
21	3.3650	1.0711	8.7662	3.3652	2.7904	8.7663	69
22	3.3882	1.0785	8.3862	3.3833	2.6694	8.3862	68
23	3.4127	1.0863	8.0399	3.4129	2.5593	8.0403	67
24	3.4451	1.0946	7.7379	3.4391	2.4585	7.7242	66
25	3.4661	1.1033	7.4332	3.4663	2.3662	7.4336	65
26	3.4953	1.1126	7.1664	3.4952	2.2811	7.1663	64
27	3.5258	1.1223	6.9198	3.5257	2.2026	6.9197	63
28	3.5579	1.1325	6.6912	3.5575	2.1300	6.6916	62
29	3.5918	1.1433	6.4799	3.5919	2.0626	6.4799	61
30	3.6276	1.1547	6.2778	3.6277	2.0000	6.2832	60
31	3.6650	1.1666	6.0979	3.6652	1.9416	6.0997	59
32	3.7043	1.1791	5.9282	3.7044	1.8870	5.9282	58
33	3.7457	1.1923	5.7710	3.7459	1.8360	5.7680	57
34	3.7894	1.2062	5.6181	3.7826	1.7882	5.6178	56
35	3.8349	1.2207	5.4754	3.8351	1.7434	5.4770	55
36	3.8830	1.2360	5.3431	3.8834	1.7013	5.3448	54
37	3.9336	1.2521	5.2201	3.9261	1.6616	5.2200	53
38	3.9867	1.2690	5.1028	3.9921	1.6242	5.1026	52
39	4.0482	1.2867	4.9866	4.0416	1.5890	4.9920	51
40	4.1010	1.3054	4.8873	4.1012	1.5557	4.8874	50
41	4.1626	1.3250	4.7885	4.1540	1.5242	4.7884	49
42	4.2273	1.3456	4.6949	4.2272	1.4944	4.6948	48
43	4.2956	1.3673	4.6065	4.2956	1.4662	4.6062	47
44	4.3671	1.3901	4.5223	4.3675	1.4395	4.5225	46
45	4.4428	1.4142	4.4428	4.4428	1.4142	4.4428	45

of teeth — .1269 × 16 = 2.030 = pitch diameter. Add 2 pitches — two ⅛ = ¼ and 2.030 + .25 = 2.28 inches outside diameter.

The lead of spiral for 10 degrees for small wheel is 18.092. Divide by pitch = 18.092 ÷ 8 = 2.2615. Multiply by number of teeth, 2.2615 × 16 = 36.18, the lead of spiral, which means that it makes one turn in 36.18 inches.

For the other gear with its 80-degree angle, find the addendum, 5.7587. Divide by pitch, 8 = .7198. Multiply by number of teeth, 10 = 7.198. Add two pitches, or .25, gives 7.448 as outside diameter.

The lead of spiral is 3.1901. Dividing by pitch, 8 = .3988. Multiplying by number of teeth = 3.988 the lead of spiral.

When racks are to mesh with spiral gears, divide the number in the circular pitch columns for the given angle by the required diametral pitch to get the corresponding circular pitch.

If we want to make a rack to mesh with a 40-degree spiral gear of 8 pitch: Look for circular pitch opposite 40 and find 4.101. Dividing by 8 gives .512 as the circular pitch for this angle. The greater the angle the greater the circular or linear pitch, as can be seen by trying an 80-degree angle. Here the circular pitch is 2.261 inches.

SECTION VII

GRINDING

CHAPTER I

TYPES OF GRINDING MACHINES

Grinding machines as commonly used in manufacture may be grouped under the following classifications:

(1) Machines for grinding cylindrical and conical surfaces, both external and internal.

(2) Machines for grinding plane surfaces.

(3) Cutter, tool and drill grinders for keeping in order milling cutters and reamers, lathe and planer tools, and twist drills. These are ordinarily sharpening machines and not for sizing work. In certain designs, however, the functions of cylindrical and surface grinders are combined with those of the cutter, reamer and tool grinder.

(4) Center and portable grinders for use in the tool post.

(5) Bench, floor and swing frame grinders for general shop and foundry purposes, also for polishing and buffing.

GROUP 1

MACHINES FOR GRINDING CYLINDRICAL AND CONICAL SURFACES

In group 1, we have the following types of machines:

(*a*) **Plain grinders,** especially adapted for manufacturing purposes such as the grinding of rolls and shafts, machine spindles, columns, sleeves, bushings, and a great variety of other work, both cylindrical and taper. With suitable attachments they are used for grinding crankshafts, camshafts, etc. A plain grinder, 14 by 96-inch machine, is shown in Fig. 1.

(*c*) **Universal grinders,** designed for grinding, in addition to the classes of work noted above, conical and disk-shaped pieces which may be rotated between centers or upon the face plate, and which require grinding across the face as well as upon the periphery, as in the case of a collar, a beveled blank, or a cutter. Such grinders are also used for finishing internal surfaces, both straight and taper, as the bore of a milling cutter, sleeve or ring gage. A universal grinder is illustrated in Fig. 2.

Some types of universal grinders are arranged for grinding the

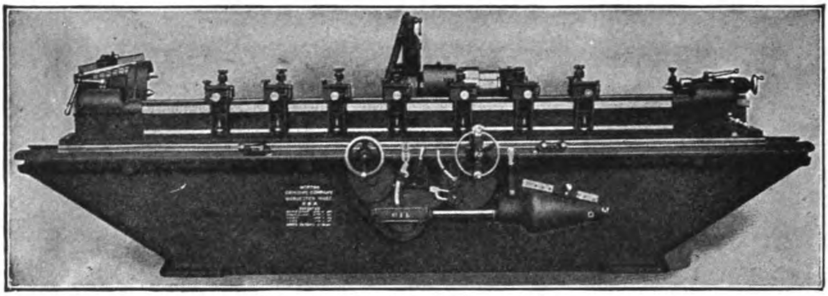


FIG. 1.—Norton plain grinder.

teeth of cutters, reamers and tools generally, in addition to accomplishing the operations outlined above. They may also be used for surface grinding.

(*c*) **Internal grinders,** for finishing the inner surfaces of bushings,

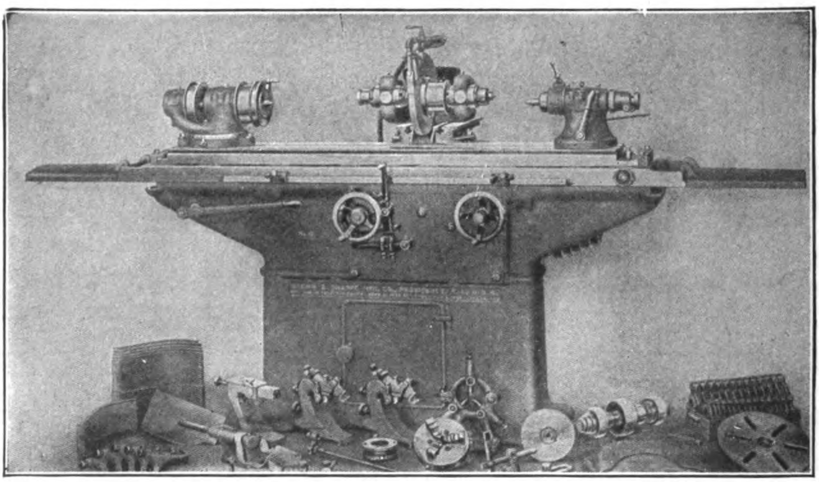


FIG. 2.—Brown & Sharpe universal grinder.

gears, gages, sleeves, etc. One specialized form of the internal machine is the cylinder grinder extensively used in automobile factories and in repair shops. One make of cylinder grinder is shown by Fig. 3.

(*d*) **Bench precision and traverse spindle grinders,** small high-speed machines for extremely accurate operations on light, delicate work, in tool rooms, watch shops, and other places. Grinders of this general nature, but with special features, are used extensively in finishing ball races, and various other accurate parts required in large quantities.

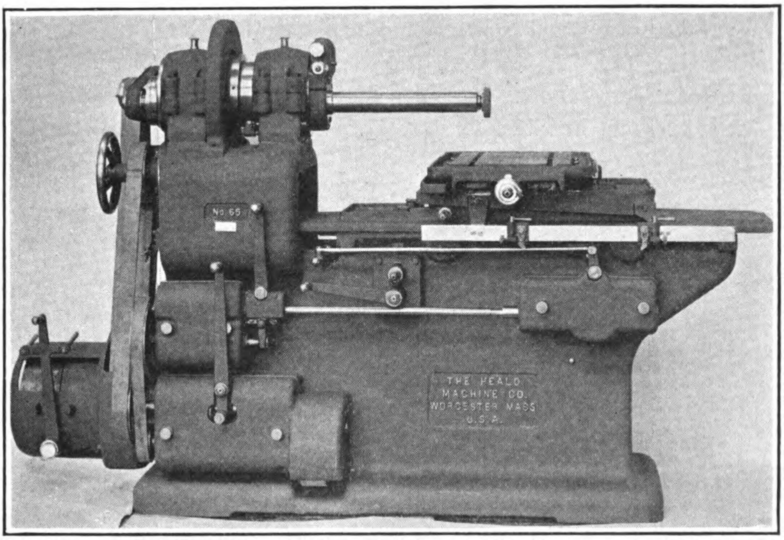


FIG. 3.—Heald cylinder grinder.

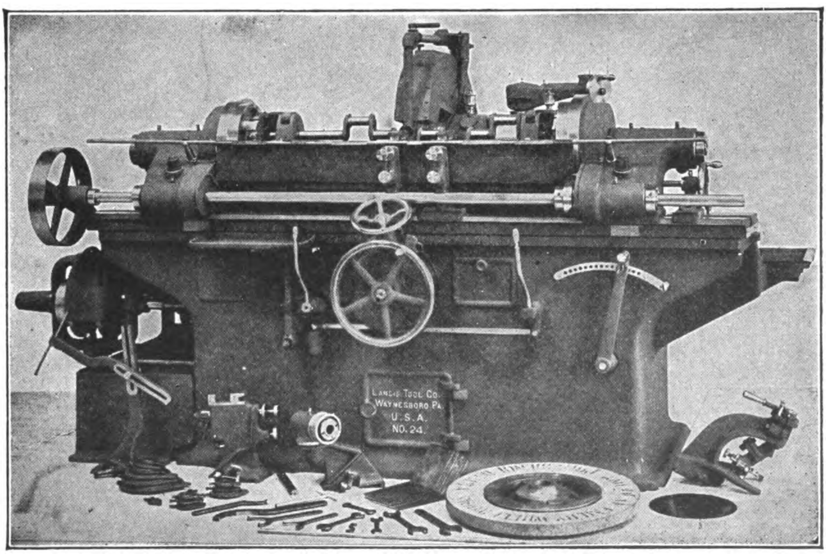


FIG. 4.—Landis crank grinder.

(*c*) **Miscellaneous,** including crankshaft and camshaft grinders developed particularly for operations on such parts for gasoline engine and similar work; roll grinders, for finishing calendar, milling, and other rolls; chucking grinders, a recent development in which three-wheel spindles are provided for external and internal operations on all kinds of cast iron and steel parts; pulley grinders, for finishing pulleys, flat or crowned, from the rough; car-wheel grinders for grinding wheels on their axles, etc. A crank grinder is represented by Fig. 4. The chucking grinder is shown in Figs. 14 and 15. Automatic and sizing grinders are shown in Figs. 12 and 13.

GROUP 2

MACHINES FOR GRINDING PLANE SURFACES

Group 2 includes the following machines:

(*a*) **Horizontal surface grinders,** equipped with a plain wheel on a horizontal spindle with the work carried under the edge of the wheel,

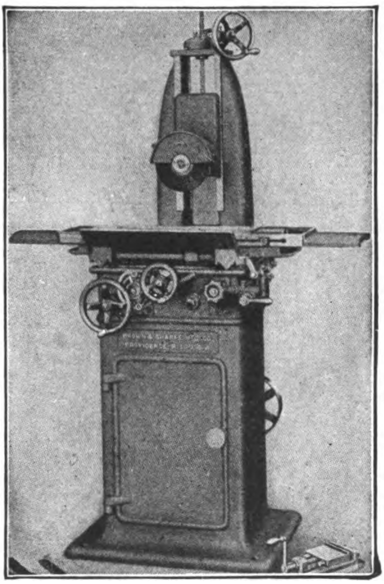


FIG. 5.—Brown & Sharpe surface grinder

usually by a reciprocating table, though in certain types a rotating table is employed. A well-known machine in this group is the planer type grinder, so called because of the general resemblance to a planer, particularly in the case of the platen and cross rail which carries the horizontal wheel head. Smaller machines of the horizontal spindle type, like Fig. 5 for example, are commonly used in tool-rooms for grinding punches, dies and various other tools and accomplishing much other work of similar character. In its simplest form, the tool-room surface grinder has a plain table without power feed across which the work is moved by hand under the wheel.

(*b*) **Vertical surface grinders,** equipped with a cup wheel mounted on a vertical spindle, under which the work is carried by a reciprocating or a rotating table so that the surface is in contact with the end of the grinding wheel. (See Fig. 34.)

(*c*) **End, edge, or face grinders,** horizontal spindle machines using a ring wheel which operates with its end against the surface of the

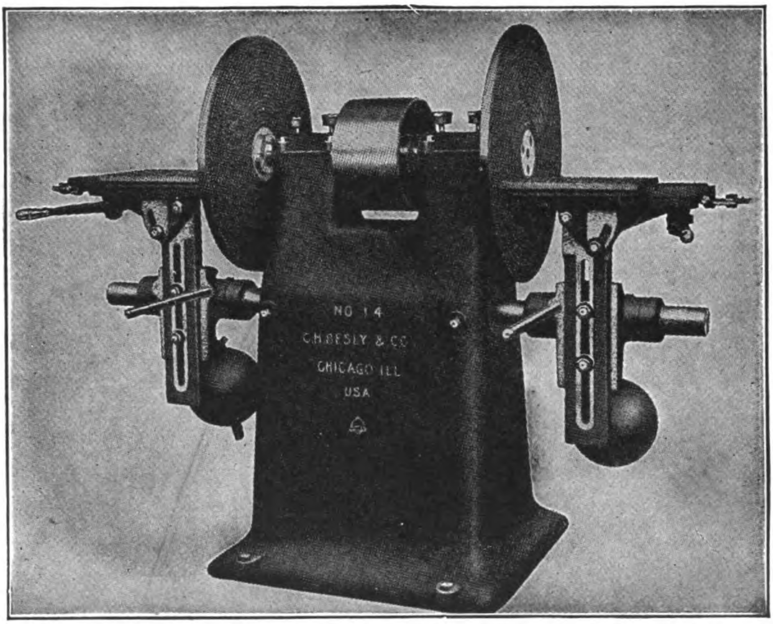


FIG. 6.—Besly spiral disk grinder.

work. Such machines in one form or another are used for grinding edges and sides of castings, and for grinding machine knives, etc. The work is either carried to and fro by a reciprocating table or remains stationary while the wheel head itself is traversed past the work. Knife grinders are also adapted for using disk wheels.

(*d*) **Disk grinders,** surfacing machines using as an abrading medium, a metal disk to the face of which a circular abrasive sheet is fastened. Such grinders are extensively employed in facing all sorts of castings, and for surfacing material of various kinds that can be brought into contact with the disks. One design is shown by Fig. 6.

(*e*) **Belt grinders or grinder belts,** these are operated either vertically or horizontally, and are covered with abrasive material for finishing flat pieces or work requiring one or more flat faces.

(*f*) **Miscellaneous,** including piston ring grinders with rotary table, for finishing the parallel faces of piston rings; disk grinders for finishing the faces of flat, concave or convex disks. Vertical and horizontal lapping machines using disks charged with fine abrasive are also made for finishing flat surfaces smoothly and accurately.

GROUP 3

CUTTER, TOOL AND DRILL GRINDERS

The machines in this group are mainly for keeping tools sharp and in condition for working properly. Under this classification are included the following grinders:

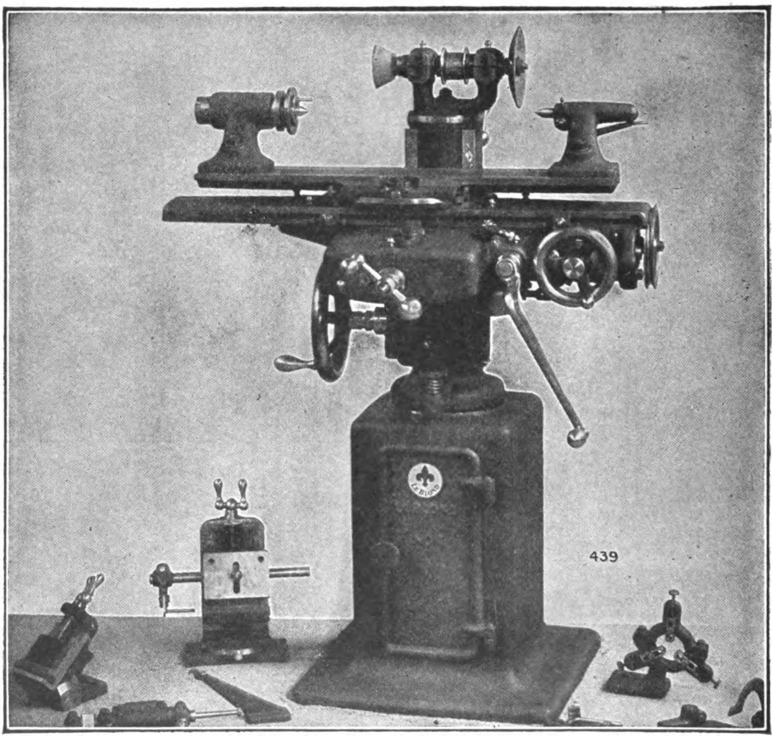


FIG. 7.—Le Blond universal cutter and tool grinder.

(*a*) **Plain cutter grinders,** primarily designed for sharpening milling cutters and similar tools; in some designs the plain machine is converted into a universal cutter and tool grinder by the addition of certain attachments.

(*b*) **Universal cutter and tool grinders,** adapted for sharpening all kinds of milling cutters, reamers, saws, taps, hobs, etc., and, as already indicated, suited to a variety of cylindrical and surface grinding operations, such as are necessary in finishing bushings, mandrels, small shafts, spindles, straight-edges, knives, plates, etc. A machine of this type is shown in Fig. 7.

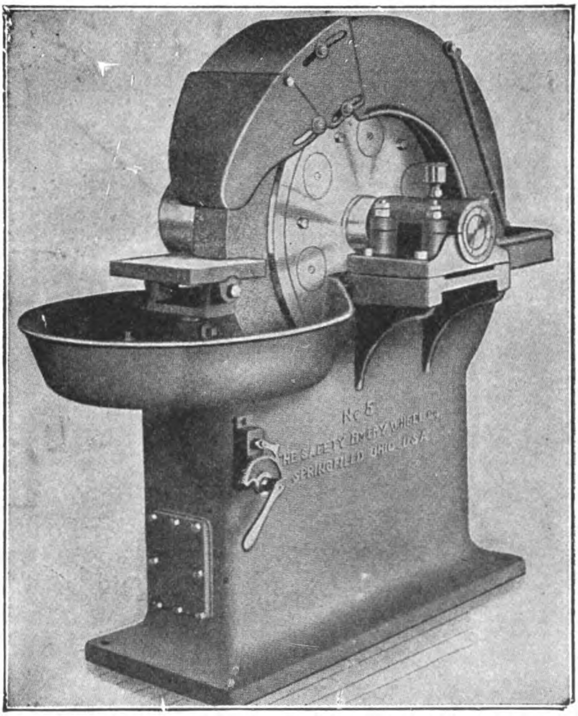


FIG. 8.—Safety Emery Wheel Co.'s wet tool grinder.

(*c*) **Tool grinders (for lathe and planer tools),** consisting in the simplest form of a wet or dry bench grinder or of a wet grinder stand and wheel for hand sharpening of cutting tools. For example, see Fig. 8. A highly developed type of tool grinder receives all kinds of lathe, planer and shaper tools as they come in the rough and shapes them accurately to predetermined forms, grinding top, front and sides to the exact contour and degree of rake and clearance desired.

(*d*) **Drill grinders,** designed for sharpening twist drills and for this purpose provided, as in Fig. 9, with an oscillating holder with V-block to receive the drill and allow its lip to be passed across the side of the wheel with an angular, swinging motion which gives the desired clearance at the point for cutting. Provision is made for securing equality

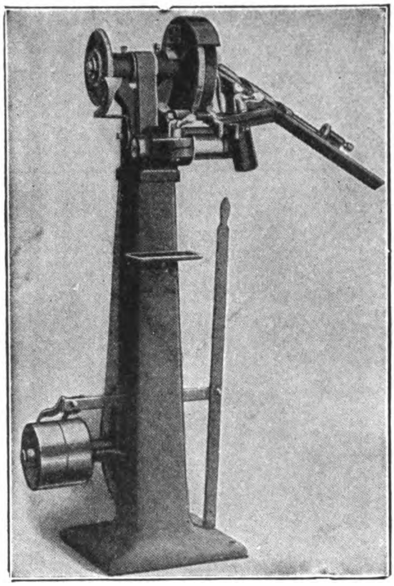


FIG. 9.—American drill-grinding machine—Heald Machine Co.

of length and uniformity of angle and clearance for the two lips of the drill.

GROUP 4

CENTER GRINDERS AND PORTABLE APPARATUS FOR TOOL POST AND OTHER OPERATIONS

(*a*) **Center grinders,** used in the lathe for grinding the live center to the correct angle, the wheel spindle being driven from the face plate, from an overhead drum, or by a small motor. One of these in operation is represented by Fig. 10.

(*b*) **Portable electrical grinders,** portable machines, usually with motor-driven wheel spindles, for use in the engine lathe tool post for finishing cylindrical work, and also used in the shaper or planer tool post and on machine tables, for special grinding operations.

(*c*) **Portable machines,** with some form of pulley drive or with flexible-shaft drive, for grinding drop-forge dies, metal patterns, irregular blanking dies, and for external and internal operations on other bench-work.

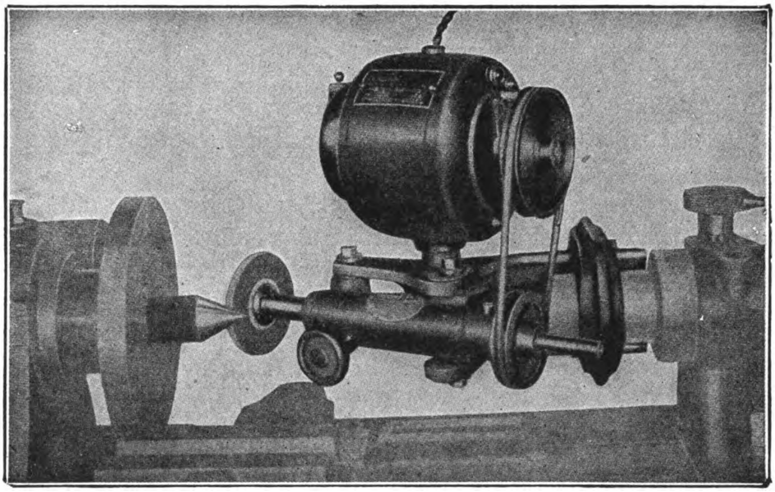


FIG. 10.—Motor-driven center grinder.

GROUP 5

BENCH, FLOOR AND SWING-FRAME GRINDERS FOR SHOP AND FOUNDRY

Under this head may be grouped a great variety of simple grinding apparatus for smoothing castings, surfacing bosses and pads, grinding off scale and fins, rounding corners and performing an endless number of similar operations, where the casting, forging, or other piece can be

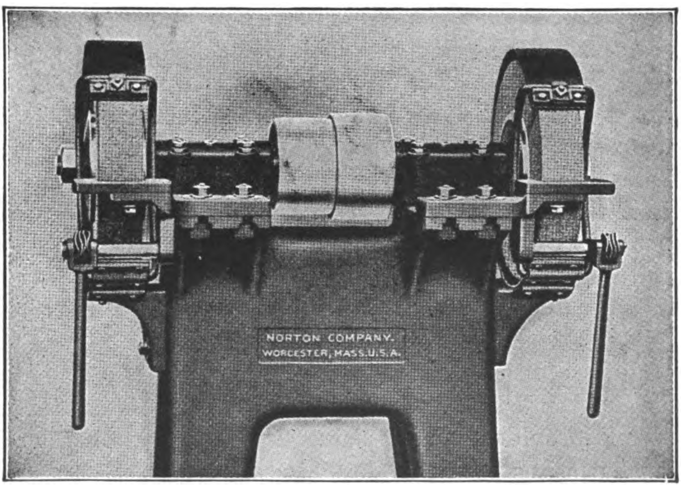


FIG. 11.—Norton floor grinder with protection hoods.

held in contact with the wheel without the necessity of mounting it upon a power actuated table.

(*a*) **Bench and floor grinders** are usually made up as in Fig. 11, of a plain stand with a simple horizontal spindle at the top carrying a wheel at each end. The spindle may be either belted or direct motor driven.

Machines of quite similar character, with abrasive and buffing wheels, are used extensively in polishing and buffing work for plating. They are commonly known as polishing jacks, polishing stands, buffing heads, etc.

(*b*) **Swing-frame grinders** are suspended in such manner as to enable the operator to pass the wheel over castings of almost any form or size.

NOVEL FEATURES IN GRINDING MACHINES

In addition to the grinders shown under the foregoing groups a few which contain unusually novel and radical features have been selected for brief description in this chapter.

AUTOMATIC GRINDING MACHINE

Figure 15 shows the automatic grinding machine built by the Norton Grinding Company for grinding cylindrical work up to 6 inches in diameter. The machine shown is fitted for grinding the outside of ball races. The rings are held in a magazine feed, ready to roll down and be gripped in the chuck as soon as the retaining plunger is withdrawn at the proper time. The ring, which is dropped out of the chuck, falls on the small chain belt conveyor and is carried in a box placed at the end of the machine. The heavy grinding head is very similar to that used on the regular Norton machine, but its movement to and from the work is controlled automatically by a cam on the shaft at the rear, in such a way as to secure absolute certainty of movement at each stroke. The grinding wheel is independently driven to secure the correct speed for the wheel, other movements being timed by gearing from the pulley at the back through the medium of a positive clutch and planetary gearing.

AUTOMATIC SIZING GRINDERS

The machine illustrated by Fig. 12 is an automatic sizing grinder built by the Pratt & Whitney Company for cylindrical and taper work. This grinder is provided with a sizing device and automatically controlled feed by means of which duplicate parts may be automatically finished to uniform size regardless of the wear of the wheel during the progress of the work. When the mechanism is once set for the first piece ground, the operator has simply to remove the piece when completed, place another piece between the centers and start the feeding mechanism, which continues to advance the wheel to the work until the latter is ground down to the required size, when the feed is automatically thrown out of action. The ingenious mechanism for accomplishing this important operation of bringing the work accurately to size, without the necessity upon the part of the operator of calipering the diameter and feeding the wheel slide to compensate for any wear of the wheel prior to the final finishing passes, provides for the taking of

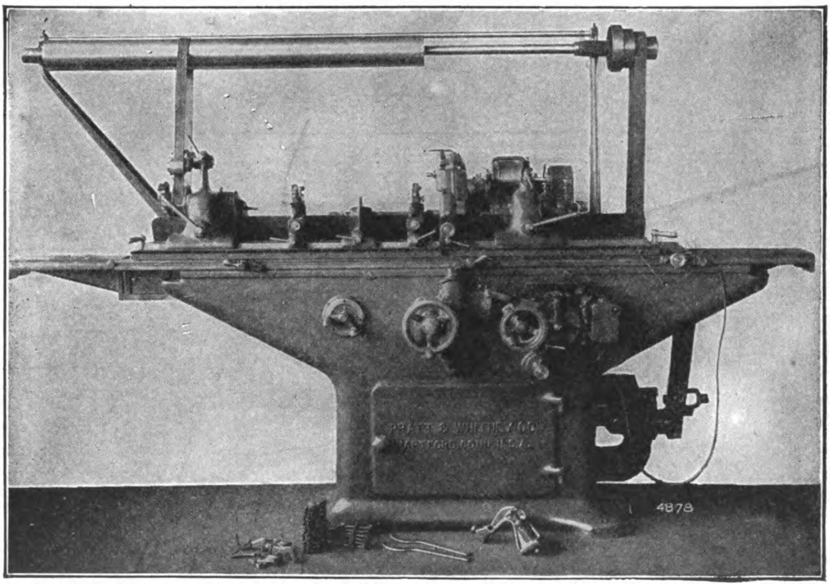


FIG. 13.—Pratt & Whitney automatic sizing grinder.

coarse feeds until the work is nearly to size, when a very fine feed is automatically thrown in for the finishing operation.

THE CHUCKING GRINDER

A grinding machine brought out by the Bryant Chucking Grinder Company of Springfield, Vt., is illustrated in Fig. 13. The principle of the wheel-slide control of this machine is radically different from that of any other. This difference lies in the fact that this grinder has no cross slide. Instead, the head carrying the grinding spindle is suspended on a substantial bar. This bar is held in journals and is free to both swing and slide, giving both the cross feed for hole diameter and the longitudinal feed of the wheel in and out of the work.

This design makes it easy to swing the wheel to the work and to remove it for gaging. It also permits of a rigid stop to the cross motion which also acts as a guide or control plate, as the wheel traverses the work. This guide can in fact, be used to grind special forms or contours, so that the machine is not confined to plain interval grinding.

The grinding spindle is located midway between the overhead bar and the control plate and so gives a feed screw control over the wheel of two to one. It also assists in alignment control.

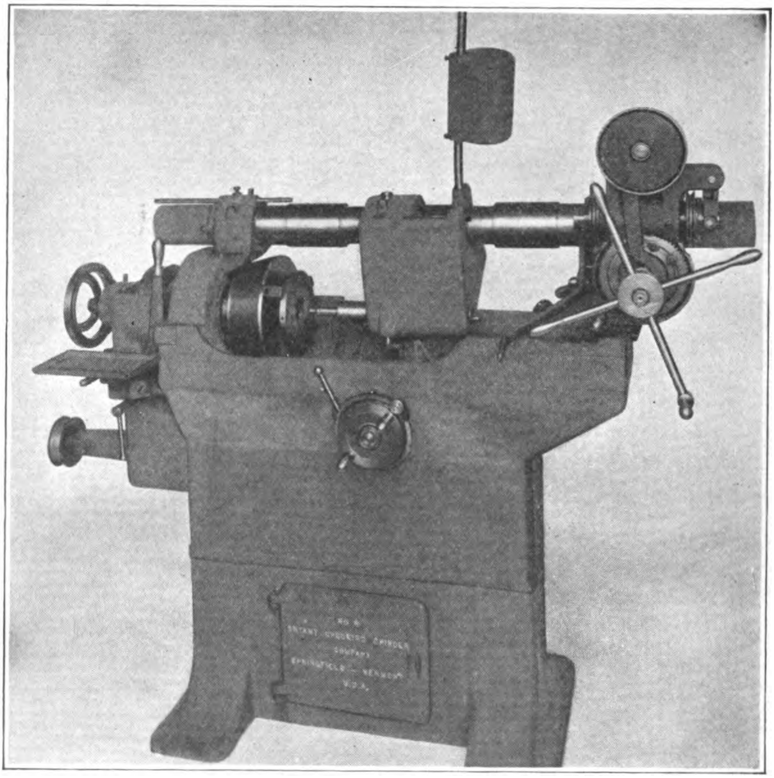


Fig. 14.—Bryant chucking grinder.

The longitudinal movement of the wheel slide is secured by a rack and pinion from the four spoked pilot wheel shown or by a power feed as preferred. The rack is formed on the end of the bar, and, being circular, is in mesh in any position.

In operation, the act of carrying the wheel slide backwards to clear the work automatically swings the grinding wheel back out of line with the work center. This gives ample room for inspection with plug gages or otherwise and is very quickly operated.

Proper alignment of the machine is easily made by adjusting the control plate or guide. Or it can readily be shifted for taper work if desired. This machine is also made with a second wheel spindle for face grinding.

One of the essential conditions for successful grinding is the right wheel for the work, and this machine allows the proper selection in the same way that a chucking machine has the right tools for every operation.

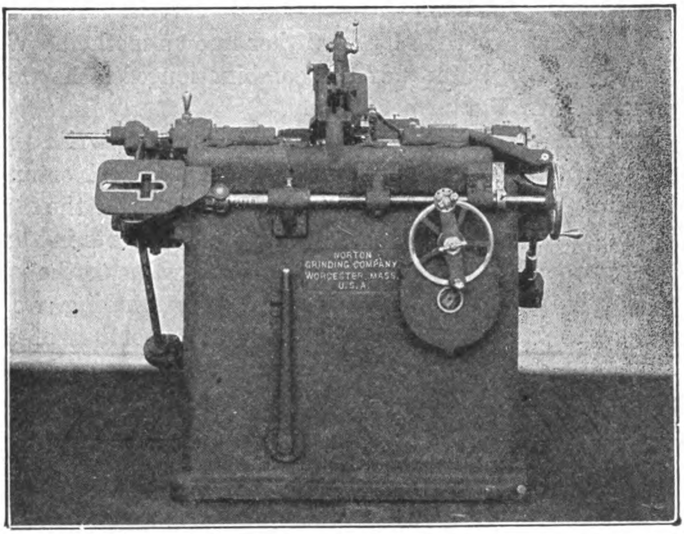


Fig. 15.—A 6-in. automatic grinding machine.

Figure 15 shows very clearly the grinding of a tempered collet, which is all done at one operation, although four grinding wheel positions are necessary. The first of these shows the collar held on a taper draw chuck and the internal grinding wheel at work sizing out the nose. In the second position the front face is being ground by the large outside wheel and also being buffed by the wheel on the rear spindle. In position three, the large wheel is grinding the outside and the back face, while in the fourth position the work spindle has been swung to the necessary angle, 15 degrees, and the outside wheel is grinding the tapered front seat.

CHAPTER II

THE CYLINDRICAL GRINDING FIELD

It is probably true that the majority of engineers do not have a proper conception of the field of metal grinding. Grinding is a manufacturing operation, permitting us to produce certain classes of work cheaper, faster and better than by any other known method. We need, however, a more careful study of the combination of lathe work and grinding to obtain maximum production.

There is no one better qualified by experience to write upon the subject of the grinding machine and its field than C. H. Norton, of the Norton Grinding Company, whose numerous articles in the *American Machinist*, along with those contributed by other experts in the art of grinding, have proved of the highest educational value to thousands of readers of that journal. In defining the field for grinding, we can do no better than to incorporate in this chapter a portion of a paper presented by Mr. Norton before the American Society of Mechanical Engineers and published in slightly condensed form in the *American Machinist*.

Grinding in various forms has been known to man from the very beginning of history, yet it is doubtful if many engineers have a clear conception of the field for metal grinding.

The intelligent use of the process of grinding yields such large returns that it warrants careful study by the very best engineering and scientific minds and a place in the courses of our technical schools. The field is constantly broadening with each year's improvements in grinding wheels and grinding machines.

The fact about grinding with the modern grinding machine and grinding wheel is that it enables us to size all round work cheaper than by turning and filing, that it takes the place of what we formerly called the finish cut of the lathe and all filing, giving us not a theoretically perfect cylinder or perfect finish, but a much nearer perfect cylinder and finish than we obtained with the lathe. It gives us diameters to such small limits as to be called exact, but whoever insists that none but exact work be ground loses the very pith of grinding, which is economy. Modern grinding means cheaper cost for all work, many grades of work to suit many requirements, and cheaper turning than is possible without the use of the grinding machine.

TURNING BEFORE GRINDING

As a rule, the coarser the turning the greater the economy of grinding. The greatest economy is obtained by the combination of cheaper turning and grinding. It is no longer necessary to turn work smooth, straight or correctly to size and the lathe is no longer necessary as a precision tool. If it has a carriage traverse of from four to ten threads per inch, has sufficient power to carry high-speed tool cuts at that feed and is well supplied with steady rests to prevent springing of the work, it is ready for coöperation with the grinding machine. It is easier with modern grinding machines and wheels to grind off a given amount of metal when in the form of crude screw threads than in any other form, and with long work having several sizes the grinding requires less time if $^1/_{32}$ inch to $^5/_{64}$ inch is left on the diameter for grinding than if the work is turned carefully to within 0.002 inch to 0.005 inch. In all cases, accurate turning increases the total cost of production and in some it makes the grinding very expensive.

The greatest economy is usually obtained by the combination of grinding with very rough turning. Yet there are cases where the least expensive way is to grind direct without turning, notably the greater part of crank shafts of automobiles and small gas engines and very long and slender work where turning is difficult.

Developments warrant the conclusion that we should no longer assume that simply because a tool is a grinding wheel it cannot remove metal and size and shape work as quickly as a steel tool. Rather, we should use the steel tool when it can be made to remove metal, size and shape work cheapest, and the grinding wheel when it excels. It is no longer to be taken as a matter of course that we can turn, plane and mill faster than we can grind.

The grinding wheel as now made is really a milling cutter with millions of cutting teeth. Although these teeth are not as large or as strong as the teeth of a steel cutter and, therefore, cannot cut as deeply, yet they are capable of cutting at much greater speed. Since there are so many more of them they are capable of much more work in a given time when the nature of the work is such that a large number of these cutting points can be used simultaneously. In some cases we can use as many as 2 billion cutting points per minute. Eight hundred million per minute is not uncommon and 400 million per minute is very common.

The modern grinding wheel, mounted in a good machine, can be used at a cutting speed of 6000 or more surface feet per minute and owing to this high speed it need not cut deeply relative to the rigidity of the work. Therefore it is able to remove metal from many forms of work more quickly than the milling cutter or the lathe tool.

AN ILLUSTRATION—GRINDING SMALL CAMS

The accompanying illustrations show a notable example. In Fig. 16, Nos. 1 to 4, inclusive, show the process of making small cams. An order for a hundred of these cams was received. It is evident that drop forgings for so few would be out of the question, as the expense of dies would make the cost of the cams prohibitive. It was, therefore, necessary to devise means for producing them from the bar stock. This was done by providing an eccentric chuck for the automatic screw machine. To prevent the bar from turning in the chuck while feeding forward, the spline was made the full length and a mating key was

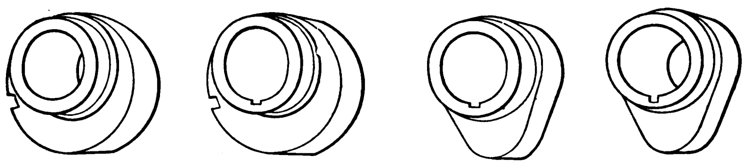


FIG. 16.—Grinding cams for automobile engines.

placed in the chuck. Pieces like No. 1 were made in the automatic machine at the rate of 10 per hour. A keyway in the hole was made in the ordinary way, No. 2. These blanks were ground to rough shape, No. 3, at the rate of 10 per hour. The cams were then hardened and finished ground to No. 4 at the rate of 40 per hour. It should be clear that such a cam could not be milled to shape from the blank in nearly so short a time with the milling cutter. When manufacturing such cams in large numbers drop forgings would be used, and here again the grinding wheel is quicker than the milling cutter.

GRINDING PINS AND BEARINGS OF AUTOMOBILE CRANKSHAFTS

Another case where the grinding machine can accomplish the results desired in less time than the lathe is that of the pins and bearings of the automobile crankshaft. The results desired are as follows: Five bearings, all round within 0.00025 inch; the axis of all parallel and exactly in line; all of the right length within 0.004 inch; distance between bearings within 0.004 inch; accumulated error not over 0.008 inch. Four crank pins, all round within 0.00025 inch;

the axis of all exactly parallel; all to length within 0.004 inch; all parallel with the bearings; all within 0.005 inch of the same plane;

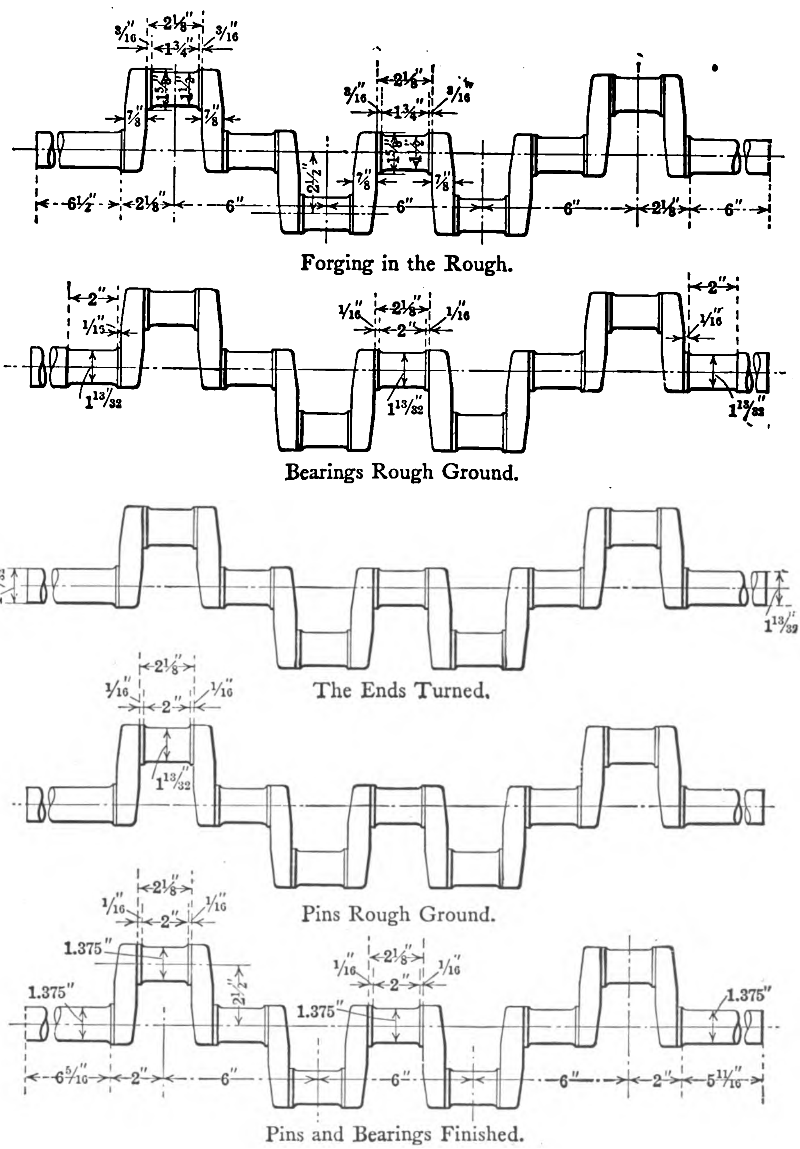


Fig. 17.—Stages in the grinding of an automobile crankshaft.

all of correct throw, within 0.010 inch; overall length, accumulated error not over 0.008 inch; all fillets correct radius and exactly concentric with the bearings and pins; all bearings and pins straight within 0.00025 inch; and all a good, smooth surface.

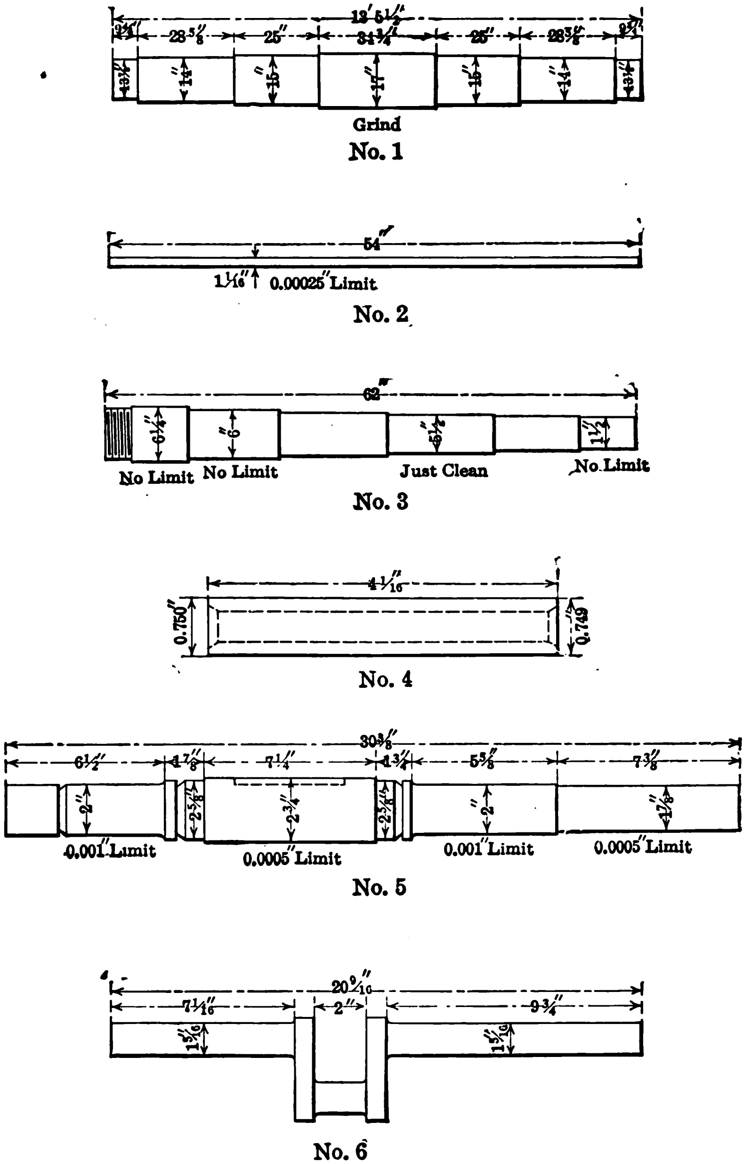


FIG. 18.—Work done on cylindrical grinder.

In the case of cranks designed with clearance for the arms of the cranks, as shown in Fig. 17, the width of the wheel is identical with the required length of the pins and bearings, so that no measuring or setting of the tool is necessary for cutting to length. The act of grinding cuts the bearing or pin the right length and forms the fillets. The location of the pins and bearings within the small limits allowed is accompanied by a massive index bar, so that the workman does no measuring whatever for location of bearings or pins. The entire time of handling and producing these five bearings and four pins from the rough forging to the nicely sized and finished condition is 85 minutes. It is clear that when all the conditions of the finished work are considered the grinding wheel and machine have removed metal faster than the lathe. Again, it is not simply a case of removing pounds of metal per hour, but the removal of it in such a manner as to accomplish certain results in the least time.

The ends of these shafts beyond the bearings are turned before grinding. The entire list of operations to make a finished shaft from the forging is as follows:

	Minutes
Cut off ends and center	6
Rough grind bearings	15
Turn ends	8
Rough grind pins	20
Finish grind pins	20
Finish grind bearings and ends	25
Square ends	6
Total time	100

OTHER ILLUSTRATIONS

There are many other cases where the grinding wheel is used to remove metal in a more economical manner than with steel-cutting tools, some of which are shown in Fig. 18.

Automatic grinding is a late development in the field. Certain work of which large numbers of pieces are made is ground by wholly automatic means. The work is conveyed to the machine by gravity in a hopper or chute and is chucked, ground and delivered to the receptacle. In a case where formerly, at piece work, 300 per day were ground, the automatic machine grinds four in a single minute, about 2300 per day.

CHAPTER III

CYLINDRICAL GRINDING DETAILS

THE WORK AND THE TIME

In the examples that follow the turning time is given whenever possible as it is on the total turning and grinding time that the real economy depends.

So the first step in using a grinder economically is to learn how to turn work that is to be finished in that way.

The first example in Fig. 19 is plain grinding from cold-rolled steel stock where only 0.018 inch was removed so that no turning was necessary. The wheel used was a 24-inch combination grit of L grade and 15 pieces were ground in 44 minutes.

The next example, No. 2, was turned to closer limits than is desirable for economy and as the turning time is not known we cannot compare the total cost of finishing with the other pieces. The limits of accuracy are very close on some parts as can be seen from the sketch. The material is 0.30 carbon steel, stock removed 0.018 inch, the wheel 24-inch combination L, as before and 12 pieces were ground in 150 minutes, or 12½ minutes each, but a single piece is not as good a test as the average of a lot.

A similar piece is shown in No. 3, which is also a low-carbon steel. The stock removed was only 0.015 inch in this case. The same wheel is used. The limit on bearings was 0.0005 inch only; 25 pieces were ground in 505 minutes or $20^1/_5$ minutes each as an average.

The rest of the examples show the turning time, which, it will be seen, is very low indeed and shows where a decided economy can be effected over usual practice.

Number 4 was rough turned in one cut (the sketch, not being to scale, is a little confusing in this, but the diameters given show that this is easily possible) leaving $^3/_{64}$ inch for grinding. The turning speed was 60 feet per minute with a feed of $^1/_{16}$ inch per revolution and the turning time was only 20 minutes. Then the ends were squared up, oil grooves cut and shoulders finished, which took 50 minutes more. The grinding averaged from 30 to 40 minutes, but a single piece of this kind has been done in 18 minutes. The total time per piece was 100 to 110 minutes.

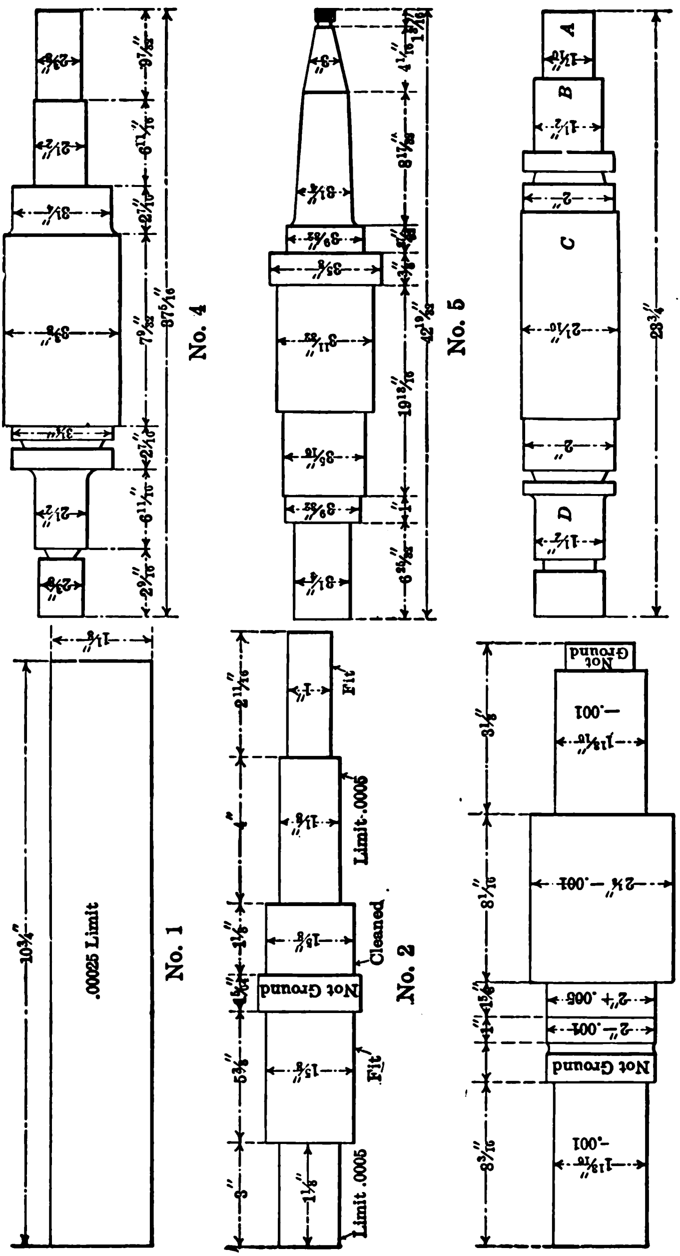


Fig. 19.—Example of cylindrical grinding.

Number 5 is another example of the same kind which was rough turned in one cut so as to leave $^3/_{64}$ inch of stock for finishing, being turned at 65 feet per minute with a feed of $1/8$ inch per revolution. Turning time was 15 minutes. The squaring up of the ends, finishing of shoulders and cutting of thread took 45 minutes. The grinding averaged to take 30 to 40 minutes, although a single piece has been done in 14 minutes. The total time was 90 to 100 minutes.

The last example is somewhat similar to No. 4, but is shorter so that it takes less time to go over it. This was rough turned in two cuts, leaving $^1/_{32}$ to grind. Turning time 20 minutes. Ends were squared, shoulders finished and oil grooves cut in 25 minutes. Grinding time 18 to 22 minutes. Here the parts *A* and *C* were ground to limits of 0.0005 inch and *B* and *D* to 0.001 inch, while all lengths are to gage. The total time on the piece is from 60 to 70 minutes.

In all grinding it is necessary to use the wheel best suited to the work to get the best results and in this there seems no better way than to tell the wheel-maker just what the work is.

The examples shown with this were furnished by the Norton Grinding Company, Worcester, Mass.

LIMITS IN GRINDING—GRINDING ALLOWANCES AND TIMES

As is the case with all other branches of machine work, grinder practice varies in different shops and the recommendations of grinder builders themselves show interesting variations in regard to speeds, feeds, allowances in turning for finishing with the wheel, wheel selection, etc.

Different firms have compiled much valuable material in the way of grinding limits and allowances and some very useful data of this character from the records of the Brown & Sharpe Manufacturing Company, Providence, R. I., are presented herewith along with illustrations of work of various kinds, and particulars of the time required for grinding under the conditions specified.

These data were originally presented in a paper read by W. A. Viall before the American Society of Mechanical Engineers. Mr. Viall's paper in substance is as follows:

In considering a piece of work to be ground, first of all the question arises as to the size and the limits suitable for the purpose for which it is intended. Table 1 gives the limits used at the Brown & Sharpe Manufacturing Company's works for varying conditions. There are special cases where it may be necessary to increase or to decrease these limits, and this table is not offered as the final word but as a guide toward selection.

TABLE I.

GRINDING LIMITS FOR CYLINDRICAL PIECES

as adopted by Brown & Sharpe Mfg. Co.

The limits shown below should be followed under ordinary conditions. Special cases should always be given special consideration as it may be desirable to vary slightly from the tables.

It is Brown & Sharpe practice to consider the hole as being standard, and the limits shown below are based on the standard hole. The grinding limits for holes apply to hardened pieces. The holes in soft pieces are chucked to standard diameter.

RUNNING FITS, ORDINARY SPEEDS

These limits are satisfactory for shafts running under 600 R.P.M. and under ordinary working conditions. Spindles for all purposes are to be considered as special cases.

To ½-inch diameter, inclusive	.0005	to	.001	Small
To 1 -inch diameter, inclusive	.00075	to	.0015	Small
To 2 -inch diameter, inclusive	.0015	to	.0025	Small
To 3½-inch diameter, inclusive	.002	to	.003	Small
To 6 -inch diameter, inclusive	.0025	to	.004	Small

RUNNING FITS, HIGH SPEED, HEAVY PRESSURE AND ROCKER SHAFTS

These limits are satisfactory for shafts running more than 600 R.P.M. and where the working conditions are severe. Spindles for all purposes are to be considered as special cases.

To ½-inch diameter, inclusive	.0005	to	.001	Small
To 1 -inch diameter, inclusive	.001	to	.002	Small
To 2 -inch diameter, inclusive	.002	to	003	Small
To 3½-inch diameter, inclusive	.003	to	.004	Small
To 6 -inch diameter, inclusive	.004	to	.005	Small

SLIDING FITS

These limits are for shafts where a gear, clutch or other similar part slides on it continuously while the machine is in operation. These limits are the same as for "Running Fits, Ordinary Speeds."

To ½-inch diameter, inclusive	.0005	to	.001	Small
To 1 -inch diameter, inclusive	.00075	to	.0015	Small
To 2 -inch diameter, inclusive	.0015	to	.0025	Small
To 3½-inch diameter, inclusive	.002	to	.003	Small
To 6 -inch diameter, inclusive	.0025	to	.004	Small

STANDARD FITS, WHERE THE LOAD IS NOT HEAVY AND WHERE THE PART IS KEYED TO THE SHAFT AND CLAMPED ENDWISE WITH A NUT

These limits are suitable for light service only and where no fitting is to be done.

It is possible that where both parts are hardened, closer limits may be necessary, assuming that the parts are to be assembled without fitting.

To ½-inch diameter, inclusive	Standard	to	.00025	Small
To 3½-inch diameter, inclusive	Standard	to	.0005	Small
To 6 -inch diameter, inclusive	Standard	to	.00075	Small

STANDARD FITS

These limits are to be used where it is desirable or essential that the parts fit together without play, and still be put together or taken apart without difficulty. Some fitting may be required and also some selecting may be necessary to attain the proper results.

The Feed and Speed Cases for Milling Machines are good examples of where these limits might be used.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To ½-inch diameter, inclusive	Standard	to	.00025	Large
To 3½-inch diameter, inclusive	Standard	to	.0005	Large
To 6 -inch diameter, inclusive	Standard	to	.00075	Large

DRIVING FITS

For use where parts must fit tightly and where the location of the parts is such that they could not be put together if the drive was too great. These limits will apply where the assembly is permanent.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To ½-inch diameter, inclusive	Standard	to	.00025	Large
To 1 -inch diameter, inclusive	.00025	to	.0005	Large
To 2 -inch diameter, inclusive	.0005	to	.00075	Large
To 6 -inch diameter, inclusive	.0005	to	.001	Large

DRIVING FITS

To be used where the assembly is permanent and the duty severe, and where there is room for the handling and the driving of the parts.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To 2 -inch diameter, inclusive	.0005	to	.001	Large
To 3½-inch diameter, inclusive	.00075	to	.00125	Large
To 6 -inch diameter, inclusive	.001	to	.0015	Large

FORCING FITS

These limits may be used where parts are not expected to be taken apart and where service is very severe. This assembling is done under the arbor press for the smaller parts and under the hydraulic press for the larger parts.

The method of forcing the parts together and the length of the parts will have influence on how large to leave the shaft.

It is possible that where both parts are hardened, closer limits may be necessary, assuming the parts are to be assembled without fitting.

To ½-inch diameter, inclusive	.00075 to 001 Large
To 1 -inch diameter, inclusive	.001 to .002 Large
To 2 -inch diameter, inclusive	.002 to .003 Large
To 3½-inch diameter, inclusive	.003 to .004 Large
To 6 -inch diameter, inclusive	.004 to .005 Large

SHRINKING FITS, FOR PIECES TO TAKE HARDENED SHELLS ⅝-INCH THICK AND LESS

To 1 -inch diameter, inclusive	.00025 to .0005 Large
To 2 -inch diameter, inclusive	.0005 to .00075 Large
To 3½-inch diameter, inclusive	.0005 to .001 Large
To 6 -inch diameter, inclusive	.001 to .0015 Large

SHRINKING FITS, FOR PIECES TO TAKE SHELLS, ETC., HAVING A THICKNESS OF MORE THAN ⅝ INCH

To ½-inch diameter, inclusive	.0005 to .001 Large
To 1 -inch diameter, inclusive	.001 to .002 Large
To 2 -inch diameter, inclusive	.002 to .003 Large
To 3½-inch diameter, inclusive	.003 to .004 Large
To 6 -inch diameter, inclusive	.004 to .005 Large

GRINDING LIMITS FOR HOLES

To 2 -inch diameter, inclusive	Standard to .0005 Large
To 3½-inch diameter, inclusive	Standard to .00075 Large
To 6 -inch diameter, inclusive	Standard to .001 Large

The second necessity is that sizes should be established to which the work should be rough turned ready for the grinding room. In the above works, as in all factories, the aim is to produce the desired results as cheaply as possible. The desired ends have been accuracy and nicety of finish where the parts ground are for fits, and nicety of finish where no fit is required. To do this work as cheaply as possible this company believes that it is economical to turn the pieces to about the sizes indicated in Table 2. It will be noted that from 0.008 inch to 0.012 inch in diameter is allowed, an amount easily obtained by the ordinary class of lathe help. In order to make this work as easy as possible for the lathe department, a plain "go" and "not go" limit gage is furnished. Practice varies on this point, and a thorough endeavor has been made to try out the plan of allowing correct limits, but it has been found fully practicable to hold the lathe to the limits given. By so doing the finished product is obtained free from all tool marks and at what is believed to be the minimum cost.

EXAMPLES OF COMMERCIAL GRINDING

In Fig. 20, Nos. 1 to 6 show some samples of commercial grinding taken from actual practice for the purpose of giving an idea of what can be done in a commercial way, as well as to give some definite data as to speeds, feeds, etc. While it is perhaps not possible to give a rule that will fit all work, these illustrations should suggest ideas that will help in producing the work as well and as cheaply as this has been done in the cases shown. When enough pieces of any kind are to be made it is possible to specialize to a higher degree than can be done in the general run of work, and better results may be obtained than are shown here.

Size	Not go on	Go on	Size	Not go on	Go on	Size	Not go on	Go on
Inches			Inches			Inches		
3/8	0.383	0.387	15/16	0.9455	0.9495	1 1/2	1.508	1.512
7/16	0.4455	0.4495	1	1.008	1.012	1 9/16	1.5705	1.5745
1/2	0.508	0.512	1 1/16	1.0705	1.0745	1 5/8	1.633	1.637
9/16	0.5705	0.5745	1 1/8	1.133	1.137	1 11/16	1.6955	1.6995
5/8	0.633	0.637	1 3/16	1.1955	1.1995	1 3/4	1.758	1.762
11/16	0.6955	0.6995	1 1/4	1.258	1.262	1 13/16	1.8205	1.8245
3/4	0.758	0.762	1 5/16	1.3205	1.3245	1 7/8	1.883	1.887
13/16	0.8205	0.8245	1 3/8	1.383	1.387	1 15/16	1.9455	1.9495
7/8	0.883	0.887	1 7/16	1.4455	1.4495	2	2.008	2.012

TABLE 2.—LIMIT GAGES FOR LATHE WORK WHICH IS TO BE FINISHED BY GRINDING.

The examples of commercial grinding given in Nos. 1 to 6 illustrate what is being done under actual working conditions in commercial work on the variety of pieces indicated, which are of various materials,

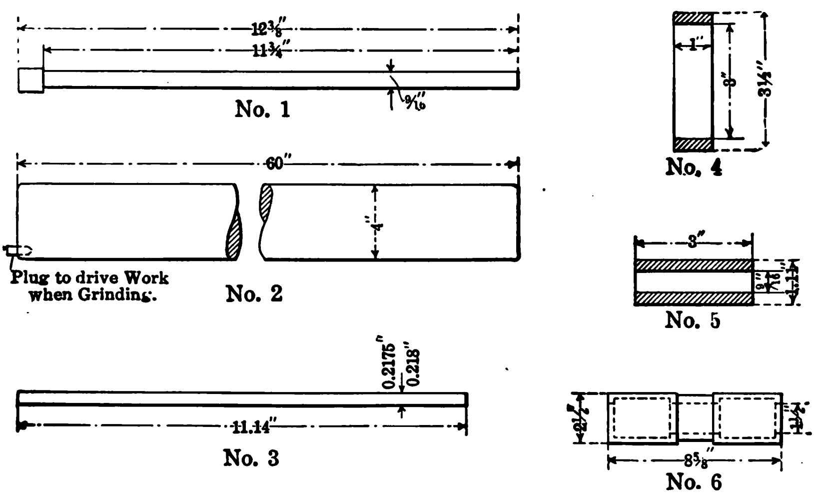


FIG. 20.—Examples of commercial grinding.

both soft and hard. A reversal of the usual rule, where economy is gained by having one man operate more than one machine, is shown in No. 6, where work is most economically produced by using two men to run one machine, that is, having one man to operate it and a helper to

Example No.	1	2	3	4	5	6
Material	Soft machinery steel.	Machinery steel.	Machinery steel, case-hardened.	Machinery steel, case-hardened.	Cast iron.	Bearing bronze.
Part ground	External.	External.	External.	Internal.	External.	External.
Machine used	No. 11 plain.	No. 28 plain.	No. 11 plain.	No. 1 universal (special).	No. 11 plain.	No. 14 plain.
Wheel used	Monarch, 12 in. × 1 in. corundum, No. 46, grade 2½.	Norton, 24 in. × 2 in. alundum, No. 3846, grade K.	Norton, 12 in. × ½ in. alundum, No. 36, grade 5, elastic.	Norton, 2½ in. × 2 in.; alundum, No. 5, grade 2½ elastic.	American, 12 in. × 1 in. corundum, No. 46, grade K.	Abrasive, 16 in. × 1½ in., corundum, No. 60 grade L.
Periphery speed of work, feet per minute.	35	35 roughing; 60 finishing.	35	100	55	75
Travel of work, in. per minute.	96	48 roughing; 30 finishing.	13	By hand.	37	30
Periphery speed of wheel, feet per minute.	7000	6000	5500 to 6000	5500	6500	6000
Amount of stock removed, diameter.	0.012 in. roughing, 0.005 in. finishing.	0.025 in. roughing. 0.005 in. finishing.	0.005 in. roughing. 0.001 in. finishing.	0.018 in. to 0.020 in. / 0.010 in. to 0.010 in.	0.020 in. to 0.025 in.	0.012 in. to 0.015 in.
Number of pieces completed per hour.	13	3.5	15	16 / 20	54	32 1 man. / 59 2 men.[1]
Required limit	Standard to 0.00025 in. small.	Standard to 0.001 in. small.	Standard to 0.0005 in. small.	Standard to 0.0005 in. large.	Standard to 0.0005 in. small.	Standard to 0.0005 in. small.
In lots of	100	50	500	200	200	100
Remarks	21 roughed; 35 finished per hour. Handled twice.	7 roughed; 7 finished per hour. Handled twice.	Handled twice roughing and twice for finishing.	....	....	[1] A man operates the machine and a helper puts the work on and off the arbor.

TABLE 3.—GRINDING RECORDS—SEE NUMBERS 1 TO 6 INCLUSIVE, FIG. 20.

drive the work on and off the arbor. All other data are based on one man to a machine.

These pieces passed inspection within the limits given. The average loss from work of this class coming below the required limit or being otherwise spoiled is less than 1/4 of 1 per cent in the grinding department.

The examples shown in Fig. 21 are each notated to show the peculiar

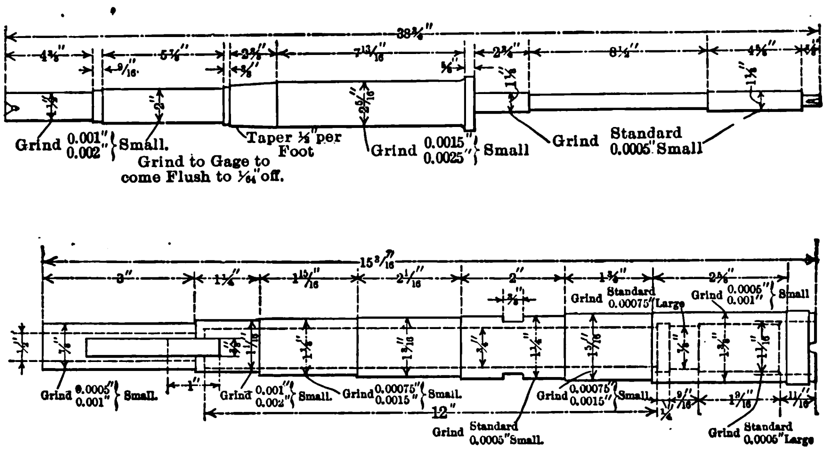


FIG. 21.—Examples of cylindrical grinding.

features that exist in the work, together with the data that may be of help in deciding upon other work of this class.

ANOTHER TABLE OF GRINDING ALLOWANCES

One of the features of the preceding pages is the table of limit gage sizes to which work is turned before going to the grinders. Table 4, below, shows the practice of the Landis Tool Company, Waynesboro, Penn., in reference to grinding allowances. This table covers work up to 12 inches diameter, and lengths to 48 inches.

FURTHER EXAMPLES IN MODERN GRINDING PRACTICE

A number of interesting examples of work of all kinds performed upon the grinder are described in the following pages, these examples in most cases having been ground by H. Darbyshire, and illustrated by him in the *American Machinist*.

Length	3″	6″	9″	12″	15″	18″	24″	30″	36″	42″	48″
Diam.											
½	.010	.010	.010	.010	.015	.015	.015	.020	.020	.020	.020
¾	.010	.010	.010	.010	.015	.015	.015	.020	.020	.020	.020
1	.010	.010	.010	.015	.015	.015	.015	.020	.020	.020	.020
1¼	.010	.010	.015	.015	.015	.015	.015	.020	.020	.020	.020
1½	.010	.015	.015	.015	.015	.015	.020	.020	.020	.020	.020
2	.015	.015	.015	.015	.015	.020	.020	.020	.020	.020	.025
2¼	.015	.015	.015	.015	.020	.020	.020	.020	.020	.025	.025
2½	.015	.015	.015	.020	.020	.020	.020	.020	.025	.025	.025
3	.015	.015	.020	.020	.020	.020	.020	.025	.025	.025	.025
3½	.015	.020	.020	.020	.020	.020	.025	.025	.025	.025	.025
4	.020	.020	.020	.020	.020	.025	.025	.025	.025	.025	.030
4½	.020	.020	.020	.020	.025	.025	.025	.025	.025	.030	.030
5	.020	.020	.020	.025	.025	.025	.025	.025	.030	.030	.030
6	.020	.020	.025	.025	.025	.025	.025	.030	.030	.030	.030
7	.020	.025	.025	.025	.025	.025	.030	.030	.030	.030	.030
8	.025	.025	.025	.025	.025	.030	.030	.030	.030	.030	.030
9	.025	.025	.025	.025	.030	.030	.030	.030	.030	.030	.030
10	.025	.025	.025	.030	.030	.030	.030	.030	.030	.030	.030
11	.025	.025	.030	.030	.030	.030	.030	.030	.030	.030	.030
12	.030	.030	.030	.030	.030	.030	.030	.030	.030	.030	.030

TABLE 4.—ALLOWANCES FOR GRINDING (LANDIS TOOL CO.)

GRINDING SPHERICAL-END ROLLERS

Some roller bearings were wanted in large quantities of a size and shape shown in Fig. 22. They were made from ⅝-inch bar stock in a Herbert turret lathe, one spherical end being formed by an end-rounding tool in the turret and the other by means of a form-cut-off tool held in the tool post. A chip was taken over the body, leaving from 0.010 to 0.015 inch for removal by grinding, one end only being centered; they were then carbonized and allowed to cool slowly in a box of lime to give them something of an annealing process. After this they were reheated and plunged vertically in an acid bath to harden them. A No. 3 Brown & Sharpe universal machine with a few little innovations was used to grind them. It being considered that a faster table feed than was provided would be of advantage, a wood sheath was fitted to the cone pulley of the overhead work, which increased the table feed about 80 per cent. The work was driven by means of a plug fitted in the center hole of the fast headstock, as shown in Fig. 22, the pressure of the center in the spring poppet being sufficient to prevent any slipping; with this method of driving it was not necessary to stop

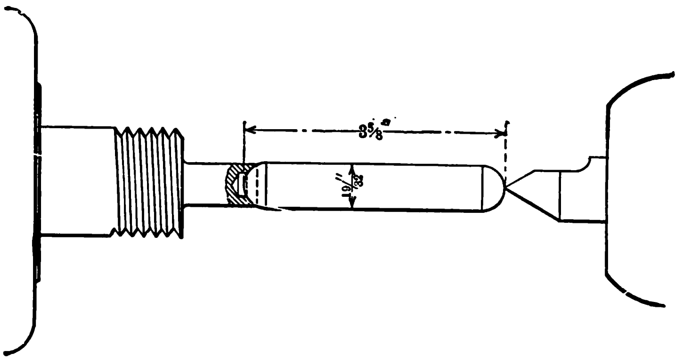


FIG. 22.—Grinding a spherical-end bearing roller.

the work driver to place in position or remove the work. That is, the universal head ran continuously and the work could easily be removed or placed in the machine while the spindle was running. The rollers were first roughed down with the automatic feed to within 0.0015 to 0.0025 inch of finished size at the rate of 138 per hour. A Norton 46K

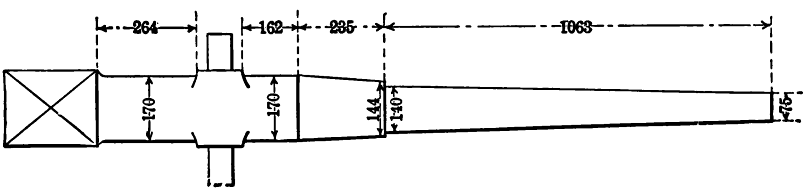


FIG. 23.

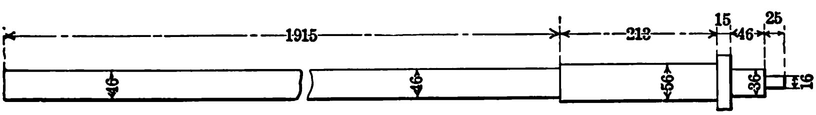


FIG. 24.

FIGS. 23–24.—Gun and shaft to be ground.

wheel was used with 1-inch face and a cross-feed of six teeth, or 0.0015 inch, was given at each end of the stroke. For finishing the same wheel was used, nicely trued up, one tooth feed being used, of 0.00025 inch at each end of the stroke and 125 per hour were finished to a limit of 0.000125 plus and minus. The same speeds of work, wheel and table were used throughout, the work revolving at 180 r.p.m., the wheel speed being 5500 feet per minute. The wheel lost an average of 0.001 inch in diameter in roughing nine pieces, but in finishing it maintained its size for an average of 30 pieces. The gaging was done with an ordinary tolerance snap gage and after a few dozen had been ground it was found that applying the gage was merely a matter of form, that is to say, it was possible to guess pretty correctly when the work was to size by the density of the sparking from the wheel and the gage was only applied to about every twentieth piece ground. That this judgment was effective may be gathered from the fact that only an average of 3 per 1000 had to be returned to the machine for a slight reduction.

FRENCH ARSENAL WORK

Tenders were asked for by a French naval arsenal for a plain grinding machine to grind the gun and shaft shown in Figs. 23 and 24. The specification was that both gun and shaft were to have 1 mm. removed by grinding to have good surface finish and to pass gages provided, these gages gave a tolerance of 0.02 mm. plus for the shaft and 0.25 mm. plus and minus for the gun. The gun, the Norton Grinding Company guaranteed to grind complete in 45 minutes, and for the shaft it guaranteed a time of 45 minutes, and the machine, an 18×96-inch electric driven self-contained, was delivered and set up. There were only two guns prepared for grinding, so that all experience of the job had to be gathered from grinding the first one; this occupied a time of 75 minutes but note was taken of the graduation marks of the swivel table when set for the tapers, as some precaution for the future against losing time in finding these tapers. One universal steady rest was fixed on the portion to the left of the trunnions, another near the muzzle and a third where the two tapers meet.

The gun was first rough ground on either side of the trunnions, then the table was swung over and the steep taper roughed and after this the long taper was roughed, the table first being readjusted to suit; the amount left for finishing was about 0.05 mm. The wheel was now trued up nicely and the long taper finished to gage, next the short taper, then the table was set at zero and the parallel portion finished, the total time being 41 minutes.

GRINDING SHAFTS

There were four shafts to be ground and after grinding two to get some practice it was decided to have the time test on the third. The first shaft had occupied 95 minutes and the second 62 minutes, so that there was some 17 minutes to pull up. Five universal steady rests were used equally distributed along the shaft and the larger diameter was first roughed down to within 0.05 mm. of finished size; the same was done with the longer portion and after truing up the wheel this same part was finished to gage and the shaft turned end for end in the machine; the two shorter diameters were then finished by forming cuts, also the collar, and the larger diameter last, the whole shaft being completed in 40 minutes. A 24L Norton alundum 2-inch face wheel was used in both cases, running at 6000 feet per minute. The side feed or travel of the work in both examples was 5 feet per minute, this being the fastest feed on this particular machine. For the shaft (machine steel) a work speed of some 30 feet per minute was given, but for the gun 55 feet was given, as it was of somewhat harder material and really required a softer wheel.

A WIRE-WOUND GUN

Using about the same speeds and with a similar wheel another type of built-up wire-wound gun was ground on a Norton 18×168-inch machine which gave very satisfactory results; the *A* or inner tube was ground in 2½ hours, it being necessary to use 21 separate gages for variations in diameter. This job was of interest from the fact that the diameter had to vary every 5 inches from 0.001 to 0.002 inch, this to correspond with the bore of the shell to be shrunk on. The wire winding was afterward ground, and here it should be said that grinding was found to be an immense advantage over turning in this operation. The grinding of this occupied 1 hour. The last operation was grinding the built-up gun, which was done in 2¾ hours, removing about $^1/_{32}$ inch of material from its diameter. The length of the gun was about 13 feet and the total time for grinding was 6¼ hours as against some 50 hours in the lathe for the same work, with the advantage in the grinding machine of a superior job.

EUROPEAN CAR AXLES

For the finishing of railway passenger-car and wagon axles, as well as locomotive axles, the grinding machine is now considered an economic necessity.

Several attempts had been made to grind these axles previous to the year 1904 but although the results obtained were highly satisfactory the cost was thought to be too great as compared with the ordinary method of finishing with hand tools, which, by the way, was the common method and was speedy and cheap. In that year a large concern put in an 18×96-inch Norton plain grinder as an experiment, and the results were so gratifying that a "repeat" order resulted and later this firm was producing 1000 axles per month with the two machines and have probably improved on that in the intervening time.

A WHEEL SHAPING DEVICE

It was at first the practice to grind the parallel portions of the axles only, then to return them to the lathe where the radii or fillets were cut out by hand tools; now it is the general practice to grind the fillets also with the saving of much time and altogether more satisfactory results.

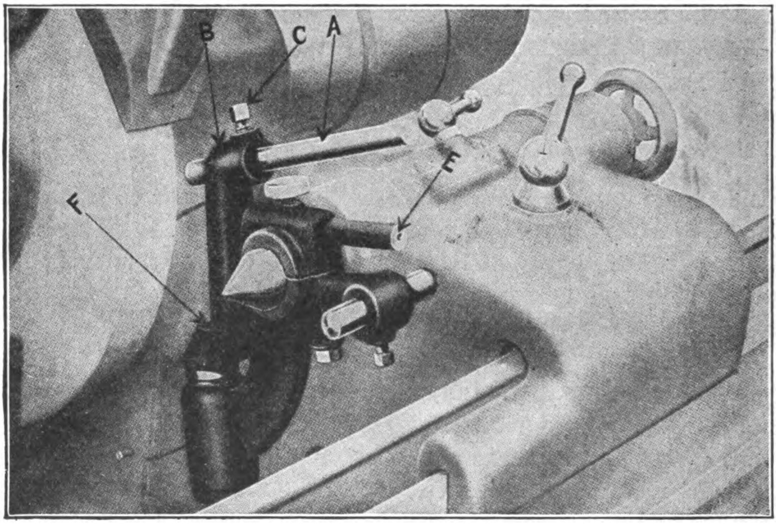


FIG. 25.—Radial truing device, on 10-in. machine.

For forming the required curve on the wheel the Norton Grinding Company provide a neat fixture with their machine, which is shown in Fig. 25. In view *A* is the diamond tool, *B* is the swinging frame in which the diamond tool is held, *C* is the set-screw for holding the diamond. *E* is the handle of a plug which is inserted in a taper slot in the swinging frame whenever the fixture is desired for truing the face of the wheel. When radial truing is done, this plug is withdrawn. *F* is a hole in the axis of the swinging frame in which a stud is inserted that is used for setting the radius of the diamond point. This swinging frame revolves on ball bearings in order that there may be no lost motion at any time; these ball bearings are adjustable to take out all lost motion. For whatever radius is required to be formed a stud must be turned of a corresponding diameter which fits in the axis of the fixture. The diamond is first clamped in position with its point touching this stud, the stud may then be removed and the wheel turned to shape.

METHOD OF HANDLING AXLES

It may be of some interest to describe the manner in which the axles are ground and the general machining, which is as follows, as practiced by one of the most modern plants: The forged axles are first rough turned in special lathes which grip them in the middle and the journals, wheel seatings, etc., are rough turned by a tool at work at either end; about 0.5 to 1 mm. is left for removal by grinding and a coarse feed is used for turning, the fillets being turned approximately to shape. In the same lathe the axles are cut to length and then taken to another machine to be recentered; for this purpose the journals are run in roller steadies and centered in the usual way, the axle being

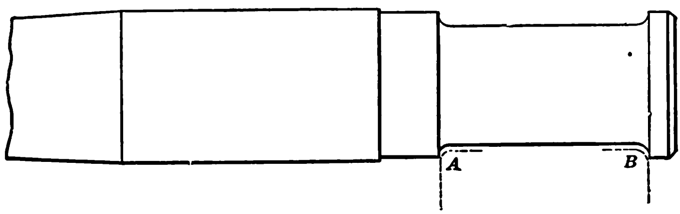


FIG. 26.—Car axle grinding.

driven direct by a belt from the overhead works. In the grinding machines the wheel seating is ground with roughing cuts to a fixed size (and it is found an advantage to leave this surface as coarse as possible for the pressing on of the wheel), the dust-proof seating is next rough ground, also the collar on the end of the axle and then we proceed to grind the journal. In the Norton plain grinding machine the table stops may be so arranged that the table trips automatically about $^{1}/_{16}$ inch short of the point from which they are set, which is an especial advantage in this class of work. In grinding these journals the stops are set as dead stops so that the wheel cannot pass beyond the width of the journal, as shown by dotted lines in Fig. 26, at the same time when traversing automatically it trips a little short of this distance. The journal is first roughed down to within 0.05 mm. of finished size by the automatic feed and then the face of the wheel is nicely trued up, after this the journal is nicely finished to size (care being taken to note the position of the ratchet wheel when down to size), the wheel is then moved back and the table brought up by hand to the dead stop, radius *A* being formed first and then *B*, feeding the wheel steadily into a point which it occupied in grinding the journal. It is then allowed to take one chip across the journal to match up with the forming cuts at either end, and after this the dust-proof seating and collar are just touched up and the axle is finished.

SURFACE FINISH OBTAINED WITH A FLAT GROUND PEBBLE

The steel from which these axles are usually made is of a quality which will not take a high finish by the ordinary methods, but by just glazing wheel slightly with a flat ground pebble a fine luster may be obtained. This must be applied very lightly or the wheel is likely to be put slightly out of true, or else cause slight chatter marks on the surface of the work; a pebble ground to shape may be used to dress the radius on the wheel.

Axles of the size shown have been ground at the rate of four in 2 hours 10 minutes, including all the handling and changing over and there is good reason to believe that the pace has been accelerated by the operators of two separate firms.

GRINDING SHELLS

Number 1, Fig. 27, shows a shell of large size which is hardened from the point well up to its ring and is ground on an 18×96-inch machine in an average time of 18 minutes. It is driven by means of a three-jaw chuck which grips the interior of the bore, the chuck being fitted with a plug to enable it to run on the headstock center; the other end of the shell is supported on a ball-bearing revolving center, No. 2, which has an adjustable shoe. This latter feature is found necessary because the points generally distort in hardening and it is a ready and convenient means of setting the shell true. Some 0.020 inch is ground from the diameter of the shell and the wheel is turned to form the small cone by means of a special device fitting on the footstock. The point of the shell is smeared with loose emery powder to insure its having a positive grip in the adjustable shoe. There was some little tendency to chatter in this job and this was attributed to the limited bearing surface. It is proposed that balls be dispensed with on the cone and a similar bearing to that for the smaller shells be provided with the addition of a ball-thrust collar. The chatter was overcome by fixing a wooden steady rest against the revolving center bush which acted as a cushion for absorbing the slight vibration.

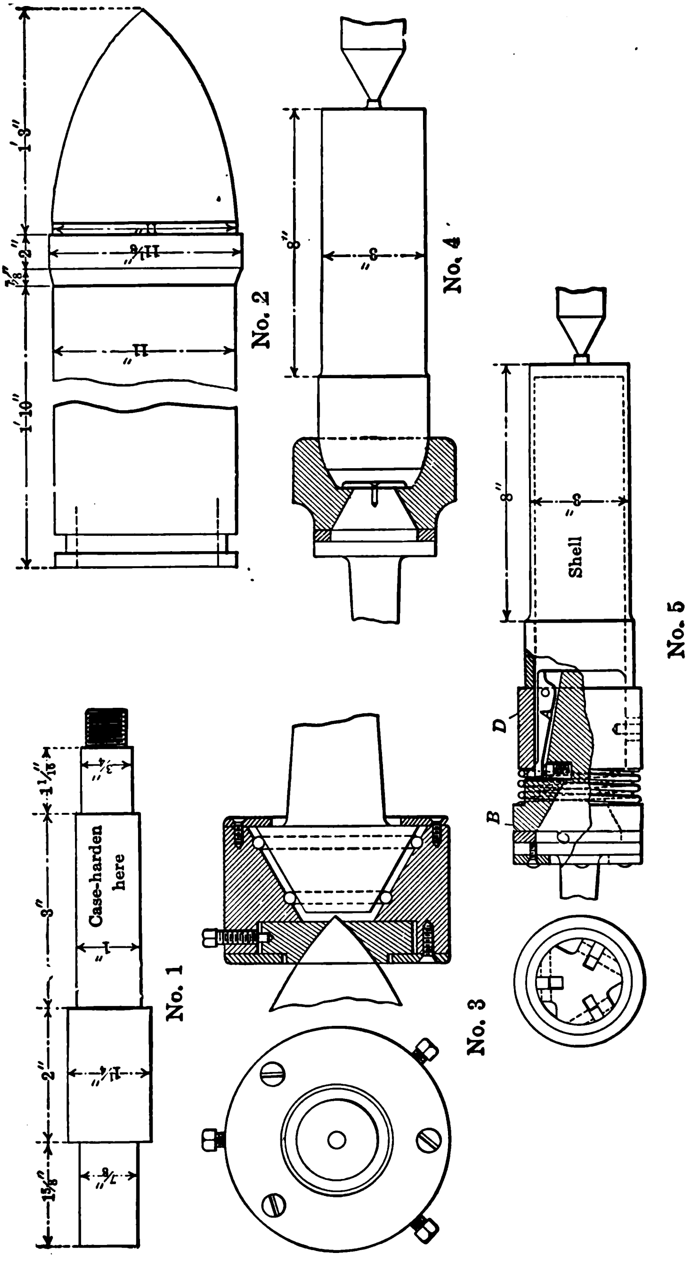


FIG. 27.—Grinding shafts and shells.

SHRAPNEL CASES

Number 3 is a type of shrapnel shell made in a hydraulic press. The shells are first rough turned in lathes of a special type where about $^{1}/_{32}$ inch is left for removal by grinding and 25 per hour are ground in a 10×50-inch machine. The method of driving may be clearly seen. It consists of a revolving bushing running on a center pilot fitting in the headstock. The pressure of the supporting center insures proper drive and the shells are placed in position and removed without halting the work drive. The driving dog (not shown) is fixed on the larger diameter of the bush. A similar size of shell but of different type is shown by No. 4. Here the method of driving is, of course, different, but the output is the same. The bore is not machined and is somewhat out of round but the variation from size does not exceed 0.010 inch. The drive is obtained from three triggers *A* fixed in a revolving steel bushing on a center plug *C* fitting in the headstock. The triggers are serrated and are expanded by means of a hardened sliding bush *D* which is rounded at the corner of the bore and which presses on the tapered heel of the triggers when the shell is placed in position; light springs below the heels of the triggers cause them to contract when the pressure is taken from the supporting tail center. Some little slip invariably takes place here when grinding commences but it is only momentary and the drive is found to be quite efficient. It will be noted that the corner of the revolving bushing is rounded so as to facilitate the chucking and removal of the shells after completion.

In these methods of chucking work there is an excessive amount of tail-center pressure involved and a white-lead paste mixed with a few grains of graphite is found an excellent center lubricant, it answers well where heavy weights are carried either in the lathe or grinder and jobs weighing a few tons have been run some 6 hours, without a sound being heard from the centers, the latter having the appearance of burnished silver when the job was removed.

MISCELLANEOUS OPERATIONS

Some miscellaneous examples of cylindrical grinding in addition to those shown by Mr. Derbyshire are illustrated in Fig. 28. On the piece shown at *A*, 0.220 inch was removed from the diameter at a surface speed for the work of 28 feet; traverse movement of wheel 2¼ inches roughing, 1½ inches finishing; wheel feed, 0.013 inch; wheel used, carborundum, 2½×18 inches, grade 36 N, O D bond; material, chilled iron; time complete, 6 hours; number of cubic inches removed per minute to finished surface, 0.53.

These rolls were ground from the rough and given a high finish with a limit of variation of 0.0005 inch.

At *B* the material was chilled iron; removed from the diameter, 0.032 inch; time, 90 minutes; surface speed of work, 30 feet; wheel used, American corundum, 24×3 inches, grain 60, grade J; wheel

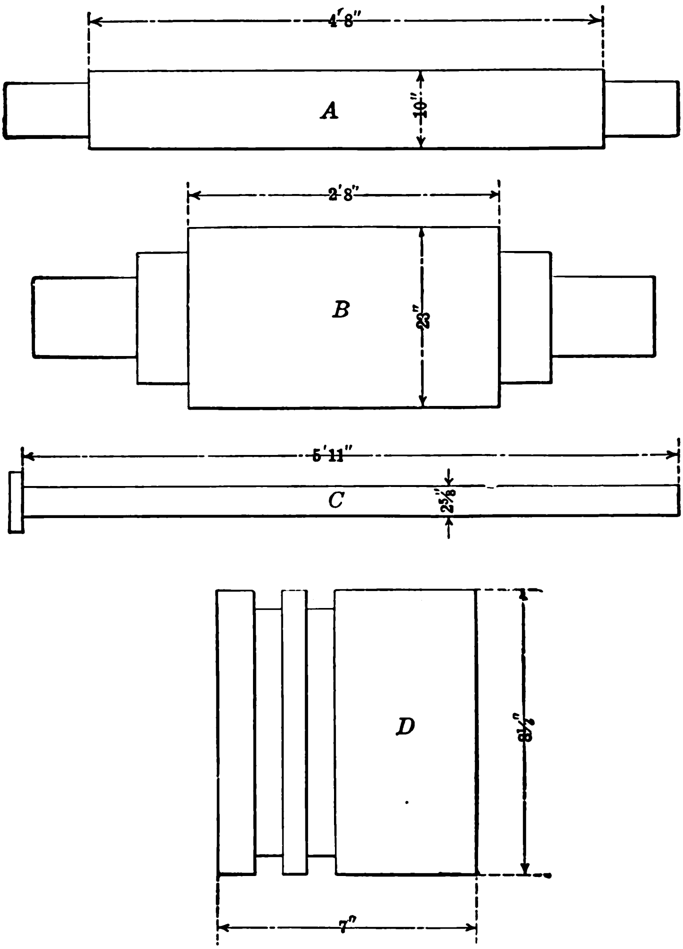


FIG. 28.—Variety of cylindrical work.

traverse, 1½ inches per revolution of work; cubic inches removed per minute to finished surface, 0.40 inch.

In grinding chilled-iron rolls where an extremely high finish is required, it is sometimes necessary to give the grinding wheel a somewhat smaller traverse movement and this movement is sometimes as small as ½ inch, when using a wheel 2 inches in width.

By the foregoing examples it will be seen that wheels of a comparatively soft grade were used, which is good practice in grinding hard material, the standard rule for selecting grinding wheels being, for hard metal a soft wheel, and for soft metal a hard wheel. It is believed that in grinding soft metal too much has been expected of hard wheels, for to grind economically a wheel must wear in order to keep sharp and free cutting, and, by the example shown at *C*, it will be seen that while the wheel was of a softer grade than generally used, the results were excellent.

On the piece referred to, 0.075 inch was removed from the diameter, the material being soft steel; time, 40 minutes; limit of variation, 0.00025 inch; wheel used, Aloxite, grade 303 O, bond D 496; wheel traverse, 3 inches per revolution of work; surface speed of work per minute, 15 feet; cubic inches removed per minute to finished surface, 0.54.

This work was roughed down to within 0.003 inch of finished size, no difficulty being experienced in getting the work to run perfectly true, which can be attributed to the fact that by using the soft wheel a good, free-cutting action took place, and that spring rests were used, which allowed the work to center itself as it was freed from internal strains. It is also very important that a spring tension be used in connection with the tail center to allow longitudinal changes in the work while being ground.

The gas-engine piston shown at *D* was finished in one operation, it being only necessary to true the grinding wheel after grinding every seven or eight pistons. The material was cast iron; surface speed, 80 feet per minute; wheel used, carborundum, grade and grain 403 P, bond O F, size 2×25 inches; wheel traverse, $1\frac{7}{8}$ inches per revolution of work; removed from diameter, 0.040 inch; cubic inches removed per minute to finished surface, 0.40 inch; time 9 minutes.

By comparing the above methods to those employed a few years ago, it will be found that they are far superior by reason of the decrease in amount of time taken to get the results, which is made possible by the modern grinding machine, embodying all the features that go toward rapid production of work of a superior quality.

In general practice, work should be finished in one operation, but this cannot always be done, depending greatly on the quality of the job. When grinding work in two operations, it is always advantageous to grind close to the finish size in the roughing operation, allowing just enough on the piece to insure its truing nicely.

GRINDING SMALL DRILL ROD PIECES

In experimenting with different wheels in the grinding of the small, soft Stub's wire rod, as shown in Fig. 29, it was found that a 24 combination, grade K, Norton alundum wheel was too hard. The piece would continue to spring in such a manner as to give the operator a lot of trouble so that it required 20 minutes to grind each piece. A

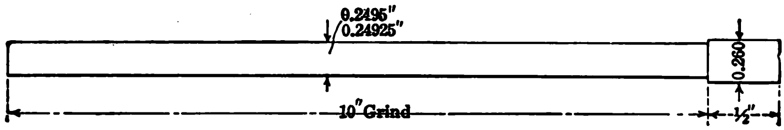


FIG. 29.—Grinding small drill rod.

46-grain, grade I wheel was substituted and the pieces were produced in 3 minutes each. In the latter case, the free-cutting wheel allowed the operator to attend to the business of grinding instead of to that of juggling.

FORM GRINDING

Form grinding is believed by some who have given the matter long and careful study to be the cheapest method of finishing work if proper care is taken of the wheels and the work. It is not the easiest way nor can it be done with the cheapest men, but it pays in dollars and cents when the men are trained to handle it as it should be.

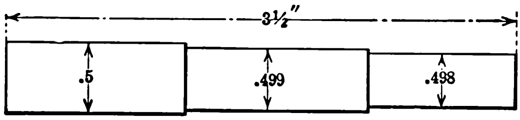
A very narrow wheel traversed across the work requires the least attention as the wheel need not be kept as true or in as good shape as with the wide wheel. But a wheel having a face wide enough to do the work without traversing will do the work quicker and better if the machine is heavy enough and the wheel kept in proper order.

The wider the wheel the more cutting points we have at work and the more work can be done in a given time. It is almost identical with the use of forming tools in screw machine or turret work and formed cutters in milling work. In either case the cutting tools must be kept in shape and kept sharp, which is just what must be done with a grinding wheel. While it is probably not advisable to use wheels having forms of as intricate shape as in the case of form tools of steel, owing to the difficulty of maintaining the form while truing and sharpening the wheel, the keeping of the wheel in shape is less difficult than might be imagined. The only difference between this and tools of steel is that we can sharpen the tools by grinding on the flat face while in this case we must sharpen by truing off the formed face. And this can be done much more easily than could be done with steel cutters if they had to be sharpened in this way.

Then, too, it is well to remember that, instead of wearing away as rapidly as we are apt to think, a grinding wheel wears less in grinding a bar from end to end than a steel tool does cutting a chip from the same bar.

But form grinding does not necessarily mean the grinding of fancy shapes and applies to plain grinding as well as any other, when the surface is ground by the wheel being fed in and not being traversed with relation to the work. In other words, when the ground surface depends on the shape of the wheel, whether it be a plain cylindrical surface of one diameter, be shouldered with several different diameters, or be given round corners or other shapes desired.

Crank pins and crankshaft bearings for automobiles and other engines are frequently ground in this way, especially the crank pins,



No. 1

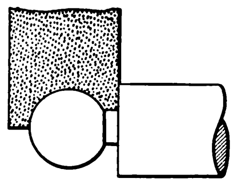

No. 2

FIG. 30.—Examples of form grinding.

and the wheel retains its shape much longer than might be considered possible.

They are often ground from the rough forging, the roughing wheel leaving about 0.04 inch for finishing. The roughing wheel will grind from 4 to 16 pins at one truing and the finishing wheel will finish from 6 to 24 pins at one dressing. The difference depends mostly on the operator and the way he handles the work.

A few examples of form grinding from actual practice may be of interest.

The small pins shown in No. 1, Fig. 30, are about 3½ inches long and ½ inch in diameter, having three diameters. The ends of these are bearings and the center diameter is a drive fit. The only vary about 0.001 inch from one to the other.

The wheel is dressed so as to give these diameters and there is no difficulty in maintain the sizes. The wheel is simply fed into the work and grinds a large number of pieces at one truing.

Another and perhaps more difficult piece of work is shown in No. 2, where a ball is ground on the end of a shaft. The shaft is formed in a screw machine and finished after hardening, by the form wheel shown. This is a more difficult shape to maintain on the wheel, but it is done without difficulty, the radius being turned out with an ingenious little holder which swings the diamond in exactly the right path.

A very different and much easier proposition is the grinding of the outside of a number of ball races at one operation by the use of a wide-faced wheel as shown. This is a very practical application of the principle and one that can be widely adopted with little difficulty. The main requirement is to get a machine which is stiff enough to stand the power necessary to do the work without springing.

The fear that the wheel will be worn in ridges and require frequent truings that will waste the wheel, is entirely unfounded. The cost of the wheel is one of the least items of expense when the cost of labor is considered with relation to the work done.

The following case will serve to illustrate the use of steady rests: A piece of machine steel, about 4 feet long and 1½ inches diameter, was rotating on the centers of a grinding machine, no steady rests in contact. A coarse wheel was used to grind it; no chatter marks could be obtained. Another wheel somewhat finer was used, and the work was covered with chatter marks. These marks when counted proved to be 7 to the inch of circumference. A deeper cut was taken and the marks showed 10 to the inch. A slight cut was taken, and the marks showed 16 to the inch. The table traverse was changed and the marks showed 32 to the inch. This was done all with one speed for the work. A change of work speed showed as many different marks per inch, until a speed was reached at which chatter marks were impossible. The use of steady rests enabled grinding without chatter at a faster speed than was possible without them.

The vibration shown by lines parallel with the axis is always the vibration of the work independent of the surrounding or supporting machine. It is caused by the wheel at the point on the work where the wheel is cutting, even though the axis of the wheel and the headstock and footstock may remain perfectly rigid. This vibration may be transmitted to the centers, and it may, if the machine is poorly designed, be transmitted to the heads and finally to the entire machine. Vibrations may show on the work when there is absolutely no vibration of any part of parts of the machine.

Vibration of the work is never shown by spirals, mottles, or spots; but always by lines parallel to the axis. Work may be vibrated by the wheel cut no matter how large or short it may be. In case of heavy work the vibration is transmitted to the center points, and the number of vibrations per rotation of work is affected by them. This is where the rigid steady rest comes in; it serves to connect the heavy work to the entire table along its entire length, like resting it on an anvil.

NECESSITY FOR RESTS

Long, light work is easy to hold steady while grinding; but heavy, "stiff" work is the most difficult to grind rapidly without chatters; therefore it should always be supported by the best and the most steady rests, because of the weakness of all center points. We need steady rests with slim work, because it is more slender than the center points and vibrates in spite of them. We need steady rests with heavy, "stiff" work, because center points are often not heavy enough to hold it steady.

To assist rapid grinding the center holes in the work should be as large as practicable, in order that contact may be on as large a surface of the center as possible. We are often told by grinders that they have no use for steady rests on heavy work and that they have no trouble with chatters with high speed of work and fine wheels. If all such were to grind with a wide wheel face and produce more work per minute, they would discover that as the product is increased the necessity for changes in handling would increase. The history of chattering shows that it has been common to all types and makes of machines when the conditions were right and that it has increased in proportion to the increase in product; that it has been overcome by changes in wheels, adoption of steady rests and reduction of work speed, and that these things have produced similar results in all types and makes of machines.

THE MOTTLED SURFACE

When work shows a mottled, or mottled spiral surface, the cause may be vibration of any part of the machine caused by the motion of the wheel, the jar of a heavy belt joint, or an unbalanced wheel.

A well designed and constructed machine, however, should be so rigid and self-contained that the axis of the wheel and work will remain in constant relation whatever the vibration of the machine or floor, unless in case of a wheel out of balance; when, if the machine is placed on a solid foundation, there would in some cases be a jar that would cause the axis to change relation enough to show a mottled surface. Another cause of mottled surface is a wheel and spindle too light and running loose in the bearings.

Another case of mottled spirals is a wheel too hard for the work, or one having an uneven cut on its surface.

The mottled and spiral surface is not known with the more modern heavy machines when the best wheels are used.

When work has vibrated enough to show on the surface it has produced an irregular surface on the wheel and the wheel must be trued off before smooth work can be ground, even though the work may be so supported or changed in speed as to prevent further vibration.

SPEEDS ON THE GRINDING MACHINE

In connection with grinding speeds H. F. Noyes gives the results of some interesting experiments as follows:

The question of proper work speeds on the wet-grinding machine has always been open to discussion, and shows a diversity of practice. This has originated in part from variations in the cutting qualities of the wheels. Within the past few years, however, manufacturers have been able to duplicate wheels quite closely. This fact, coupled with the experience gained by the machine manufacturers themselves, has gradually crystallized the practice for general work along two lines; one is a comparatively slow work speed, with a traverse nearly equal to the width of the wheel and uses a soft wheel and slow wheel speed; while the other involves a higher work speed, shorter traverse, harder wheel and higher wheel speed.

The question chiefly affecting wheel speed is that of safety, for it is a foregone conclusion that other things being equal, more work can be obtained with the higher speeds. Just where this speed should stop depends on the construction of the wheel, its shape and the provisions for protection. The safe limit is usually recommended by the maker. Common practice is to limit this speed to 6000 feet per minute rim speed for machine grinding. Some manufacturers of machines recommend speeds of 7000 feet and even of 8000 feet, and as the wheels are usually tested at 9000 feet these speeds are probably not excessive, provided the wheel is a plain disk, without a recess, and of strong bond. The wheels usually used at these speeds are in connection with the second of the two practices mentioned, and are combination wheels which are harder and stronger than the wheels used for the first-mentioned practice.

It is recognized that a variation in the construction of the wheel must be made to grind different materials, and this feature will sometimes influence the wheel speed. The proper wheel for any material is usually given in the makers' catalogs. As a general proposition, however, harder materials require softer wheels. Recessed wheels, with the clamping or fastening ring located within the recess, are necessarily weaker; their speeds should be limited to 6000 feet. This is particularly the case with the thin wheels used for crank grinding, where the wheel must be of large diameter in order to gain clearance for the cheeks of the crank. For these wheels 5500 feet is probably a safer limit. All wheels should be carefully handled in being changed on the machine. Probably in the majority of cases where a wheel breaks, the real cause is an incipient crack which was caused by careless handling or by allowing the wheel to run against a shoulder when in use.

A study of the other speed conditions necessary to obtain the greatest output from a grinding machine brings uot many possible combinations, and it is often hard to pick out the best without considerable experimenting. These are the items which enter into the combination; the speed of the wheel, the grade of the wheel, the surface speed of the work, the traverse of the wheel or work per revolution of work, and the depth of the cut. As stated before, the two general lines of demarkation are a softer and usually wider wheel, slower wheel speed, slower work speed, and greater traverse; as compared with a harder and narrower wheel, higher work speed and shorter traverse.

RELATION OF CUT AND FEED

The depth of the cut bears an inverse ratio to the traverse in either case, and can be increased, in general, without changing the results, provided the traverse is correspondingly decreased. It usually happens, however, that with the same grade of wheel, better sizing conditions and less wear of the wheel are obtained by lessening the cut and increasing the traverse. These general statements refer chiefly to roughing out, and to obtaining an ordinary commercial finish. To obtain a fine finish a higher work speed and smaller traverse are desirable.

Getting to the question of actual speeds for the work in these two combinations, there is a wide latitude. The first combination uses as a basis an average work-surface cutting speed of about 20 feet per minute, and often much lower, 10 and even 5 feet being suitable in some cases for roughing out. For finishing, especially where a fine finish is required, a faster speed is desirable, up to about 40 feet, which is about the highest to be recommended for these conditions. This speed is suitable for wheels of a grade of 30 to 46 on soft steel; a harder grade is needed for cast iron. A traverse of from two-thirds to almost the full width of the wheel is suitable for these conditions.

The second combination calls for a work-surface cutting speed of 60 to 100 feet per minute, a traverse up to about one-half the width of the wheel, and a grade of wheel of 46 to 60, for the average line of work. A study of tests which were made from actual working conditions in the shop, made, however, for another purpose, will bring out some of these points. The basis of comparison was the amount of metal removed per minute. The amount of power required was recorded; one interesting point which was demonstrated was that the amount of power required to remove a certain amount of metal per minute was practically the same, regardless of the size and type of machine; that is, that the horse-power used per cubic inch of metal removed per minute was approximately the same, regardless of the machine. It was about 4 horse-power for cast iron and 10 horse-power for steel. Of course the power required to run the machine light varied with the size of the machine; but when this was subtracted, the net horse-power required for removing the stock bore a regular relation to the amount and kind of metal removed per minute.

While these experiments were made along the line of the first mentioned set of conditions, they brought out some interesting points in regard to its limitations. One of these was that for cast iron, the best results in the way of removing metal were obtainable with a slower traverse, deeper cut, and preferably higher work speed.

RESULT OF TESTS

The conditions and results of thirteen tests are shown in Table 5.

In this table compare test 1 with tests 2 and 3. These tests were taken on a small machine about 10×30 inches. In 1 and 2 all conditions were the same, except the traverse and the depth of cut. The increase from 0.5 cubic inch of metal removed per minute to 0.8 showed a distinct advantage for the slower traverse, without any particular difference in the wear of the wheel. In the third test an increase in the work speed was also made, which apparently gave the same result, but showed more wear of the wheel. Tests 7 and 8, with all conditions the same, except the wheel speed, show the distinct advantage to be gained by increasing the speed of the wheel. The speed used in No. 8 is toward the safe limit, however, considering the construction of the wheel, and would hardly be advocated for regular practice.

Experiments 9 and 10 vary only in surface speed and depth of cut. They were made on thirty pieces, and show absolutely no difference in results. The same is practically true of tests 4, 5 and 6. The fourth used a slow traverse and high surface speed; the second a high traverse and slow surface speed; the third a high traverse and higher surface speed. Experiments 11, 12 and 13, though not comparative, were made on the same machine, and show what can be done in the way of removing metal. Experiment No. 11 is a lively record.

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Wheel grade......	46 L	46 L	46 L	60 M	60 M	60 M	46 K	46 K	36 L	36 L	36 L	24–36 $3\frac{1}{2}$	36 L
Dia. × face........	$10\frac{1}{2}\times1\frac{1}{2}$	$10\frac{1}{2}\times1\frac{1}{2}$	$10\frac{1}{2}\times1\frac{1}{2}$	$13\frac{3}{4}\times1$	$13\frac{3}{4}\times1$	$13\frac{3}{4}\times1$	$13\frac{7}{8}\times1$	$13\frac{7}{8}\times1$	17×2	17×2	$19\frac{1}{2}\times3$	24×3	24×3
Wheel surface speed.	4950	4950	4950	6840	6840	6840	5440	6890	5340	5340	4080	5026	5026
Wheel wear.......	0	0	0.005	0.040	0.050	0.055	0.020	0.025	0.003	0.003	0	0	0.032
Work length × dia.	$10\frac{1}{2}\times2$	$10\frac{1}{2}\times2\frac{1}{4}$	$10\frac{1}{2}\times2$	$17\times1\frac{3}{4}$	$17\times1\frac{3}{4}$	$16\frac{1}{2}\times3\frac{1}{4}$	17×2	17×2	$10\frac{1}{4}\times1\frac{1}{2}$	$10\frac{1}{4}\times1\frac{1}{2}$	$19\frac{1}{2}\times3$	$19\frac{1}{2}\times3$	$20\frac{1}{2}\times3\frac{1}{2}$
Work material....	C.I.	C.I.	C.I.	Soft steel	Soft steel	Soft steel	Soft steel	Soft steel	Soft steel	Soft steel	C.I.	C.I.	Crucible steel
Work surface speed	39 ft.	42 ft.	60 ft.	35 ft.	12 ft.	35 ft.	22 ft.	22 ft.	12 ft.	6 ft.	9 ft.	31 ft.	11 ft.
Trav. per rev. of wk.	1 in.	$\frac{3}{16}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	1 in.	1 in.	1 in.	1 in.	2 in.	2 in.	$2\frac{1}{8}$ in.	$\frac{5}{8}$ in.	$2\frac{1}{8}$ in.
Depth of cut......	0.004 in.	0.013 in.	0.010 in.	0.004 in.	0.004 in.	0.004 in.	0.002 in.	0.025 in.	0.003 in.	0.006 in.	0.030 in.	0.020 in.	0.010 in.
Total reduction...	$\frac{1}{8}$ in.	$\frac{1}{8}$ in.	$\frac{1}{8}$ in.	$\frac{1}{16}$ in.	$\frac{1}{16}$ in.	$\frac{1}{16}$ in.	$\frac{1}{16}$ in.	$\frac{1}{16}$ in.	$\frac{1}{32}$ in.	$\frac{1}{32}$ in.	$\frac{1}{8}$ in.	$\frac{3}{32}$ in.	$\frac{3}{32}$ in.
Time........ ...	8 min.	5 min.	5 min.	10 min.	9 min.	20 min.	20 min.	12 min.	2 min.	2 min.	2 min.	$2\frac{1}{2}$ min.	4 min.
Cu. in. material r. p. m.	0.5	0.8	0.8	0.3	0.3	0.26	0.16	0.26	0.31	0.31	5.5	3.5	1.8

Table 5.—Tests of Grinding Wheels.

The deductions which have been made from these and other experiments are that a great number of work speeds is not necessary, provided they are arranged so that certain desirable limits can be obtained. Take, for example, tests 4, 5, 6, 9 and 10. They show conclusively that the same results can be obtained with practically a wide range of speeds, if a proper combination is made with other items.

Let us consider a plain grinding machine with a swing of, say 12 inches. This would be considered suitable for a regular run of work up to 3 or 4 inches in diameter, and for occasional jobs of larger size. In arranging for the speeds we will assume that for each size of work from ¾ inch to 5 inches, we would like to have surface speeds of approximately 10 feet, 20 feet and 40 feet per minute. Such a range would be sufficient for all practical purposes and conform to the best practice. With six work speeds of respectively 10, 17½, 31, 54, 94½ and 165 revolutions per minute, each speed being 75 per cent greater than the previous, we can get very close to the desired surface speeds for almost any diameter of work within the range mentioned.

CHAPTER IV

SURFACE GRINDING

Although the surface grinder has long been one of the most useful of our standard tools, of recent years it has become more and more important as a manufacturing machine and it is the purpose in this chapter to show some typical operations on several types of grinders of this class.

MODERN SURFACE GRINDING METHODS

As pointed out by B. M. W. Hanson, surface grinders have usually been made with the wheel grinding on its periphery and in some instances it may be necessary to continue to do work on this principle, as grooves and irregular shapes sometimes have to be ground and the thinness of the wheel makes it possible to get into narrow places; but when flat surfaces are wanted, the cup-shaped wheel on the vertical surface grinder has taken a foremost place in grinding. The wheel covers the whole width of the work at once and water is forced through the center of the spindle, centrifugal force throwing the water outward and compelling it to pass between the work and the wheel.

The wheel problem in connection with the machine has been most difficult. It has been found essential to select the right kind of wheel for different classes of work and for different materials. For grinding steel, either hardened or soft, corundum wheels have proved the best and for grinding cast iron the carborundum wheel has proved the best. The different degrees of hardness must be taken into consideration when the width of the surfaces to be ground varies.

A much larger machine by the same makers [The Pratt & Whitney Co.] has a table stroke of 6 feet and can grind a piece 6 feet long and about 25 inches wide. It can also grind circular rings and disk surfaces up to 30 inches in diameter. The wheel has a diameter of 30 inches and the whole machine is driven from a single belt by a 40 horse-power motor. It is for such work as grinding guide bars, slide valves and link motions for locomotives, large stamping dies such as are used in electric works, facing automobile cylinders and automobile-engine frames. In one of the trials, a surface of cast iron, 6 feet long and 20 inches wide was reduced in thickness 0.01 inch in five minutes, leaving an excellent finish and an exact flatness. In fact, when tested, no point in the surface showed out of true more than 0.0005 inch. In grinding steel this type of surface grinder produces chips that look very much like metallic wool, which seems to indicate that when a cupped wheel passes over the work the chips are made by the outer edge of the wheel in the same manner as chips produced by the outer edge of an end-milling cutter. If the chips were made underneath the broad contact surface of the wheel there would not be room for them to curl up in the small places which are left between each cutting particle of the grinding wheel. The large surface in contact with the work simply smooths the surface.

EXAMPLES OF WORK DONE

In Figs. 31 and 32 photographs are reproduced of work which has been ground on vertical cupped-wheel machines. In some instances, such as in the production of small gun parts, like hammers and triggers, the work has been done from 15 to 20 times faster than it can be milled, and it has a smoother and more accurate surface. This is especially true where the surfaces are not too wide.

SOME FURTHER EXAMPLES OF WORK ON THE VERTICAL SURFACE GRINDER

On the Pratt & Whitney grinder referred to the wheel is presented to the work in the manner indicated by the engraving, Fig. 33, which shows the regular reciprocating table under the wheel. For certain classes of operations a rotary table is mounted upon the main table and revolved with the work under the wheel face.

The feed mechanism on this machine gives two table feeds which may be obtained while the machine is in operation through a gear box which is controlled by a lever at the front. The lever also serves as a means for starting and stopping the table.

The vertical spindle is so designed that the thrust is taken by a ball bearing, and the driving pulley which is at the top of the machine is mounted upon a hardened and ground bearing entirely independent of the spindle so that the pull of the belt is not transmitted to the spindle. The spindle is operated at one speed only. The spindle head is properly counterbalanced and it is accurately controlled through the feed mechanism, which may be operated by hand or automatically. Graduations enable the vertical movement to be accurately gaged, and provision is made for automatically disengaging the power feed.

The pump forces water through the hollow spindle to the interior of

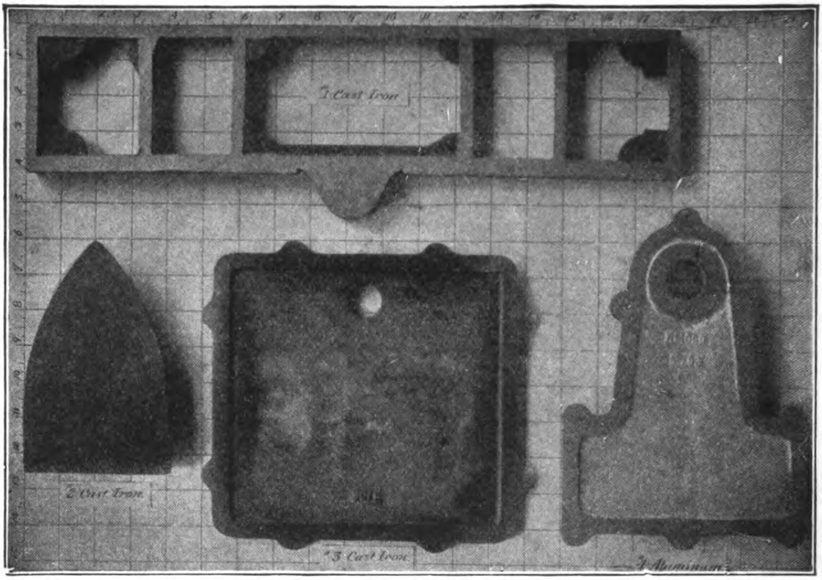


FIG. 31.—Examples: No. 1, cast iron, 15 to 20 per hour; No. 2, cast iron, 60 per hour; No. 3, cast iron, 25 per hour; No. 4, aluminum, 30 per hour.

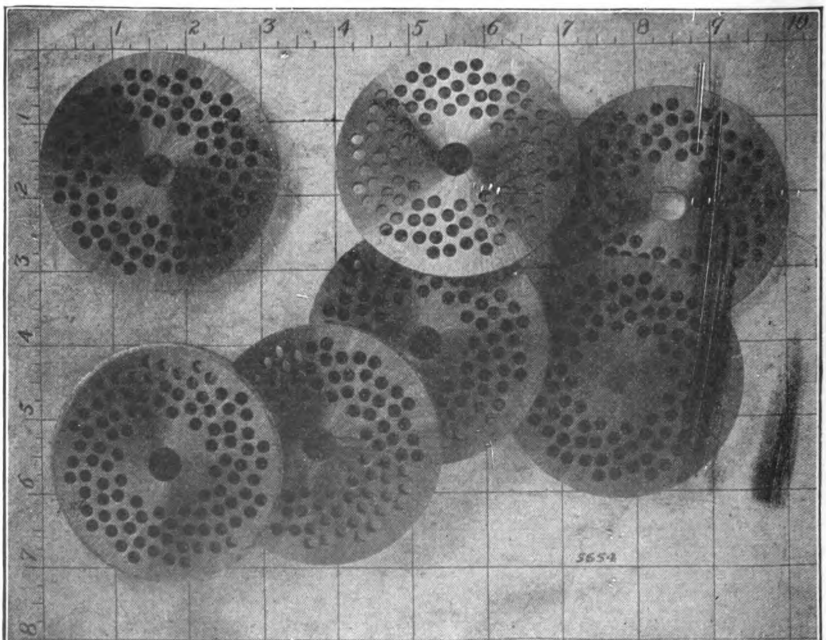


FIG. 32.—Meat-chopper knives.

the wheel where it is carried out by centrifugal force between wheel and work, to keep both cool and free from dust. Another stream is provided for the outside of the wheel and for cleansing purposes. The table is surrounded with a high guard within which the wheel operates,

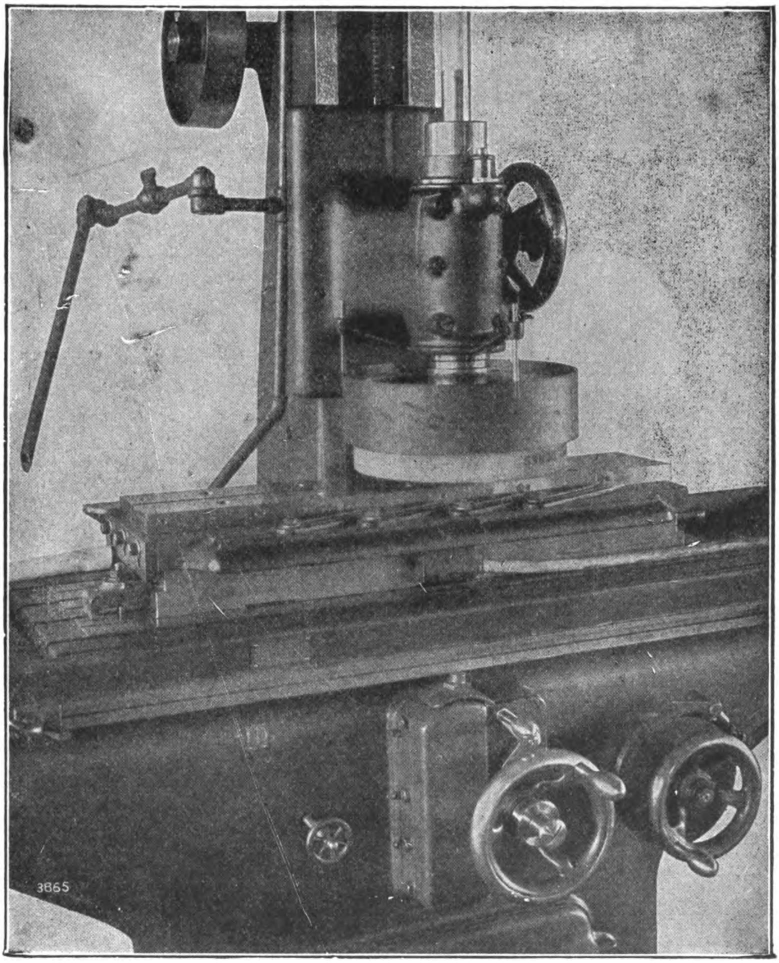


FIG. 33.—Pratt & Whitney 3-ft. surface grinder.

this preventing the escape of water. The wheel guard also aids in the control of the water.

The rotary chuck for use with a variety of work which is ground by revolving under the wheel, is driven by mechanism located outside of the water guard, making it impossible for water to enter the chuck.

The chuck may be tilted to permit the grinding of concave or convex work, such as saws, cutters, etc.

Magnetic chucks, both rectangular and rotary, are used for holding various classes of work, and special holding appliances are also constructed to meet unusual requirements.

The Blanchard Vertical Surface Grinder, Fig. 34, made by the

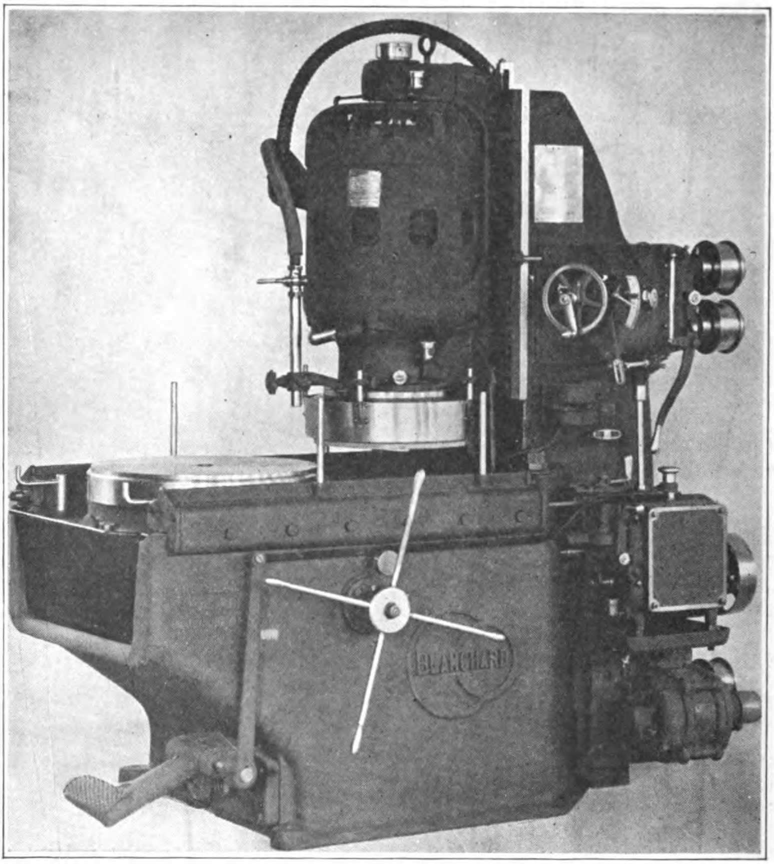


FIG. 34.—Blanchard direct drive surface grinder.

Blanchard Machine Co., Cambridge, Mass., carries the work to be ground on a magnetic chuck rotating under a cylinder or ring wheel. This arrangement rotates the work in a plane parallel to that of the rotating edge of the wheel; and, since the chuck is completely filled, keeps the wheel pressure uniform on the work. The machine is of such massive construction that vibration and spring are practically eliminated, and this together with the uniform wheel pressure are factors which bring about accurate work and rapid production.

Rapid production in some cases depends on large amounts of stocks being removed in short periods, and to meet this requirement a considerable amount of power is needed. The Blanchard Direct Drive Grinder is driven by an induction motor, of which the rotor is pressed onto the wheel spindle. The motor so placed provides ample power, prevents trouble through slippage and repair of belts, and being a constant speed motor, keeps the surface speed of the wheel uniform. The machine is also made in belted style, to be run by either a ceiling or floor motor.

The grinding position of the table is such that the center of the chuck is under the outer edge of the wheel. The table is slid out from under the wheel to facilitate handling the work. The chuck is rotated through a gear box giving a wide range of speeds. The wheel spindle turns clockwise, while the chuck rotates in the opposite direction.

The column is supported and bolted to the base at three points by means of which supports the wheel face may be adjusted to run parallel to the chuck face, or to give slightly concave or convex surfaces.

Water is supplied to the inside of the wheel by a centrifugal pump which draws water from the base. In addition to the inside water an auxiliary water nozzle is provided to facilitate complete cooling in the case of very broad surfaces.

Supplied with this machine (at the option of the purchaser) and as an integral part, is a continuous reading caliper which actually *measures* the work while the grinding is taking place, and consequently enables the operator to increase his production.

The machine is made in two sizes. The larger machine uses a 16-inch or 18-inch ring wheel and takes work up to 30 inches in diameter and 12 or 14 inches high. The smaller machine uses a 10-inch wheel, and takes work 18 inches in diameter and 6 inches high.

Due to the large surface contact in this type of surface grinding it is necessary to use a soft and coarse wheel. The wheels range only as hard as "I" or "1½" in grade and only as fine as "30" on ordinary work. It has been found by experience that the most economical wheel to use is one that wears freely and consequently never needs dressing. Truing the wheel is seldom necessary for, while the unit wheel pressure is low, a high spot on the wheel face is quickly worn away, because the whole pressure is taken by this small surface when passing over the work. Since the grain depth of cut and consequently the rate of wheel wear depends entirely upon the rate of feed and the surface contact, a wheel which glazes or burns the work may usually

Table 6.—Wheels for Blanchard Surface Grinder

Revised to September 13, 1919.

Material	Width of Surface	Finer Finish and Narrower Surfaces	Best Wheel for Average Work	Faster Cutting and Broader Surfaces	Finer Finish and Narrower Surfaces	Best Wheel for Average Work	Faster Cutting and Broader Surfaces
		Norton Crystolon			American Carbolite		
Cast iron	Narrow	30-H	20-I		30-H	20-I	
	Medium	30-G	20-H	14-H		20-H	14-I
	Broad		14-H		30-G	14-H	
Chilled iron	Narrow		20-I			20-I	
	Medium		20-H			20-H	
	Broad		14-H		30-G	14-H	
Bronze	Narrow		20-I	14-I		20-I	14-I
	Medium		20-H			20-H	14-H
	Broad		14-H		30-G	14-H	
Aluminum	Narrow					20-I	
	Medium					20-I	
	Broad					14-H	
		Norton Silicate No. 38 Alundum			American Silicate Corundum		
Malleable iron	Narrow		3824-I			24-1¼	
	Medium		3824-H			24-I	
	Broad	3830-G	3824-H			24-I	
Soft steel	Narrow	3830-I	3824-I		30-1	24-1¼	
	Medium	3830-H	3824-H	3814-I	30-1	24-1	14-1¼
	Broad	3824-H	3814-I		30-¾	24-1	
Steel castings	Narrow		3824-I		30-1	24-1¼	
	Medium		3824-H	3814-I	30-1	24-1	
	Broad	3830-G			30-¾	24-1	
Hardened carbon steel	Narrow	3846-H	3830-H		46-¾	30-1	24-1
	Medium		3830-G	3824-H		30-¾	
	Broad		3830-G			30-½	
Hardened high speed steel	Narrow		3830-H			30-1	
	Medium		3830-G			30-¾	
	Broad		3830-G			30-½	

TABLE 7. DATA ON BLANCHARD GRINDING

Name of Piece	Size Overall	Material	Number Surfaces Ground	Cond. Rec'd	Amount Stock Rem. per Side	Limits	No. on Chuck	Production per Hour
Rifle hammer	$2\frac{1}{2}''\times 1\frac{1}{2}''$	Steel forging	2	R	0.20″	±0.001″	105	300
Ball races	$\frac{21}{32}''$	Hard steel	2	M	0.007″	±0.0005″		700
Steady rest jaws	$5\frac{11}{16}''\times 1\frac{1}{8}''\times 2\frac{1}{8}''$	Cast iron	4	R	$\frac{1}{32}''$	±0.0015″	25	25
*Push rod	$1''\times 3\frac{1}{2}''$	Hard steel	2	M	0.015″	±0.0005″	104	700
Shuttle rack	$3''\times 2\frac{3}{8}''$	Cast iron	2	R	0.032″	±0.001″	45	337
Friction disk	$8\frac{1}{2}''$ O. D. $5\frac{1}{2}''$ I. D.	St. punching	2	R	0.035″	±0.0015″	5	40
Valve lifter roll	$\frac{11}{16}''\times\frac{5}{16}''$	Hard steel	2	M	0.020″	±0.001″	250	500
Flat iron	$6\frac{1}{2}''\times 3\frac{3}{4}''$	Cast steel	2	R	0.035″	Clean	16	80
Auto starter frame	$8\frac{1}{8}''\times 4\frac{1}{2}''\times 5\frac{3}{8}''$	Steel forging	3	R	0.018″	±0.001″	6	30
Thrust washer	$3\frac{7}{8}''$ O. D. $2\frac{1}{4}''$ I. D.	Hard steel	2	M	0.015″	±0.001″	27	100

* Duplicate fixture. M—Machined. R—Rough.

be made to work more satisfactorily by either increasing the feed or decreasing the surface to be cut. A wheel which wears excessively may be treated in exactly the opposite manner and good results obtained. When the feed is increased it is sometimes necessary to decrease the speed of the chuck rotation in order to keep the power within the maximum output of the motor. When the feed is decreased production may be kept up by increasing the speed of the chuck rotation.

Table 6, which will probably be found convenient in the selection of wheels, is given above on page 291.

The wheel is mounted in a ring by using molten sulphur and the ring is then fastened by screws to the faceplate in the spindle.

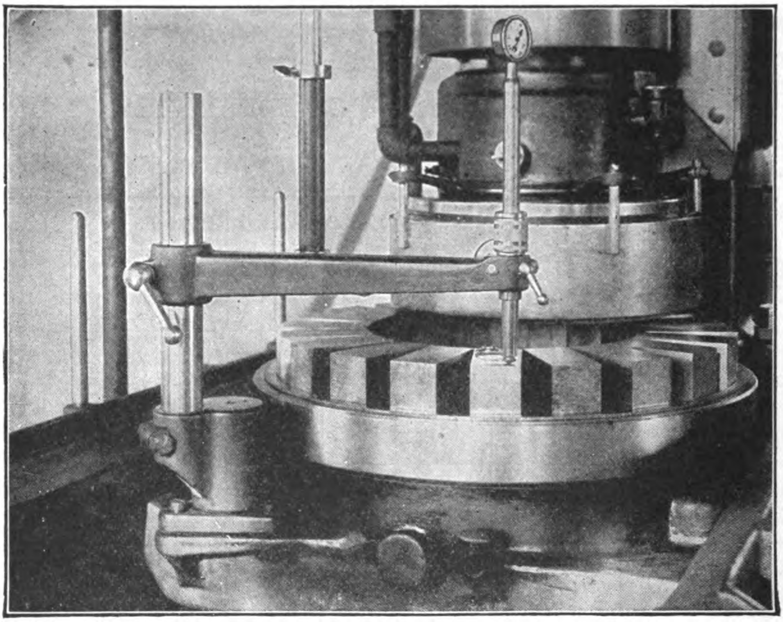


FIG. 35.—Continuous-reading caliper on Blanchard high-power vertical surface grinder.

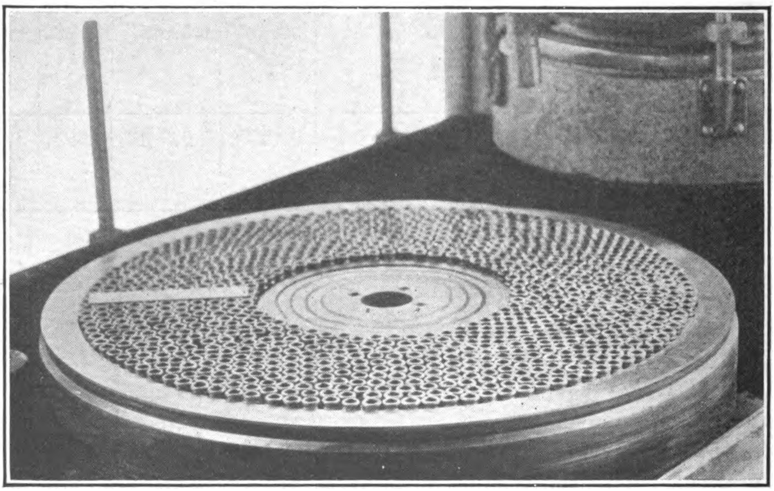


FIG. 35A.—Grinding a large number of bushings at once.

The automatic feed mechanism is arranged to feed once every revolution of the chuck. A feed of 0.001 of an inch is an average feed, but feeds as high as 0.003 of an inch per revolution of chuck are sometimes used. The feed may be varied by fifths of a thousandth from 0.0002 inch to 0.005 inch.

The average speed of the table is 13-17½ r.p.m.

The work is held on the chuck magnetically and is prevented from slipping by inner and outer rings as in Fig. 35.

On page 292 are given some production data—the figures are from data supplied by users of the machine.

CONTINUOUS READING GRINDING CALIPER

A recent development in connection with this machine is the application of a continuous reading caliper which may be briefly described as

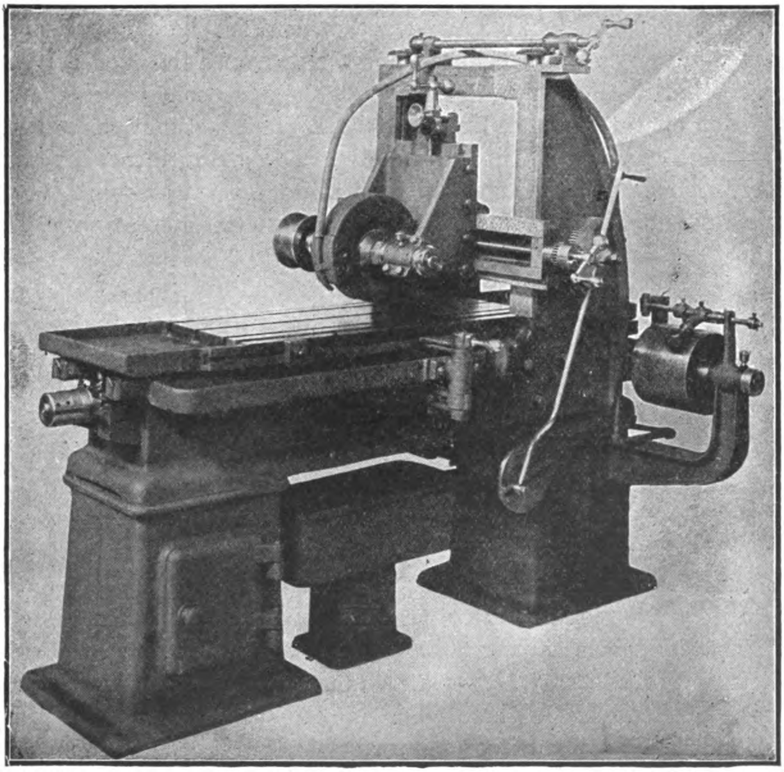


Fig. 36.—Automatic planer type surface grinder.

a device which measures the work thickness continuously during the grinding operation, showing the operator by means of a dial the exact amount in thousandths of an inch by which the work exceeds finished size. The caliper is attached to the carriage of the grinder in such a position that the rotary work table carries the pieces which are being ground, alternately under the wheel and under the caliper, so that each piece is measured after every pass under the wheel.

In Fig. 35 the caliper is seen in the foreground with its contact point resting on one of the steel blocks which are placed around the rotary work table in position for grinding. The 16-inch cylinder wheel of the grinder, surrounded by a steel safety hood, is seen at the rear of the table. When removing or placing work the table is moved out from under the wheel and the caliper, which moves with it, swings to one side, leaving the table entirely clear.

The contact point on the caliper is a hardened steel button which rests on the surface of the work and connects by a light rod inside the vertical tube, with the Ames gage head seen in Fig. 35, at the top of the tube. The tube slides in a split sleeve, which may be clamped to it by the large knurled nut, seen just above the arm, and this sleeve, in turn, has a limited motion vertically, through the arm, controlled by a rack and pinion operated by the knurled wheel. This last motion is clamped by the small screw with the ball handle. These movements are simply for convenience in quickly setting the contact point after an approximate adjustment is made by sliding are arm up or down on the column.

SETTING THE GAGE

To set the caliper for size a finished piece known to be correct in thickness is placed on the table. After setting the arm about 2 or 3 inches above the surface of this piece, the tube is moved down, bringing the button in contact with the piece and giving an indication on the gage. All adjustments are then clamped and the dial of the gage revolved until the zero mark coincides with the pointer. With the caliper set in this way, it will indicate zero when the work is ground to size, and if the work is oversize, the readings will show the excess stock in thousandths of an inch.

Readings are taken by the operator without interrupting the grinding. The caliper is simply swung over the work while the latter is revolving, and the dial shows at a glance how much more stock to remove. The caliper may be brought into action as soon as the grinding begins and left there, giving a continuous indication, which approaches zero as the stock is removed; but this is not necessary, and considerable wear on the contact button can be saved by using the caliper only at intervals, until close to size. The wear of the button becomes appreciable only after several lots of pieces have been ground, and is readily compensated for by checking a piece in every fourth or fifth lot with micrometers, and setting the dial ahead an amount equal to the variation found. This applies to work where the limits are ± 0.001 in. For closer limits checking must be more frequent. The contact button can be easily replaced when worn.

THE PLANER TYPE OF SURFACE GRINDER

The machine in Fig. 36 is the planer type of surface grinder built by the Springfield Manufacturing Company, Bridgeport, Conn.

This form of surface grinder, in which the wheel is carried upon a horizontal spindle, is built in several sizes, from small grinders intended for tool-room work, up to machines with a capacity for work 48 inches wide by 10 feet in length. These grinders are built for a general line of work requiring surfacing, the one illustrated being adapted especially for tool-room work and small grinding in general. From the shape of the wheel and the nature of the contact, it is obvious that this type of grinder is particularly suited to the handling of work requiring grinding along grooved surfaces or finishing up to a shoulder.

This form of grinder is also built with an oscillating wheel head which is given a lateral movement that is simultaneous with the travel of the work under the wheel; the combination of movements passing the wheel across the work at many different angles to produce a fine finish and preserve the truth of the wheel. A very wide face wheel is used with the type of machine, and in the larger sizes of grinders the space between uprights admits of very wide work being surfaced.

On all these planer type machines provision is made for supplying a liberal quantity of water to the work and wheel.

The arrangement of the power feed for the head, the reversing drive for the table operating screw, and other features of importance are shown clearly in the halftone, Fig. 36. The magnetic chuck can, of course, be used for holding work whenever reqired.

DISK GRINDING

The type of grinding machines known as the disk grinder and shown in Fig. 36, is being used in a large variety of surfacing work. The disks are made of steel, usually running from 12 inches to 48 inches in diameter and from ½ to 1 inch in thickness.

The cutting or abrasive disks are cemented to the face of the steel disk, clamped in a press until the cement is set, and then mounted on the spindle of the machine just as a grinding wheel would be. The grinding circles, as the abrasive disks are called, are covered with any abrasive desired, different materials giving best results on different work. These were originally made from sheets of emery or other abrasive cloth, having the grains all over the surface. The small particles of the material being ground clogged the grains of the abrasive and reduced the efficiency. Grooves were cut in the steel disk to form a sort of cushion under the circles and among the latest development is the spiral circle, in which the abrasive is deposited on the cloth base or foundation in the form of a spiral with a blank space between. This gives a continual shearing action as the grains of abrasives pass by the face of the work being ground and the spaces also serve as a clearance for the chips ground from the work. These cut faster than the older forms of circles and give remarkable results in many cases. Another form has the cutting surface divided into small squares or other shaped parts.

The speed varies from about 2200 to 3000 feet per minute at the rim of the disks, according to the work to be ground. The power required varies with the work being done, its surface in contact with the grinding circle having a direct bearing on this point. With motor-driven machines a 12-inch disk machine is fitted with a 2 horse-power motor, an 18-inch disk with 5, and a 23- or 26-inch disk with a 10 horse-power motor.

With a belt-driven machine the 12-inch has about a 5-inch pulley and a 3-inch belt, while for a 26-inch disk the spindle pulley is 7 inches in diameter for a 6-inch belt. With belt drive it is customary to figure on about half the power consumption as that indicated by the size of motor, which represents maximum requirements, the belt being average power required.

Where work is to be finished in this way the allowance for finishing need not be large, although large amounts can be ground off if necessary. On work that is machine first, from 0.005 inch to 0.050 inch is plenty for a good finish.

The main considerations are: Stock to be removed, distance to be traveled by grindings before escape, area of surface to be ground, and the thickness of the adjacent stock for absorbing heat from the grinding and to prevent spring and distortion.

WORK DONE BY DISK GRINDERS

The following table from tests with Besley Helmet spiral disk on bars 1 inch square gives some idea of the possibilities and can be used as a general guide. These were all 24 grain and an 18-inch circle.

	Average time in seconds for grinding 1 cubic inch during life of circle
Yellow brass	25
Aluminum alloy	42
Phosphor bronze	60
Malleable iron	90
Cast iron	100
Cast crucible steel	444
Wrought mild steel	600

Another feature to be considered in disk grinding is to avoid rigid clamping as much as possible. This requires time and often makes the grinding time longer owing to more metal being removed where it is simply a case of cleaning up a surface. In cases of this kind it is better to let the work float against the disk so that all the high points come in contact first and reduce the total grinding to the simple taking down of the high points to just clean up the low spots.

Where work is small and can be ground all over the surface of the grinding circle, they can be worn out very evenly and economically, but on work which can only use the outer surface, grinding circles are made with an extra large hole and are more economical for this work.

Grinding circles glaze the same as grinding wheels and can be sharpened with a wheel dresser or a stiff wire brush. The brush, such as is used for cleaning castings, is particularly good when grinding carbon, brass, aluminum or cast iron.

Work should always be moved across the face of the grinding disk both on account of prolonging the life of the circle and for grinding a perfectly flat surface.

Most disk grinding machines are designed to use single belts, the pulleys being made wide enough to allow of this.

In grinding aluminum and copper there is a tendency for the abrasive material to come off the cloth backing sheet on which it is held. If this occurs it can be helped by filling the circle with paraffine, beeswax or machine oil before starting to grind.

FINISH GRINDING

For finishing brass for nickel plating or when a specially nice finish is wanted, the disks can be faced with leather disks about $^3/_{16}$ inch thick and charged with fine abrasive, such as 120 or even finer, alundum, carborundum or other abrasive material.

Leather disks are also good for fine finish on any kind of work, as it can be made to very closely resemble handwork. An even closer resemblance to handwork can be had by using a felt disk, about $^7/_{16}$ inch thick, and charged with very fine abrasive.

Generally speaking the "mile-a-minute" speed, about 5300 feet per minute, is good for most disk grinding, while for brass finishing work, 6500 feet per minute is good practice.

Summed up in tabular form this gives:

Diameter of disk	R. p. m. for removing stock	R. p. m. for brass and burring and finishing
12 inches	2000	2600
18 inches	1400	1800
20 inches	1250	1600
23 inches	1100	1300
26 inches	1000	1250

RECOMMENDED SPEEDS

Taking an 18-inch disk as an example, the recommended speed for cast iron is 1400, for general work such as machine steel 1650, and for brass work 1800 revolutions per minute. This corresponds to about 6650, 7840 and 8550 feet per minute for rim speed of the disks.

CHAPTER V

GRINDING WHEELS

Grinding wheels are made by three processes, vitrified, silicate (or semi-vitrified) and elastic.

Wheels are manufactured in a great number of shapes and sizes, to suit all classes of grinding machinery. Among the commercial abrasives of which they are composed are emery, corundum, carborundum, alundum, crystolon, carbolite and carbonite. They vary in hardness, though it does not follow that the hardest grit is the best for cutting purposes; the shape and form of fracture of the particles must also be taken into consideration. We may imagine a wheel made up from diamonds, the hardest substance in nature, and whose individual kernels were of spherical form; it is quite obvious that it would be of little service as a cutting agent. On the other hand, if these kernels were crystalline or conchoidal in form it would probably be the ideal grinding wheel.

Emery is a form of corundum found with a variable percentage of impurity; it is of a tough consistency and breaks with a conchoidal fracture.

Corundum is an oxide of aluminum of somewhat variable purity according to the neighborhood in which it is mined; its fracture is conchoidal and generally crystalline.

Carborundum is the name given the carbide of silicon as manufactured in the electric furnace by the Carborundum Company. The principal materials entering into its manufacture are coke, which supplies the element carbon; and sand, supplying the silicon. The mass of coke and sand is raised to a very high temperature which destroys all substances in the coke and sand except the carbon and silicon, the atoms of these two elements then uniting as carborundum, a product that breaks with a sharp, crystalline fracture.

The grade table of the Carborundum Company will be found on page 308. This table gives grit numbers and grade letters for carborundum wheels as recommended by the makers for all classes of grinding operations.

Alundum is an artificial product, being a fused oxide of alumina. It is of uniform quality, of about 98 per cent of purity. It breaks with a sharp, conchoidal fracture and has the toughness of emery.

The mineral, bauxite, from which alundum is made by fusing in the electric furnace, derives its name from the ruined city and castle of Les Baux, in the southern part of France where it was originally discovered. It is now obtained in higher degree of purity in the United States. The alundum process has been perfected and commercially applied by the Norton Company for their grinding wheels.

Crystolon, which is also used by the Norton Company in the manufacture of wheels, is carbide of silicon, and is one of the most recent abrasive materials put into commercial use. Like alundum, crystolon is an electric furnace product. Its characteristic property of brittleness makes it efficient for polishing and grinding such metals as cast iron,

FIG. 37.—Grinding wheel with wire web.

chilled iron, brass, also marble, granite and pearl, in fact such materials in general as possess a low tensile strength.

The tables for selections of grades beginning on page 305 show clearly the different classes of work for which the abrasives, crystolon and alundum, are respectively recommended.

Aloxite is an aluminum oxide, fused in an electric furnace and one of the later products of the Carborundum Company.

Carbolite (carbide of silicon) is an electrical abrasive forming one of the materials used in the products of the American Emery Wheel Works. Carbolite wheels are recommended by the makers for grinding the softer metals, especially cast iron and brass, and also for grinding such materials as rubber, leather, pearl, etc.

Carbondite is another artificial abrasive made in the electric furnace. It is one of the materials used in the wheels of the Safety Emery Wheel Company.

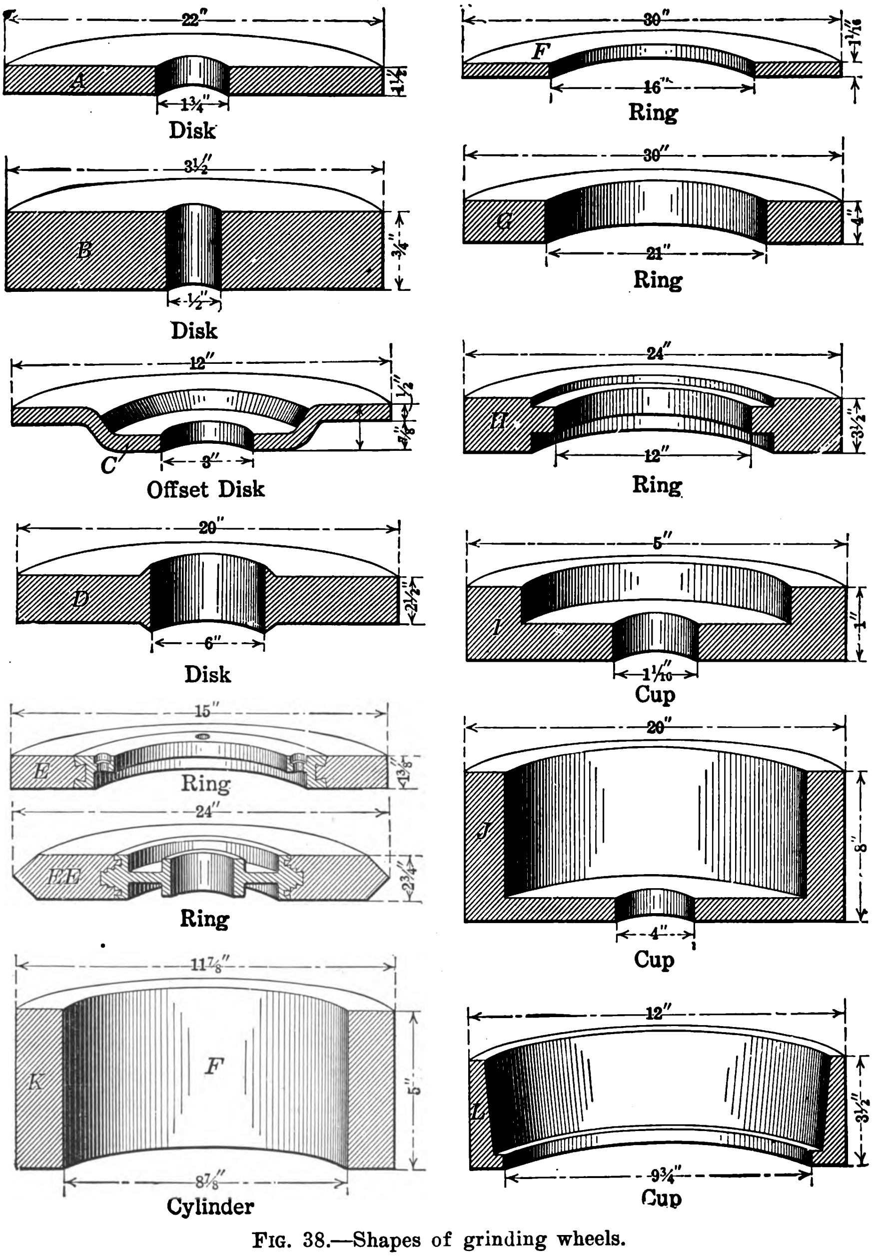


FIG. 38.—Shapes of grinding wheels.

THE WHEEL-MAKING PROCESSES

The vitrified process produces open texture, free-cutting wheels. They are not affected by weather, time, water, oils, acids or soda, and are used for both wet and dry grinding.

Silicate wheels are made by the tamping process. Wheels are made of larger diameter and greater thickness by this process than by other methods. They are made either with or without the wire web shown in Fig. 37. These wheels are water-proof and are, therefore, equally serviceable for wet and dry grinding.

Wheels made by the elastic process are the only wheels that can be made very thin and at the same time have the necessary strength and elasticity to make them durable. Elastic wheels are bonded by gums such as rubber, shellac and resins; the mixture of bond and abrasives being heated and pressed in molds. Wheels are made by this process as thin as $^1/_{32}$ inch up to 4 inches diameter; $^1/_{16}$ inch thick up to 10 inches diameter; $^1/_8$ inch thick up to 12 inches diameter. Very fine wheels of small diameter have been made as thin as $^1/_{64}$ inch.

They are used chiefly for saw gumming, grinding between the teeth of gears, sharpening molding cutters, cutting off small stock, etc. They may be run in water, caustic soda, or dry.

In testing the different classes of wheels they are run on a testing machine at a peripheral speed of at least 9000 feet per minute, giving a stress of 250 pounds per square inch.

Thus the wheel under test is run at a speed from 50 to 100 per cent higher than that at which it will be operated in practice and is subjected to stresses two or three times as high as imposed by the usual operating speeds. If a wheel is defective it will break under this test.

THE GRADING OF WHEELS

A grinding wheel is made up of two kinds of material, the "grit" or cutting material, and the bond. The cutting efficiency of a wheel depends largely on the grit; the grade of hardness depends principally on the bonding material used. The efficiency in grinding a given metal is dependent largely upon the "temper," or resistance to fracture, and character of fracture of the grit or cutting grains of the wheel.

Some interesting particulars of the various bonding materials are given by George N. Jeppson:

"The function of the bond is not only to hold the cutting particles of the wheel together and to give the wheel the proper factor of safety at the speed it is to be run, but it must also be possible to vary its tensile strength to fit the work it is called upon to do. We often hear the operator say that the wheel is too hard or too soft.

He means that the bond retains the cutting teeth so long that they become dulled, and this wheel is inefficient; or, in the case of a soft wheel, the bond has not been strong enough to hold the cutting teeth and they are pulled out of the wheel before they have done the work expected.

"The bond to be used for a given operation depends on the wheel and work speeds, area of wheel in contact with the work, vibration in wheel spindle or work, shape and weight of work, and many other like variables.

"Wheels are bonded by what are known as the vitrified, silicate, elastic and rubber processes. No one bond makes a superior wheel for all purposes; each one has its field.

"**The vitrified bond** is made of fused clays, is unchanged by heat or cold, and can be made in a greater range of hardness than any other bond. It does not completely fill the voids between the grains, and therefore, a wheel bonded in this way, having

```
          E.......................................Soft
           F
            G
             H
              I.............................Medium soft
               J
                K
                 L
MEDIUM............M...  .................MEDIUM
                   N
                    O
                     P
Medium hard...........Q
                       R
                        S
                         T
Hard......................U
                           V
                            W
                             X
Extremely hard................Y
                               Z
```

TABLE 8.—NORTON COMPANY'S GRADE LIST.

more clearance than any other, is adaptable for all kinds of grinding except where the wheel is not thick enough to withstand side pressure. This bond has no elasticity.

"**The silicate bond** is composed of clays fluxed by silicate of soda at low temperatures. It is not as stable as the vitrified bond as regards dampness, gives less clearance between grains, and has a range of hardness below that of the vitrified in the harder grades. This bond has no elasticity and will not make a safe wheel of extreme thinness.

"**The elastic bond** is composed of shellac and other gums. It completely fills the voids of the wheel, has a limited range of grades, has a high tensile strength and elasticity, and can be used for the making of very thin wheels. The rubber or vulcanite bond has the general characteristics of the elastic, but its grades of hardness cannot be varied to the same extent and its uses are limited."

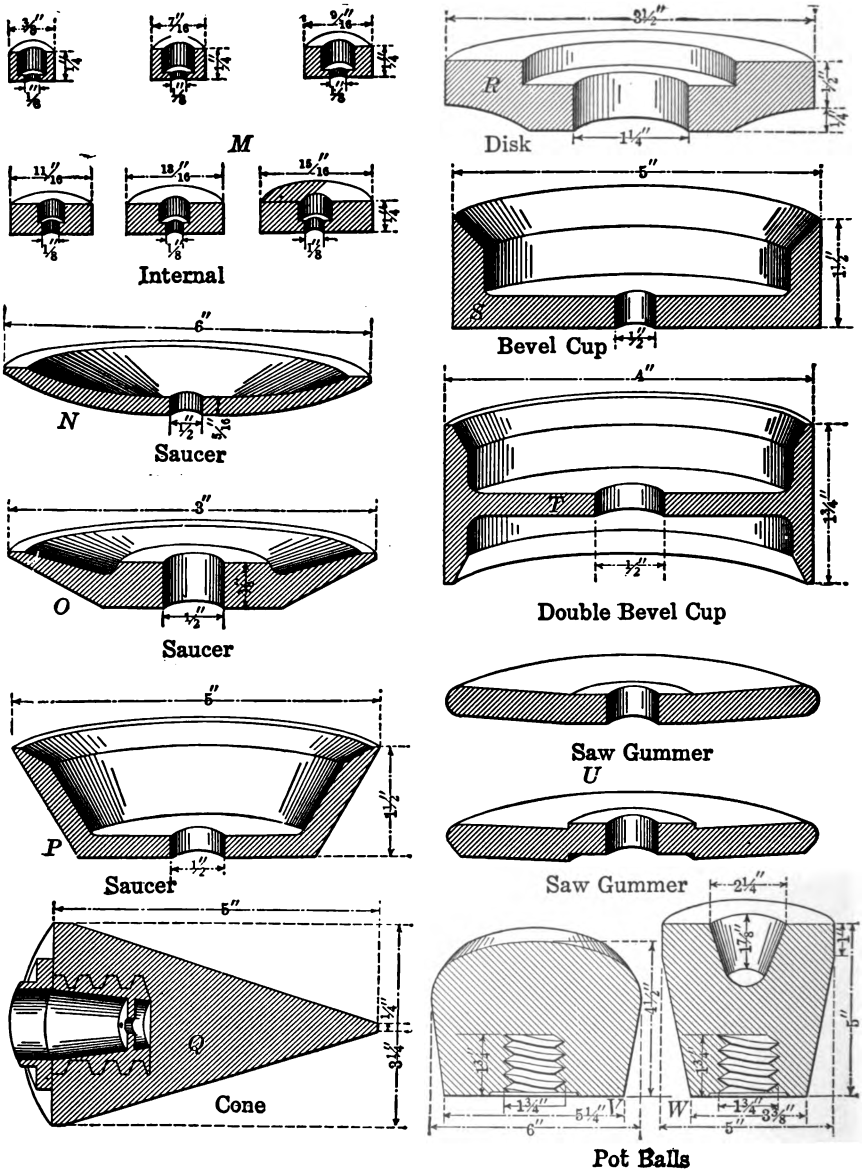


FIG. 39.—Shapes of grinding wheels.

GRAIN AND GRADE

Grinding wheels are made in various combinations of coarseness and hardness to meet the variety of conditions under which they are used. The cutting material is crushed and graded from coarse to fine in many sizes designated by number. Thus the sizes of grain used in the Norton wheels are numbered 10, 12, 14, 16, 20, 24, 30, 36, 46, 50, 60, 70, 80, 90, 100, 120, 150, 180, 200. Finer grades known as flour are also used, sometimes these being designated as F, FF, FFF, etc. By No. 20 grain is meant a size that will pass through a grading sieve having 20 meshes to the linear inch.

The term "grade" refers to the degree of hardness of the wheel or the resistance of the cutting particles under grinding pressure. A wheel from which the cutting particles are easily broken, causing it to wear rapidly, is called soft, while one which retains its particles longer is called hard. Wheels are usually graded from soft to hard, although in some instances the process is reversed.

Manufacturers of grinding wheels have different grade lists as follows:

Class of work	Alundum		Crystolon	
	Grain	Grade	Grain	Grade
Aluminum castings	36 to 46	3 to 4 Elas.	20 to 24	P to R
Brass or bronze castings (large)			20 to 24	Q to R
Brass or bronze castings (small)			24 to 36	P to R
Brick, fire			16 to 20	P to Q
Brick, pressed			16 to 20	O to P
Car wheels, cast iron			16 to 24	P to R
Car wheels, chilled	20	Q	16 to 24	O to Q
Cast iron, cylindrical	24 comb.	J to K	30 to 46	J to L
Cast iron, surfacing	20 to 46	H to K	16 to 30	J to L
Cast iron (small) castings	24 to 30	P to R	20 to 30	Q to S
Cast iron (large) castings	16 to 20	Q to R	16 to 24	Q to S
Chilled iron castings	20 to 30	P to U	20 to 30	Q
Dies, chilled iron			20 to 30	O to Q
Dies, steel	36 to 60	J to L		
Drop forgings	20 to 30	P to R		
Hammers, cast steel	30	P		
Hollowware, inside grinding			30	Q
Hollowware, thin edges			24	U
Internal grinding of automobile cylinders. (cast iron).			30 to 60	I to L
Internal grinding, hardened steel	46 to 60	J to M		
Knives (paper), automatic grinding	36 to 46	J to K		
Knives (planer),	30 to 46	J to K		
Knives, leather shaving	60	N to O		
Knives, leather splitting	24 to 30	1 to 2 Elas.		
Knives, moulding bits, etc.	{ 46 to 60 46 to 60	3 Elas. M		
Knives (planing mill), hand grinding	46 to 60	J to M		
Knives, shear and shear blades	30 to 60	J to M		
Knives, shoe	60	M		
Lathe centers	46 to 120	J to M		
Lathe and planer tools	{ 20 to 24 20 to 36	P Sil. O to P		
Machine shop use, general	20 to 36	O to Q		
Malleable iron castings (large)	14 to 20	P to U	16 to 20	R to S
Malleable iron castings (small)	20 to 30	P to R	20 to 30	Q to S
Marble, finishing			150 to F	M
Marble, roughing			16 to 46	M
Marble, coping			36 to 46	O to S
Marble, moulding			4	O
Milling cutters, automatic or semi-automatic grinding.	46 to 60	H to M		
Milling cutters, hand grinding	46 to 60	J to M		

NORTON COMPANY'S TABLE FOR SELECTION OF GRAIN AND GRADE OF ALUNDUM AND CRYSTOLON WHEELS

TABLE 9.—SELECTION OF GRADE.

Class of work	Alundum		Crystolon	
	Grain	Grade	Grain	Grade
Nickel castings	20 to 24	P to Q	20 to 24	R
Pearl grinding, roughing			30 to 50	P to U
Pearl grinding, finishing			100 to 150	M to P
Plow bodies (cast iron), surfacing			24	R
Plows (steel), jointing	20 to 24	R to S		
Plow points (chilled iron), surfacing			20 to 30	Q to S
Plows (steel), surfacing	16 to 24	Q to S		
Porcelain, roughing			36 to 50	O to R
Pulleys, (c. i.) surfacing faces of			30 to 36	K to L
Radiators (cast iron), edges of			24 to 30	R to S
Razors, grinding and concaving	46 to 120	H to O		
Reamers, taps, milling cutters etc., hand grinding.	46 to 60	K to O		
Reamers, taps, milling cutters, etc., special machines.	46 to 60	J to M		
Rolls (cast iron), wet	24 to 36	J to M	24 to 36	J to M
Rolls (chilled iron), finishing	70	1½ to 2 Elas.	70 to 80	1½ to 2 Elas.
Rolls (chilled iron), roughing			30 to 46	2 to 3 Elas.
Rubber	30 to 50	J to K	30 to 50	K to M
Sad irons, finishings			80 to 120	Q to R
Sad irons, roughing			20 to 30	Q to S
Saws, gumming and sharpening	36 to 50	M to N		
Saws, cold cutting-off	60	O to Q		
Shovels, edging	24	Q		
Spiral springs, ends of	16 to 20	Q to R		
Steel (soft), cylindrical grinding	24 comb. 46 to 60	L to N L to N		
Steel (soft), surface grinding	24 to 36	H to K		
Steel (hardened), cylindrical grinding	24 comb. 46 to 60	K J to L		
Steel (hardened), surface grinding	36 to 46	H to K		
Steel, large castings	12 to 20	Q to U		
Steel, small castings	20 to 30	P to R		
Steel (manganese), safe work	16 to 46	L to P		
Steel (manganese), frogs and switches	14 to 16	Q to U		
Structural steel	16 to 24	P to R		
Stove castings	20 to 36	P to Q	20 to 36	Q to R
Twist drills, hand grirding	46 to 60	M		
Twist drills, special machines	36 to 60	K to M		
Wagon springs, ends of	20 to 30	P to R		
Wire, ends of steel	36 to 80	Q to R		
Wrought iron	12 to 30	P to U		
Woodworking tools	46 to 60	K to M		

NORTON COMPANY'S TABLE FOR SELECTION OF GRAIN AND GRADE OF ALUNDUM AND CRYSTOLON WHEELS

TABLE 9.—SELECTION OF GRADE—(*Continued*)

Very hard	D
	E
	F
	Gx
Hard	G
	Hx
	H
	Ix
Medium hard	I
	K
	L
Medium	M
	N
	O
Medium soft	P
	R
	S
Soft	T
	U
	V
Very soft	W
	X
	Y
Very very soft	Z

TABLE 10.—THE CARBORUNDUM COMPANY'S GRADE.

Work	Grit numbers	Grade letters
Aluminum castings	16 to 24	H to I
Brass castings (large)	16 to 24	G+ to H
Brass castings (small)	24 to 36	H to I
Bronze castings	20 to 30	H to I
Brick, fire	14 to 16	H to I
Brick, pressed	14 to 16	I to J
Car wheels	14 to 24	G+ to I+
Dies (surfacing hardened steel)	30 to 36	J to K
Dies (chilled iron)	24 to 30	H to I+
Drop forgings (general)	20 to 36	G+ to I+
Files (edging)	24 to 30	D to E
Glass (rough edge grinding)	100 to 120	I to K

TABLE 11.—CARBORUNDUM COMPANY'S SELECTION OF GRAIN AND GRADE.

Work	Grit numbers	Grade letters
Glass (finish edge grinding)	20 to2 FFF	K to M
Cast iron (roughing)	16 to 24	F to H
Cast iron (finishing)	60 to 80	G+ to H
Cast iron (surfacing)	16 to 24	J to L
Cast iron (cylindrical)	24 to 60	L to N
Cast iron (plows)	16 to 24	G+ to H+
Cast iron (shoulders on shears)	90 to 100	F to H
Chilled iron	20 to 24	H+ to H
Wrought iron	16 to 24	H+ to H
Knives (leather shaving)	50 to 70	I+ to J
Knives (molding bits, etc.)	36 to 50	L to M
Knives (planer, auto.)	20 to 36	P to S
Knives (planer, hand)	36 to 50	K to M
Knives (paper, auto.)	202 to 203	P to S
Knives (shear, shear blades)	24 to 30	I+ to J
Lathe centers	60 to 80	K to L
Lathe and planer tools	24 to 36	H+ to I
General machine shop	20 to 30	H+ to I
Large malleable castings	12 to 16	G to H
Small malleable castings	16 to 24	G+ to I+
Milling cutters, reamers	50 to 80	M to O
Marble (roughing)	40 to 50	K to M
Marble (finishing)	180 to FF	M to L
Marble (sawing)	36 to 40	M to K
Nickel castings	20 to 24	G+ to G
Pearl grinding (roughing)	30 to 50	H to J
Pearl grinding (finishing)	100 to 150	E to H
Porcelain (roughing)	40 to 50	G+ to H
Razors (grinding and concaving)	70 to 100	P to R
Rolls (cast iron, wet)	24 to 36	M to N
Rolls (chilled iron, roughing)	30 to 40	2 to 3
Rolls (chilled iron, finishing)	60 to 80	4 to 7
Rubber (hard)	36 to 50	K to M
Rubber (soft)	20 to 30	J to K
Sad irons (roughing)	20 to 36	G+ to H
Sad irons (finishing)	120 to 150	G+ to H

TABLE 11.—CARBORUNDUM COMPANY'S SELECTION OF GRAIN AND GRADE—(*Continued.*)

Work	Grit numbers	Grade letters
Saws (gumming heavy)	301 to 365	J to L
Saws (gumming light)	403	K to L
Saws (sharpening)	301 to 365	K to M
Saws (cold)	50 to 80	H to I
Shovels (edging)	12 to 16	D to E
Steel (large castings)	10 to 16	F to H
Steel (small castings)	16 to 20	G+ to H
Steel (hardened tool)	24 to 36	I to J
Steel (hardened tool fine)	80 to 120	J to L
Steel (internal hardened)	30 to 60	O to T
Steel (manganese)	16	K
Steel (plows)	16 to 24	H+ to H
Steel (carriage axles)	16 to 20	H+ to H
Small tools	30 to 80	I to J
Twist drills (hand)	40 to 60	I to J
Twist drills (auto.)	40 to 50	M to O

TABLE 11.—CARBORUNDUM COMPANY'S SELECTION OF GRAIN AND GRADE—(*Continued.*)

The following grade list is used to designate the degree of hardness of vitrified and silicate wheels, both alundum and crystolon.

The intermediate letters between those designated as soft, medium soft, etc., indicate so many degrees harder or softer; e.g., L is one grade or degree softer than medium; O, two degrees harder than medium, but not quite medium hard.

Elastic wheels are graded as follows: 1, 1½, 2, 2½, 3, 4, 5, and 6. Grade 1 is the softest and grade 6, the hardest.

THE SHAPES OF WHEELS

Although grinding wheels are manufactured in a great variety of shapes and sizes, there are a few general forms into which they may be grouped. Practically all of the hundreds of commonly used shapes made for the various types of grinding machines and for the different kinds of work come under some one of these classifications, the most common of which may be designated as "disk," "cup," "cylinder," and "saucer" wheels. These shapes and some of their modifications are included in the groups of wheels illustrated in Figs. 38 and 39. These wheels are in most cases made in numerous widths and diameters, and the dimensions given in any such instances merely show the proportions of one size of wheel selected as typical from the comprehensive lists of wheel manufacturers' products.

In addition to the number of wheel shapes shown there are many modifications of the straight disk wheel for other purposes, consisting usually in a plain wheel with the edge dressed off convex or concave, or to such angles as 20, 25, 30, 50 and 60 degrees. These wheels are used for grinding cutters, gumming saws, etc.

SELECTION OF WHEELS

The tables, Nos. 8 to 11, for the selection of wheels have been compiled by the manufacturers for the purpose of giving wheel users and dealers an approximate idea of what is most commonly furnished for various grinding operations on different classes of materials handled under the customary methods.

It is recognized that the conditions under which wheels are used vary to such an extent that no hard and fast rule is possible for selecting the grades best suited to the operations in hand. Therefore it is considered the best practice in the majority of cases to supply the wheel manufacturer with complete data regarding the work and working conditions, and leave the selection to him.

STANDARD GRADING OF WHEELS

On this question of wheel selection, H. Darbyshire points out that it may be assumed that for all general purposes the aim in view is to procure a wheel which will fulfill two conditions, that is, that it shall first remove stock rapidly and at the same time give a decent finish. Wheels made from a combination of grit of different sizes are the best for this purpose, as may be seen from the following explanation. Coarse wheels of an even number of grit will remove stock faster than will fine wheels of an even number, because their depth of cut or penetration is greater. They, however, fail in giving a high surface finish except in grinding very hard material, because they are not compact enough.

THE COMBINATION GRIT WHEEL

With the combination wheel the conditions are different and it seems better at removing stock than does the coarse, even grit wheel. It may be safe to assume from this that something of a *grindstone action* takes place, that is, that the finer particles of grit become detached from the bond and both roll and cut in their imprisoned condition between the larger particles. For finishing purposes this wheel has all the compactness and smooth face of a wheel which was made solely from its finest number of grit; and for roughing, it enables a depth of cut to be got which is within the capacity of its largest kernels.

With regard to the texture or hardness of material ground it may be taken as a general rule that the harder the material is, the softer the bond of wheel should be and that cast iron and hardened steel bear some relation to each other as far as grinding wheels are concerned, for the same wheel is usually suitable for both materials.

Too large an assortment of wheels is likely to lead to confusion, and we may take the Norton plain cylindrical grinding machine as being a case in point of a limited assortment of wheels. In this machine four different grade wheels, all of 24 combination grit, are found sufficient for all classes of material that it is ordinarily required to grind. This includes high- and low-carbon steels, cast iron, chilled iron, and bronze or composition metals. These wheels are graded J, K, L, and M, and even the hardest of these, M, is superfluous. A 24 M wheel is only suitable for the softest of machine steels. It is generally called for in the belief that it lasts longer and so does more work than its next softer grade, though this need not necessarily be so. A wheel that is too hard must be repeatedly dressed with the diamond, which is one way of wearing it out, and diamonds themselves are expensive enough to be a consideration.

ONE ADVANTAGE OF GRINDING

One of the greatest advantages accruing from grinding is that it ignores the nonhomogeneity of material and that it machines work with the lightest known method of tool pressure, thus avoiding all those deflections and distortions of material which are a natural result of the more severe machining processes. Yet these objects are too often defeated by the craze for hard and long-lived wheels. A wheel that is too hard or whose bond will not crumble sufficiently under the pressure of cut will displace the work and give rise to many unforeseen troubles. It is also a prolific cause of vibration, which is antagonistic to good and accurate work. The advantage claimed for it, that it gives a better surface finish, is a deceptive one, for it mostly obtains this finish at the expense of accuracy. Quality of finish, that is, accurate finish, is merely a question of arranging of work speed, condition of wheel face and depth of cut. In the machine mentioned the suitability of wheels to materials and conditions is found to be as follows, the wheels being in each case of a combination of alundum grit:

For hard chilled iron and large diameters of cast iron and hardened steel	24 J
For medium chilled iron and medium diameters of cast iron and hardened steel and bronze	24 K
For all grades of steel which are not hardened and for bronze	24 L
For very low carbon machine steels	24 M

The table given may, speaking generally, be what would be chosen in the way of wheels for the materials given, and in actual practice they soon give evidence as to whether they are suitable. It may be gathered from the table that diameter of work is a factor in the choice of a wheel. This refers to area of wheel contact and is governed by what is shown in the table when broad differences of diameter occur; for instance, it might be necessary to use the K wheel for a large diameter of high carbon steel if the L wheel was evidently too hard.

SPEED AND EFFICIENT CUTTING

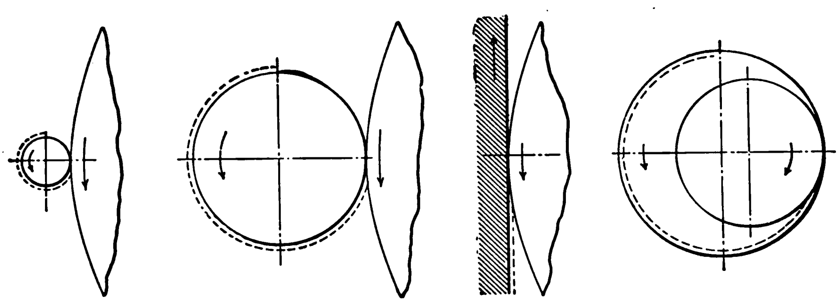
The efficient cutting of a wheel depends very much on the speed of the work, and an absence of knowledge in this respect may often lead to a suitable wheel's rejection. Revolving the wheel at the speed recommended by the maker is the first necessity, and if it is found unsuitable after experimenting with various speeds it should be changed for a softer or harder one as the conditions indicate.

If after trying all reasonable work speeds, a wheel should burn the work, or refuse to cut without excessive pressure, or persistently glaze the surface of the work, it is too hard for that particular work and material and may be safely rejected. If after trying all reasonably reduced work speeds, a wheel should lose its size quickly and show all signs of rapid wear, it is too soft for that particular work and material and may be rejected. These indications refer to all ordinary cases and it may be gathered that the most economical wheel is that which acts in such a manner as to be a medium between the two cases. There is still another point to bear in mind with regard to the size of the grit in the wheel, but which refers more especially to very hard materials such as chilled iron. Either a coarse or combination wheel may go on cutting efficiently in roughing cuts because pressure is exerted, but may begin to glaze when this pressure is much relieved as in finishing cuts. A careful microscopic scrutiny of a wheel that displays this tendency would seem to lead to the following assumption:

WHEN A WHEEL IS SHARP

The wheel face when newly trued with the diamond tool, which is necessary to obtain an accurate finish, shows a promiscuous arrangement of particles, some of which present points and others present a broader face with a rough and granular surface. When the wheel is presented to the hard surface of the work the high points of this granular face and the sharp contour of the kernels will go on cutting until they are dulled and worn down, after which their face area is too great to enter the surface without undue pressure. When the wheel has reached this condition the microscope shows these broader-faced kernels polished to a metallic luster, which bears out the explanation tendered and also makes the remedy quite apparent. This is to use a wheel of very fine grit for finishing purposes in these cases or else keep the coarser wheel in condition by repeated dressings with the diamond tool.

A reference to Fig. 40 will show what actual practice requires in



No. 1	No. 2	No. 3	No. 4
Grinding Small Dia.	Grinding Large Dia.	Grinding Flat Surface	Internal Grinding

FIG. 40.—Wheel contact with different work.

the choice of a wheel as far as the question of wheel contact is concerned. A wheel is shown in contact with four different varieties of work, all of which we will suppose to be of the same material, the depth of cut, much exaggerated, being the same in each case. In the first case, it is a shaft of small diameter, and the wheel contact being the smallest the harder grade of wheel would be suitable, comparatively speaking. Assuming that this wheel was found to be suitable it would probably require a softer wheel for the next case, which is a shaft of larger diameter and the wheel contact proportionately greater. To continue the comparison still further the third case shows the wheel engaged in grinding a flat surface, and the fourth is a wheel grinding internally. In each case practice demands that the wheel shall be progressively softer in bond or grade and this is some proof of a consistency in the action of grinding wheels.

THE CONTACT AREA OF WHEEL

The most probable explanation of this may be that as the contact area increases more work is required from each individual kernel of grit and it the sooner becomes dulled; this requires that the bond must be more friable both to allow it to escape easily and to minimize the pressure required to make the wheel cut as the cutting area becomes greater. Following on this reasoning we are able to choose a list of wheels that would be suitable for almost all purposes, and which would be as follows if of Norton grade:

For plain cylindrical grinding, J K L M.

For grinding plane surfaces, H I J K.

For internal grinding, F H I J.

This collection of wheels would be suitable for almost any type of grinding machine, though when the wheels are exceptionally narrow a grade or one-half grade higher might be possible; it would, of course, be a matter for a little trial and experiment. The wheels for external cylindrical work may preferably be combination wheels, but for plane surfaces and internal work they are better made of single grit, about 36 or 46. The great contact area of wheel in these two classes of work is liable to generate much heat so that an open and porous wheel is preferable.

As the wheel is a disk built up from a numerous assortment of minute cutting tools which are held in position by a more or less friable bond, in using it we must bring it to bear on the work with a pressure that shall not be so great as to tear these minute tools from their setting until their cutting efficiency is exhausted, for if we do so we are wasting the wheel. To gage the exact amount of the pressure required is a matter of judgment and experience, though where automatic feeds are provided on a machine the right amount of pressure or feed is soon determined. It will also be readily understood that a regular automatic feed is more reliable for the purpose than a possibly erratic hand one. The automatic feed may be set to give a certain depth of cut at each pass of the wheel, and its amount of wear noted; if this wear be found excessive the depth of cut may be reduced. It must not be here forgotten that work speed also enters into this consideration and that a high work speed will tend to wear the wheel excessively; inversely a reduced work speed will reduce the amount of wear. Having those points in mind the right combination of depth of cut and work speed is soon arrived at, and an approximate judgment attained for the future.

GRINDING ALLOWANCES

The amount of stock left for removal by the grinding wheel and the method of preparing the work have both much bearing on the economic use of grinding wheels; heavy and unnoticed losses often occur through want of a few precautionary measures.

In powerful machines which will remove stock rapidly, the grinding allowance may be anything from $^1/_{32}$ to $^1/_{64}$ inch. This broad limit allows of expedition in the preparation of work in the way of coarse feeds, nor does it necessitate the same skill in preparation as would a more refined limit.

There are many cases of an especial character when the grinding allowance stated may be exceeded to advantage so long as discretion is used. Straight shafts may often be ground direct from the black bar of raw material $^1/_{16}$ inch above finished size, or when shafts of this character must have large reduction on the ends, they can be roughly reduced in the turret lathe while in their black state and finished outright more economically in the grinding machine. Very hard qualities of steels or chilled rolls are other cases where it is often more economical to use the grinding machine without any previous machining process, and though there may be sometimes an alarming waste of abrasive material its cost is as nothing compared with other savings that are made.

Grinding allowances for hardened work are usually larger than for soft work, to allow for possible distortion. It is sufficient to say that the allowances on case-hardened or carbonized work should not be too excessive; otherwise the hardened surface may be ground away. As far as the actual grinding of hardened work goes, it is indispensable that the whole portion of a piece that is to be ground should be roughed over previous to the final finishing; if it is at all possible to allow some little time to elapse between the two operations so much the better, more especially if it has bent in hardening and been afterward straightened; this will allow of the development of any strain that may be present.

WHEELS IN USE, A GUIDE TO THE SELECTION OF NEW WHEELS

It has been pointed out in this chapter, that, as the conditions governing the uses of grinding wheels vary, so must the grain and grade. However, we can learn much from what different shops are using in the way of wheels for specific jobs and such information should be of considerable assistance when the selection of a wheel for some similar class of work is under consideration.

Along this line, the Norton Company publishes in *Grits and Grinds* a great many useful items in reference to their wheels in service, as gathered from the people who are actually using them. These brief reports show just what grain and grade are being successfully used for, a specified operation, give the diameter and width of the wheel and in many cases the name of the machine on which the work is accomplished. A number of these items which should be of general interest and value, are given below:

THE WORK AND THE WHEEL

Cylindrical grinding cast iron; 14 by 5-inch alundum wheel, "30-J" silicate.

Cast-iron valves, 3 to 6 inches diameter, 24 inches long; 14 by 3/4 by 5-inch alundum wheel, "24 Combination, grade K" (wet grinding).

Cast-iron drill press plates, grinding flat side; 8 by 1½ by 2-inch alundum wheel, "50–I" (Brown & Sharpe grinder).

Gray iron castings, finishing, off-hand grinding; 14 by 1½ by 1¼ alundum wheel, "60–O." Castings left rough by a coarse wheel and No. 60 used for polishing.

Malleable and steel castings, roughing out; 16 by 4½ by 7, 2-inch rim "20–Q" cylinder wheel used in a chuck on the spindle of a disk grinder.

Malleable iron implement castings, weighing 2 to 20 lbs.; removing small fins; 18 by 1½-inch alundum wheel, "30–R."

Cast-iron soil fittings; 20 by 2-inch wheel, "24–P."

Chilled car wheels, double flanged; 12 inches up to 18 by 2-inch wheels, "20–Q."

Chilled iron blocks, 6 by 12 inches surface ground on automatic machine; 12 by 1½ by 1¼-inch wheel, "30–N."

Chilled iron brake shoes; 18 by 3 by 2-inch alundum wheel, "20–Q."

Drop forged flanges, grinding fins; 16 by 2-inch alundum wheel, "24–R."

Forgings for surgical instruments; 24 by 2-inch wheel, "36–P."

Rough steel castings, ground on surfacing machine, also off hand on regular grinder; 16 by 2¼-inch alundum wheel, "16–S" vitrified.

Drop forgings for wrenches, grinding fins; 14 by 1-inch alundum wheel, "30–Q."

Soft steel carriage axles; 18 by 2½-inch alundum wheel, "24–Q."

Files, grinding edges and tangs; 12 by ¾-inch wheel, "46–Q."

Files, grinding on Pratt & Whitney surface grinder; 12 by 4½-inch cup wheel with 1⅜-inch rim; alundum wheel, "30–H" silicate.

Cold metal saws; 8 by ½-inch and 8 by ⅝-inch wheels, "50–Q."

The wheel is mounted on a swinging arm and passed back and forth across and above the saw.

Steel ball races; 2½ by ¼-inch alundum wheel, No. 60, grade 4 elastic. An internal operation on the Rivett grinder.

Sheet steel scraper plates, grinding edges; 18 by 2-inch alundum wheel, "30–Q."

Cams, ⅞ inch hardened steel, 0.025 inch to be removed; 11 by 1¼ by 5-inch alundum wheels, "46–M" and "46–N," both satisfactory, "N" being the better (Landis grinder).

Disks, 110 to 120 point carbon steel, 12 to 18 inches diameter; an 18 by 3-inch alundum wheel, "36–U," ground over 110,000 of these on the edge.

Locomotive guides; 12 by 4 by 7⅛-inch wheel, "30–L" silicate.

Structural steel, removing burrs left by presses and shears; 36 by 4 by 21-inch alundum wheel, "16–R" silicate.

Sewing machine spindles, cold-rolled steel; 12 by ½ by 5-inch alundum wheel, "60–N."

Small drills; alundum wheel, "60–O."

Hardened and high-speed steel, ground on Pratt & Whitney surface grinder; "30–H" vitrified wheel.

Cutting off on the Slack machine; "60–3" elastic wheel.

High-speed steel tools on wet grinder; "24–P" silicate wheel.

General tools on Diamond wet grinder; 24 by 3½ by 10-inch silicate wheel, "20–P."

Brass castings; "30–O" silicate wheel. Also "46–O" vitrified.

Bronze bushings; "60–M" silicate wheel.

Brass and copper; 10 by 1¼-inch alundum wheel, "36–P" vitrified.

Aluminum, brass and bronze, on Pratt & Whitney surface grinder; elastic wheels, "30– grade 1½."

Aluminum gas engine cases; 18 by 2-inch alundum wheel, "36–4" elastic.

WHEELS FOR GRINDING CRANKSHAFTS

The Norton Grinding Company recommends for use on its plain grinders on crankshaft work the following wheels: 24 combination, grade N vitrified, for roughing, and 24 combination, grade M vitrified, for finishing.

For 14-inch Norton plain machines for crankshaft grinding, the wheels should be ordered with 12-inch holes unless the face of the wheel is less than 2 inches wide, in which case the order should invariably specify 5-inch hole. The thickness or width of the face of the wheel depends somewhat upon conditions.

The finishing wheel in all cases should be ordered $^1/_{32}$-inch wider face than the length of the pin or bearing to be ground. For example, if the pin or beraing is 2½ inches in length between shoulders the face of the finishing wheel should be $2^{17}/_{32}$ inches.

When the crankshafts are ground from the drop forgings without turning the shoulders of pins or bearings in the lathe, the grade N wheel should be used with the face $^1/_{32}$ inch wider than the length of the pin between shoulders. If, however, it is necessary to turn the shoulders of the pins and bearings in the lathe, a roughing wheel (grade N) with face ¼ inch narrower than the length of the finished pin should be used.

The reason for the extra thickness of the finishing wheel is to allow $^1/_{32}$ inch for truing off with the diamond after the wheel is mounted in its collet, in order to get the wheel to run perfectly true both on the sides and the face.

Note the following examples: Wheels for grinding crankshafts where the length of the finished pin is to be 2½ inches, the crankshaft to be ground from the drop forging without turning the shoulders of pins or bearings in the lathe—

Roughing wheel $24 \times 2^{17}/_{32}$ inches$\times$12 inches, No. 24 combination, grade N.

Finishing wheel $24 \times 2^{17}/_{32}$ inches$\times$12 inches, No. 24 combination, grade M.

Wheels for grinding crankshafts where the length of the finished pin is to be 2½ inches to be ground after having been turned in the lathe—

Roughing wheel 24×2¼ inches×12 inches, No. 24 combination, grade N.

Finishing wheel $24 \times 2^{17}/_{32}$ inches$\times$12 inches, No. 24 combination, grade M.

CHAPTER VI

MOUNTING AND DRESSING GRINDING WHEELS

One of the most important considerations in connection with the use of grinding wheels is that they shall be properly mounted, upon suitably proportioned spindles and between properly designed flanges. A wheel which is crowded upon a spindle of weak design, or which is cramped between two imperfect flanges that are either too small or take a bearing upon the wheel at the wrong point, is subjected to conditions as likely to cause an accident as is an excessive rate of speed.

The vast number of abrasive wheels in use upon the class of machines commonly known as bench and floor grinders, grinding wheel stands, emery grinders, etc., and which are so generally in service at various points about the machine shop, blacksmith shop and foundry, makes it desirable that something should be said here in reference to the best methods of mounting wheels on such apparatus.

In the first place, the machine itself should be of rigid construction, with spindle of ample proportions; the bearings should be well fitted; and kept well oiled so that the arbor will not become overheated and by expanding, break the wheel; and the machine should be securely fastened on substantial foundations not only to insure safety but in order to secure better results with the wheel.

The following sizes of spindles are recommended by the Norton Company and by some other wheelmakers, except where the grinding wheels are extra thick:

Wheel	Spindle
6-inch diameter and less	½ inch
8-inch diameter and less	⅝ inch
10-inch diameter and less	¾ inch
12-inch diameter and less	1 inch
14-inch diameter and less	1¼ inches
16-inch diameter and less	1½ inches
18- to 20-inch diameter	1¾ inches
22- to 24-inch diameter	2 inches
Larger than 24 inches	2¼ to 3 inches

The flanges should be relieved as in Fig. 41, and they should be at least one-half the diameter of the wheel and have a true bearing at the outer edge. The inner flange should never be loose but in all cases should be fixed on the spindle. Under no circumstances should the flanges be allowed to be less than one-third the diameter of the wheel. Wheels must not be allowed to run when held only by a nut in place of a flange, as the nut is liable to crawl and cause accident.

Compressible washers of pulp or rubber, slightly larger than the flanges should be used between the flanges and the wheel. These distribute the pressure evenly when the flanges are tightened, by taking up any imperfections in the wheel or flanges.

The hole in the wheel bushing should be 0.005 inch larger than standard size spindles This permits the wheel to slide on the spindle

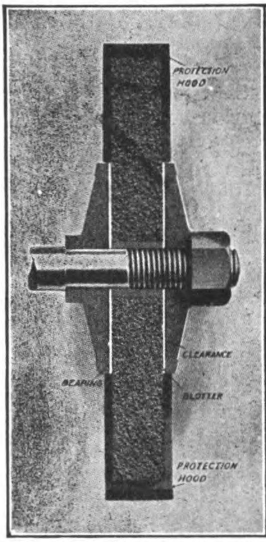


FIG. 41.—Correct mounting.

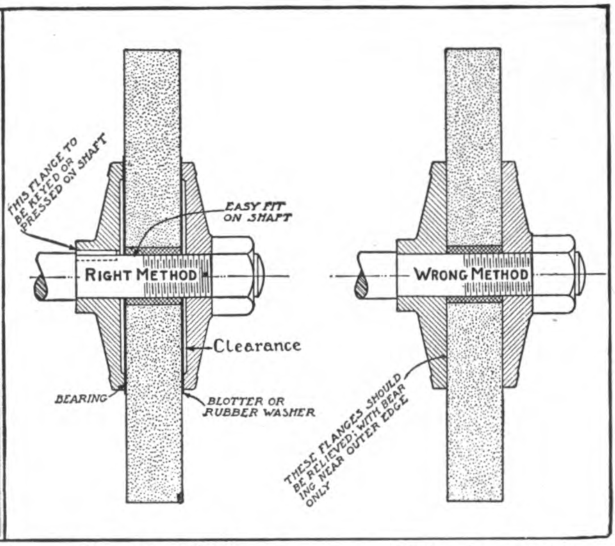


FIG. 42.—Right and wrong methods of mounting.

without cramping and insures a good fit not only on the spindle but against the inside flange, which is essential.

The flanges should be tightened only enough to hold the wheel firmly, thus avoiding unnecessary strain. The importance of this statement is emphasized by the fact that on a 1½-inch floor grinder equipped with 8-inch standard relieved flanges a man with a 2-foot wrench can easily exert a crushing pressure between the flanges and wheel of 3600 pounds.

RIGHT AND WRONG WAYS OF MOUNTING

The Norton Company in a pamphlet on "Safety as Applied to Grinding Wheels" illustrates by the sketch reproduced in Fig. 42, the right and wrong methods of mounting grinding wheels. In the view to the left relieved flanges are shown with compressible washers between the flanges and wheel, and a perfect bearing around the outer edge. The view at the right shows the improper method, straight flanges being used and no washers being applied between flanges and wheel.

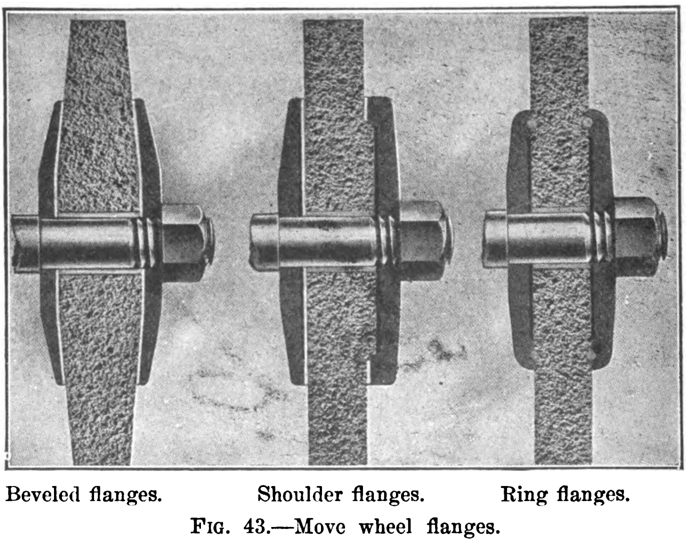
When the nut on the spindle at the right is tightened it causes the straight flanges to become slightly convex and instead of the pressure being distributed evenly over the whole bearing surface of the flanges it is concentrated near the hole, creating a dangerous condition. The inner flange should never be left loose on the spindle as in this case but should be keyed or shrunk on.

The rest should be adjusted as closely as possible to the wheel to prevent the work from catching between wheel and rest.

Great care should be taken to keep the wheels perfectly true and in balance not only to avoid accidents, but also to obtain the best results both as regards rapidity and accuracy of grinding.

PROTECTION FLANGES

Protection flanges of various kinds with wheels to correspond, are made by different wheel manufacturers. Three types of flanges of this



Beveled flanges. Shoulder flanges. Ring flanges.

FIG. 43.—Move wheel flanges.

nature made by the Norton Company are illustrated in Fig. 43. As therein designated, they are known respectively as beveled flanges, shoulder flanges, ring flanges.

The inside flange must be fixed or keyed on as with the regular flange, and all flanges should be relieved. The largest diameter in the set of flanges must be used on the full-size wheel, and flanges on both sides of the wheels should be of the same diameter whatever the size of the wheel may be. When used without a protection hood not over 2 inches radius of the wheel should project outside the flanges.

In fact, it is desirable that wherever possible a protection hood should be used regardless of the make or shape of the wheel, whether straight-faced or beveled, for there is always the possibility that through some accident the portion of the wheel outside the flanges may be broken and the pieces if not caught with a hood cause serious injury.

GRINDING WHEEL SPEEDS

At this point it may be well to refer to the matter of speeds for grinding wheels. Cup and cylinder wheels by cutting on their ends, maintain a constant peripheral velocity irrespective of wear in service. But with disk wheels the wear on the periphery reduces the wheel diameter and as it is desirable that a constant peripheral speed should be maintained, as nearly as possible the speed of the wheel spindle should be increased to compensate for the diminished wheel diameter.

Complaints are sometimes made that wheels appear softer as they wear toward the center. This is caused by the wheel becoming smaller in diameter, and with the same spindle speed the periphery speed is reduced, thus causing the wheel to wear away faster and appear softer, though in reality such is not the case.

The increase of the speed as the wheel wears away can be accomplished by different methods, i.e., variable speed countershafts, cone pulleys on the spindle of the grinder or by transferring the wheels from the first grinder to smaller and faster machines as the wheels wear down. This last system has decided advantages, and is recommended where there is sufficient grinding to warrant the use of more than one machine. These grinders should then have but one large pulley on the machine, which removes all the possibility of starting up the new wheel, when full diameter at the highest speed. When the single pulley system is not employed, great care should always be taken to start up the new wheel on the slow speed.

If on some particular work the wheel does not operate satisfactorily it can often be made to do so by changing the speed. If it fills or glazes[1] a slower speed will sometimes give better results, while if the kernels are being loosened by the work, a slight increase in speed (if not already running at the limit surface speed prescribed for that par-

[1] Glazing and loading of wheels are taken up in detail on page 326.

ticular size wheel) will usually prolong the life of the wheel, and improve its cutting qualities.

Speed tables and rules for obtaining surface speeds for wheels will be found at the end of this chapter.

Vibration due to frail spindles or machines that are not rigid, is wasteful both of wheel and power. The heavier the machine the softer the wheel can be. In order to use wheels on frail machines they must be made harder. Harder wheels require more power to produce the same work and consequently more pressure against the wheel by the operator.

METHOD OF MOUNTING A WHEEL ON A CYLINDRICAL GRINDER

A section through the wheel spindle and wheel of a Landis plain cylindrical grinder is illustrated in Fig. 44, showing the form of wheel

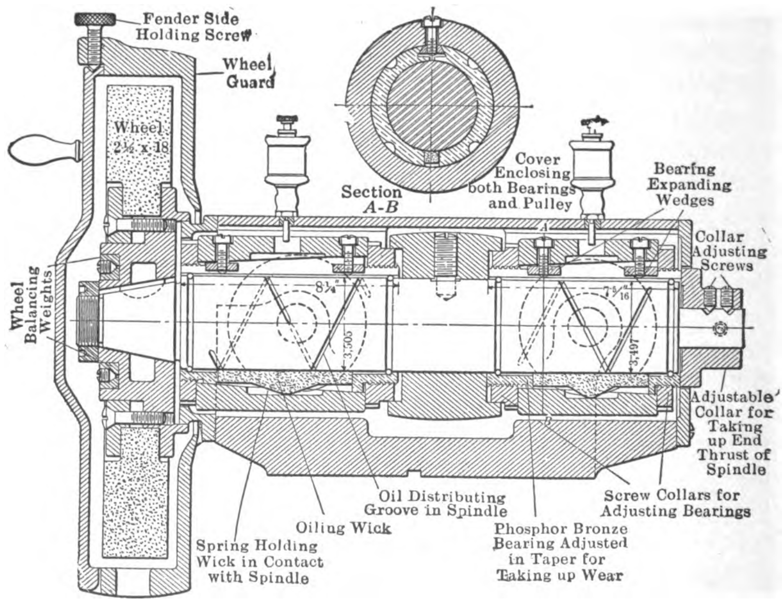


FIG. 44.—Section through Landis plain grinder—wheel, spindle and bearings.

mount employed and also the arrangement of the balancing weights with which this grinder is equipped.

There are two of these weights or blocks which are carried in a channel which runs all the way around in the face of the wheel center. The blocks are made of cast iron, are split at the bottom and have a pointed screw running in from the top which expands the blocks and holds them securely in any position.

When a wheel is brought into service and found to run unbalanced after being trued, it is taken from the machine with the center to which it is clamped, an arbor is inserted in the center hole and it is then placed on the balancing ways, the balance blocks removed and the heavy side located. The blocks are then placed in the groove together at the top (the lightest side) and adjusted so that the wheel will stand in any position.

A SURFACE GRINDER WHEEL MOUNT

The Pratt & Whitney vertical surface grinder spindle carries a wheel mount shown in section in Fig. 45. The cylinder wheel in this

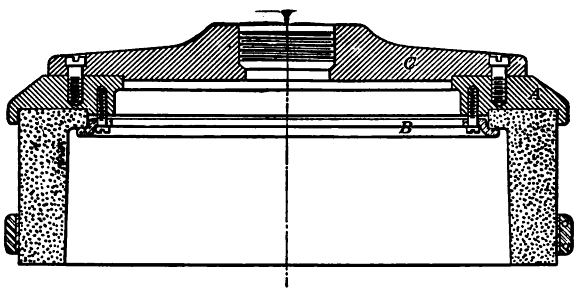


FIG. 45.—Section through wheel dowel used on the Pratt & Whitney vertical surface grinder.

case is secured in its seat by shellac and by a narrow brass clamping ring. The instructions issued by the company for mounting wheels are as follows:

Remove the wheel mount *A* from the face-plate *C* by removing the screws. Do not remove the face-plate from the spindle. Remove the ring *B*, and heat the holder *A* until the shellac runs. Remove the old wheel, and also all old shellac, using a scraper if necessary.

See that the new wheel fits freely in the groove. Put new flake shellac into the groove, and heat the ring slowly until the shellac is melted, taking care not to overheat the shellac. Warm the wheel to a comfortable handling heat, after which press it into the groove, and let it lie with a weight upon it until the ring and wheel have cooled sufficiently to let the shellac get a good hold on the wheel. Remove the wheel and ring from the flame and let them cool off together. Do not cool with water. When cooled put the brass ring *B* in place and tighten the screws. By putting pieces of leather between the ring *B* and the wheel, there is no danger of cracking the wheel when tightening the ring. In replacing the mount on the face-plate *C* be sure that both face-plate and mount are clean and free from dirt. The inside of the wheel should be covered with beeswax. Most of the makers are now treating the wheels in this manner. If omitted, it should be supplied by the user, as it is a most important factor in guiding the inside stream of water. Be sure that the wheel band is securely fastened on the wheel before starting.

DRESSING GRINDING WHEELS[1]

The difference between glazing and loading of a grinding wheel is not always clearly understood.

A loaded wheel is one whose face has particles of the metal being ground adhering to it—one in which the openings or pores of the wheel face have been filled up with metal, leaving no room for clearance. It is not necessary that all of the pores or openings between the cutting particles on the face of a wheel be filled up or loaded to prevent the wheel from cutting. The presence of a number of these pieces of metal on the face of a wheel prevents the wheel from cutting into the work and the loaded places will, of course, create heat.

A GLAZED WHEEL AND ITS EFFECTS IN GRINDING

A glazed wheel is one whose cutting particles have become dull or worn down even with the bond, the bond being so hard that it does not wear away fast enough to allow spaces between the cutting particles, or the cutting particles to escape when dulled. In a glazed wheel, the cutting particles and the bond at the extreme surface of the wheel are of the same radius.

It will be noted that in many places the space between the cutting particles is filled with bond and the corresponding spaces in the wheel on the left are open and will give room for clearance. Continued work with a wheel that glazes increases the smoothness of the wheel face and decreases the cutting.

A wheel will not load unless the bond is too hard or it is run at a speed very much too slow. The factors that cause loading are, therefore, hard bond and slow speed. Loading may indicate that the wheel is too hard or that it is running too slow, or both.

The factors that cause glazing are hard bond and high speed. Glazing may indicate that the wheel is too hard for the work, or it may be running too fast. A wheel of the right grain and grade may glaze if

[1] The Norton Company.

run too fast, or a wheel run at the right speed may glaze if it is too hard for the work. In short, a wheel loads when it is too hard or when it runs too slow, and a wheel glazes when it is too hard or runs too fast.

One remedy for loading is to increase the speed. A remedy for glazing is to decrease the speed. If the speeds are right, use a softer wheel in either case.

Loading and glazing make excessive dressing necessary, and excessive dressing wears wheels faster than grinding. Were it possible to obtain an ideal wheel for each kind of work, theoretically, dressing would not be necessary as the face of the wheel would automatically sharpen itself.

A WHEEL OUT OF TRUE SHOULD BE FREQUENTLY DRESSED

Whenever the work is of such a nature as to cause the wheel to run out of true, frequent dressing will save the wheel rather than waste it. For example, a wheel that ran out $^1/_{32}$ inch after 1 hour's grinding ran out $\frac{1}{8}$ inch after 2 hours' grinding. Had it been dressed after the first hour and again after the second hour, the amount wasted by dressing would have been $^1/_{16}$ inch, whereas after the wheel ran 2 hours it was necessary to dress off $\frac{1}{8}$ inch or twice as much.

Wheels should be kept in perfect running condition, in order to give good results and a wheel should never be used until the operator is sure the wheel runs true.

We can never grind perfect work with an imperfect wheel, and the more perfect and smooth the wheel is the more perfect and smooth will the work be, particularly when making the light finishing cuts.

DRESSERS AND TRUING WHEELS

Dressers should always be kept handy for wheels for off-hand grinding, but for truing wheels on plain, cylindrical, and universal grinding machines, cutter and reamer grinders, etc., a diamond is necessary for good results.

Dressing is not truing, but sharpening the wheel, and a dresser should never be used on wheels that grind round work on centers. When truing a wheel for round grinding, the diamond should be held in a rigid tool post on the table of the machine. We cannot do good work with a wheel that has been trued "by hand." When a dresser is used, it should be moved in a straight line across the face of the wheel, with the heel of the dresser resting firmly against the edge of the work rest.

It may be well to state here that dressing is sharpening the wheel

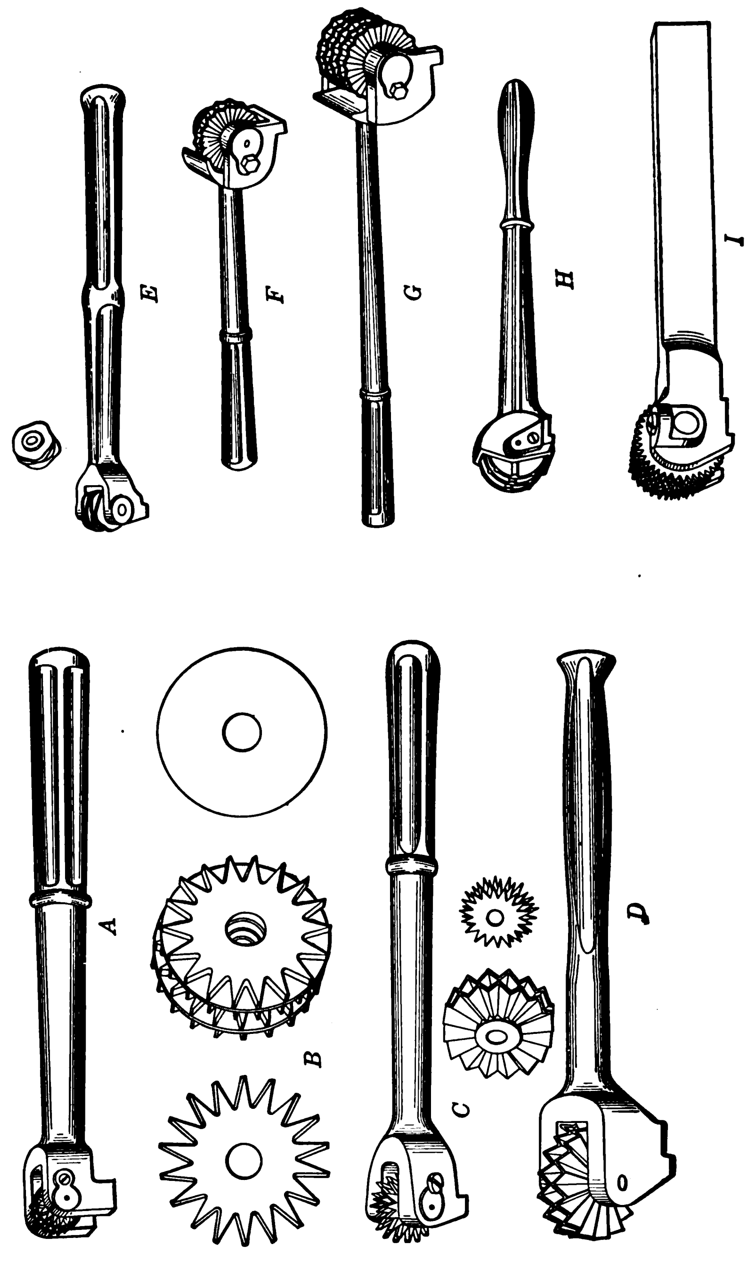


Fig. 46.—Wheel dressing tools.

and truing means to perfect the wheel—make a perfect cylinder of it, which is absolutely necessary if it is intended to grind a perfect cylinder with it.

WHEEL DRESSERS AND DIAMOND TOOLS

Several standard grinding wheel dressers are shown in Fig. 46. The dresser at *A* is of the well-known Huntington pattern, with alternating sharp-tooth cutters and plain disks as indicated at *B*. These parts are loosely mounted in the holder (which is about 12 inches long) so that they cut freely, at the same time the disks prevent excessive wear on the pointed cutters.

A dresser with a series of plain pointed-tooth cutters is shown at *C*,

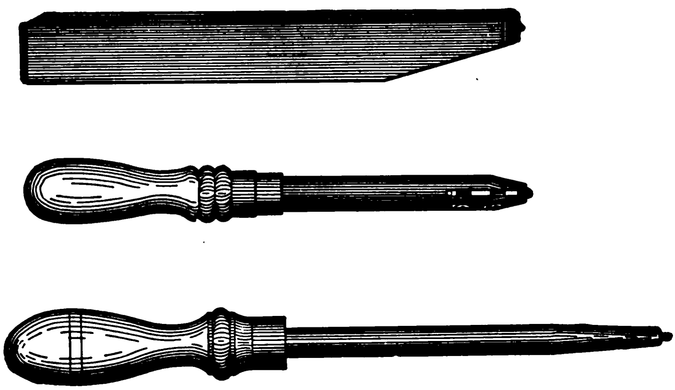


Fig. 47.—Diamonds for truing wheels.

while *D* illustrates the corrugated type of dresser. The dresser *A* is recommended for use on the smaller and finer wheels, and the two at *C* and *D*, both 14 inches long, for large and coarse grit wheels.

The dresser with twisted cutters, at *E*, is made by the Norton Company in two sizes, one for small, the other for large wheels. The Safety dressers, shown at *F* and *G*, are made by the Safety Emery Wheel Company and the larger of the two was designed for use with their plow grinding system on wheels 2½ inches or more in width. The handle holds five corrugated cutters which are 3 inches in diameter and made from tough, white iron. The handle is long and the user is fully protected by the guard from any broken pieces of the cutters and from dust from the wheel.

Another dresser with a guard (the Wrigley) is shown at *H*. The lower dresser *I* is for use in the lathe.

Some hand and lathe diamond tools which are made in various forms are shown in Fig. 47. Various methods of setting diamonds and using them are shown in the pages that follow.

USING THE WHEEL DRESSERS

In using wheel dressers set the rest firmly about level with the center of the wheel and far enough from it so that when the claws of the tool are hooked over its inner edge the points of the cutters will not quite touch the wheel when the tool is held level. Bring the cutters in contact with the wheel by firmly and gently raising the handle of the tool as the high and uneven places are cut down. In using the tool, pass or slide it slowly back and forth against the wheel, using less pressure when cutting down the corners or turning a sharp bevel. If the wheel is glazed or slightly out of true, only touch it lightly, or the fast cutting of the tool will unnecessarily waste the wheel. Hold the tool in such a manner that the cutters will revolve with the wheel and in line with its motion. If fire flies, it is a sign that the wheel is grinding away the points of the cutters, because of their running from want of oil, or an improper position of the tool.

THE USE OF DIAMONDS[1]

It is perhaps well to give the question of diamonds some little consideration here as they are sometimes a very expensive item. A diamond is a very essential part of a grinding machine's equipment, for in its absence a good and highly finished grade of work is an impossibility. The diamond tool should always be held by mechanical means when using it except in cases which are unavoidable; this may be in cases where profile shapes have to be turned on the wheel face. An attempt to turn by hand a perfectly flat face on a wheel, which is necessary for finishing, must of a necessity end in failure, putting aside the risk of grinding away the setting. As a preservation of the diamond a full stream of water should be run on it when in use and many light chips are preferable to a few heavy ones. The main thing to watch is that it does not get unduly heated, for this is disastrous to it. Where large quantities of material have to be moved from a wheel the ordinary wheel dresser may be employed to reduce the bulk of the stock and the diamond only used for finishing to shape.

SETTING THE DIAMONDS

Diamonds may be obtained ready fixed in suitable holders or the rough stones may be bought and set by any competent toolmaker. The illustrations show various methods by which they may be held securely

[1] H. Darbyshire.

and require but little explanation. At *A*, Fig. 48, is shown the method most commonly used, the diamond being either peened or brazed in position. One disadvantage of this method is that the diamond is apt to break with a chance blow of the peening chisel, or the heat from brazing will sometimes cause fractures; neither is it so easily reset when its point becomes dulled as are the other methods shown. *B* requires no explanation except that it is advisable to pack the diamond with shredded asbestos fiber to act as a cushion; this method allows of quick resetting. *C* consists of a small steel cap tapped out to fit the stock as shown. Enough shredded asbestos fiber is inserted between

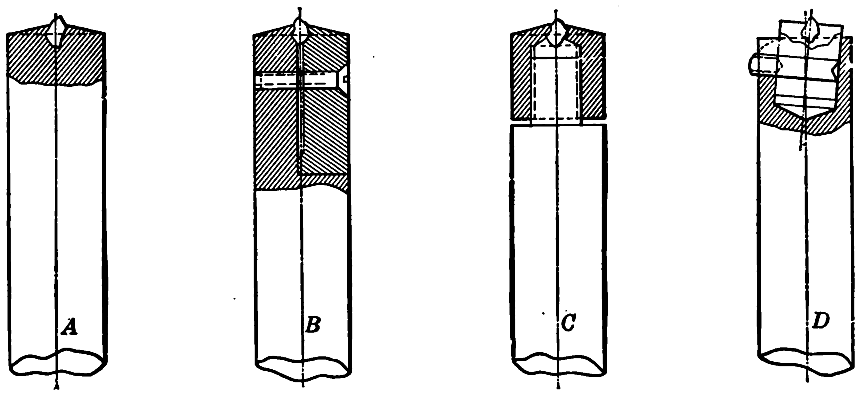


Fig. 48.—Methods of setting diamonds.

the diamond and stock to hold it firmly in position. This method also allows of quick and safe resetting. The fourth method, *D*, is, we believe, covered by patent rights and its advantage can be seen at a glance; as the diamond wears, the small peg containing it can be revolved in the stock to present a new cutting edge and be so clamped in position. Diamonds should be kept fairly sharp and as their points wear off they should be reset to present their next best one. When worn quite round they can usually be sold to the diamond dealers, who can find other markets for them. Don't let the diamond get too blunt or it will burnish the face of the wheel and so cause it to glaze and burn the work.

SPEED TABLES, RULES FOR SURFACE SPEEDS, ETC.

The table No. 12, gives the number of revolutions per minute at which grinding wheels of diameters ranging from 1 to 60 inches must be operated to secure peripheral velocities of 4000, 5000, 5500 and 6000 feet per minute.

Diameter wheel	Rev. per minute for surface speed of 4000 ft.	Rev. per minute for surface speed of 5000 ft.	Rev. per minute for surface speed of 5500 ft.	Rev. per minute for surface speed of 6000 ft.
1 in.	15,279	19,099	21,000	22,918
2 in.	7,639	9,549	10,500	11,459
3 in.	5,093	6,366	7,350	7,639
4 in.	3,820	4,775	5,250	5,730
5 in.	3,056	3,820	4,200	4,584
6 in.	2,546	3,183	3,500	3,820
7 in.	2,183	2,728	3,000	3,274
8 in.	1,910	2,387	2,600	2,865
10 in.	1,528	1,910	2,100	2,292
12 in.	1,273	1,592	1,750	1,910
14 in.	1,091	1,364	1,500	1,637
16 in.	955	1,194	1,300	1,432
18 in.	849	1,061	1,150	1,273
20 in.	764	955	1,050	1,146
22 in.	694	868	950	1,042
24 in.	637	796	875	955
26 in.	586	733	800	879
28 in.	546	683	750	819
30 in.	509	637	700	764
32 in.	477	59	650	716
34 in.	449	561	620	674
36 in.	424	531	580	637
38 in.	402	503	550	603
40 in.	382	478	525	573
42 in.	364	455	500	546
44 in.	347	434	475	521
46 in.	332	415	455	498
48 in.	318	397	440	477
50 in.	306	383	420	459
52 in.	294	369	405	441
54 in.	283	354	390	425
56 in.	273	341	375	410
58 in.	264	330	360	396
60 in.	255	319	350	383

TABLE 12.—GRINDING WHEEL SPEEDS.

The exact speed at which any specified wheel should be run depends upon several conditions, such as the type of machine, character of work and wheel, quality of finish desired and various other factors referred to at other places in this book. Wheels are ordinarily run in practice from about 4000 to 6000 feet per minute, though in some cases a speed as high as 7500 feet has been employed. An average speed recommended by most wheel makers is 5000 feet. To allow an ample margin of safety it is recommended that wheel speeds should not exceed 6000 feet per minute.

RULES FOR OBTAINING SURFACE SPEEDS OF WHEELS

The table of circumferences below will be of service in connection with the finding of surface speeds and spindle revolutions per minute.

Thus, to find the surface speed of a wheel in feet per minute:

Rule.—Multiply the circumference as obtained from the table, by the number of revolutions per minute.

Example.—A wheel 18 inches in diameter makes 1060 r.p.m. What is the surface speed, in feet, per minute?

$$4.712 \times 1060 = 5000 \text{ feet surface speed.}$$

When the surface speed and wheel diameter are given, to find the number of revolutions of the wheel spindle:

Rule.—Divide the surface speed in feet per minute by the circumference.

Example.—A wheel 24 inches in diameter is to be run at 6000 feet surface speed per minute. How many revolutions should the wheel make?

$$6000 \div 6.283 = 962, \text{ number of r.p.m. the wheel should make.}$$

Diam. of wheel in inches	Circum. of wheel in feet	Diam. of wheel in inches	Circum. of wheel in feet	Diam. of wheel in inches	Circum. of wheel in feet
1	.262	25	6.546	49	12.828
2	.524	26	6.807	50	13.090
3	.785	27	7.069	51	13.352
4	1.047	28	7.330	52	13.613
5	1.309	29	7.592	53	13.875
6	1.571	30	7.854	54	14.137
7	1.833	31	8.116	55	14.499
8	2.094	32	8.377	56	14.661
9	2.356	33	8.639	57	14.923
10	2.618	34	8.901	58	15.184
11	2.880	35	9.163	59	15.446
12	3.142	36	9.425	60	15.708
13	3.403	37	9.687	61	15.970
14	3.665	38	9.948	62	16.232
15	3.927	39	10.210	63	16.493
16	4.189	40	10.472	64	16.755
17	4.451	41	10.734	65	17.017
18	4.712	42	10.996	66	17.279
19	4.974	43	11.257	67	17.541
20	5.236	44	11.519	68	17.802
21	5.498	45	11.781	69	18.064
22	5.760	46	12.043	70	18.326
23	6.021	47	12.305	71	18.588
24	6.283	48	12.566	72	18.850

TABLE 13.—CIRCUMFERENCES OF GRINDING WHEELS.

RULES FOR FINDING SPEEDS AND DIAMETERS OF PULLEYS

The proposed speed of the grinding spindle being given, to find the proper speed of the countershaft:

Rule.—Multiply the number of revolutions per minute of the grinding spindle by the diameter of its pulley, and divide the product by the diameter of the driving pulley on the countershaft.

Example.—The driving pulley on the countershaft is 18 inches in diameter, the pulley on the grinding spindle is 10 inches in diameter and makes 1000 revolutions per minute. How many revolutions per minute does the countershaft run?

$$\frac{1000 \times 10}{18} = 555 \text{ r.p.m.}$$

The speed of the countershaft being given, to find the diameter of the pulley to drive the grinding spindle.

Rule.—Multiply the number of revolutions per minute of the grinding spindle by the diameter of its pulley, and divide the product by the number of revolutions per minute of the countershaft.

Example.—The pulley on the wheel spindle is 8½ inches in diameter and should make 1000 r.p.m. The countershaft runs at a speed of 500 r.p.m. How large should the driving pulley on the countershaft be,

$$\frac{1000 \times 8\frac{1}{2}}{500} = 17 \text{ inches, diameter of driving pulley countershaft.}$$

The proposed speed of the countershaft being given, to find the diameter of the pulley for the lineshaft:

Rule.—Multiply the number of revolutions per minute of the countershaft by the diameter of the tight and loose pulleys and divide the product by the number of revolutions per minute of the lineshaft.

Example.—A lineshaft running 150 r.p.m. is to drive a countershaft 450 r.p.m. The driven pulley on the countershaft is 9 inches in diameter. What diameter should the driving pulley on the lineshaft be?

$$\frac{9 \times 450}{150} = 27 \text{ inches, diameter of pulley on lineshaft.}$$

CHAPTER VII

SAFEGUARDS IN THE GRINDING DEPARTMENT

In the chapter on Mounting and Dressing Grinding Wheels, correct and incorrect methods of mounting wheels on spindles are illustrated, and types of flanges shown for promoting safety in operation. The reader is referred to that chapter for details of this character and for particulars as to wheel speeds, sizes of spindles recommended, and other data directly related to the subject of mounting wheels and keeping them in proper condition.

The whole subject of safeguards in grinding operations is of such importance that it has been deemed advisable to devote this special chapter to it, illustrating various devices and methods for preventing accident and guarding against injury to life and health. It has also seemed desirable to have this chapter follow immediately after the one on mounting and dressing wheels, owing to the immediate relationship between correct wheel mounting practice and safety in grinding operations. This arrangement, it is felt, may prove a feature of convenience to the reader.

In the first place it may be well to repeat a few suggestions made originally by well-known wheel manufacturers, and which, if generally adopted, ought to go a long way toward the elimination of wheel accidents.

It should be noted, in this connection, that very few wheels of standard makes are liable to break from defects due to manufacture; the improvements in wheelmaking processes and the severe tests to which the product is subjected make it seem unlikely that inherently defective wheels to any appreciable number ever find their way into service. But the abuse and misuse to which various kinds of wheels are subjected in operation gives rise to a certain degree of wonderment that accidents peculiar to grinding operations do not occur much more frequently than is actually the case.

A FEW GENERAL SUGGESTIONS

Handle all wheels with the greatest care in unpacking, storing, delivering, etc. Wheels are frequently cracked by rough usage before they are ever placed on the grinding machine. The man in charge of the storeroom should inspect each wheel before giving it out to the workman.

Wheels should be stored in a dry place.

A wheel used in wet grinding should not be left overnight partly immersed in water.

Use a rigid machine with well proportioned spindle and bearings.

Keep the bearings well oiled to avoid possibility of heating the spindle and bursting the wheel through expansion of its bushing.

Never crowd a wheel on the spindle; the bushing should be about 0.005 inch over-size, to slide nicely onto the spindle and squarely against the inside flange.

Never mount a wheel without flanges which are properly relieved and of suitable proportions. For details of flanges and methods of mounting various types of wheels see the preceding chapter.

Do not screw up the nut too tight; it should be set up only enough so that the flanges hold the wheel firmly.

Keep all rests adjusted close to the wheel so that work cannot be caught.

Avoid heavy pressure of the work on the wheel when grinding.

Keep the wheel true by dressing frequently.

If a wheel vibrates, there is something wrong. It should be trued up and the boxes should be rebabbitted after the journals are trued up.

Never hack a wheel; it is unnecessary and dangerous.

Use wheel guards wherever possible.

THE APPLICATION OF HOODS TO WHEELS

Modern machines for cylindrical and surface grinding are equipped with hoods that enclose the major portion of the wheel and which, in case of accident, would stop the broken wheel fragments and prevent injury to the operator. Such a hood is shown in Fig. 49. In fact, practically all machines doing wet grinding including tool grinders, drill grinders, knife grinders, etc., require some form of shield to control the water flying away from the surface of the wheel, and most of these machines are therefore so well hooded as to make injury from a broken wheel quite unlikely.

But most dry grinders on the other hand, such as are used for "off-hand" grinding of castings, steel strips, drop forgings, and an endless variety of other work along these lines, are still operated without hoods over the wheels and this class of machinery is only too liable to be run under conditions which sooner or later must lead to accident. For this reason it is important that so far as possible such machinery should be fitted with wheel guards, and in many cases where it has been deemed impracticable to put these on, reconsideration of the problem will reveal the fact that suitable hoods actually can be applied with no great difficulty.

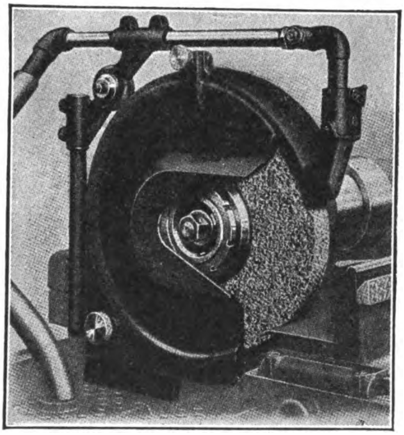


FIG. 49.—Protection hood used on Norton plain grinding machine.

There is undoubtedly a strong tendency for workmen at an unhooded wheel to grind castings and such work at the front, top, back and both sides of the wheel at some time during the course of the day, particularly if the piece in hand does not from sheer weight and

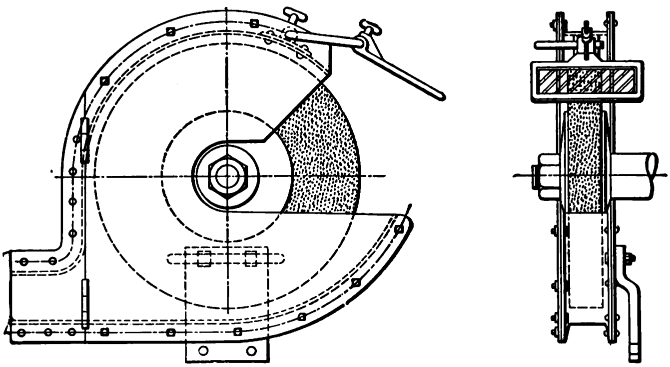


FIG. 50.—Riveted steel hood, with exhaust connection and glass shield for the protection of operator's eyes.

size make dependence upon the wheel rest obligatory. But it will be found that when the wheel is hooded the somewhat restricted area of wheel surface available will answer all legitimate purposes except in the cases of unusually large or awkward shaped castings. And these, after all, are not the kind commonly handled on grinders of this kind in the majority of shops.

A type of hood made by the Norton Company is illustrated by Fig. 11, Chapter I. It is stated that this form of hood has been in use 15 years and the manufacturers know of no operator of a grinder equipped with one of them who has been seriously injured by a broken wheel. Figure 50 represents a riveted steel hood with exhaust connection and glass shield for protecting the operator's eyes.

Another type of guard for the eyes consists of a leather spark brush which is merely a flap of leather attached to the hood and so adjusted as to interrupt sparks and dust. Goggles are also used extensively around the grinder department, and many shops keep these in the tool room for use by anyone who has work to do at the wheel.

LIMITING THE SPEEDS OF WHEELS

The subject of wheel speeds has already been discussed in Chapter VI and it is there pointed out that the peripheral speed of a wheel may

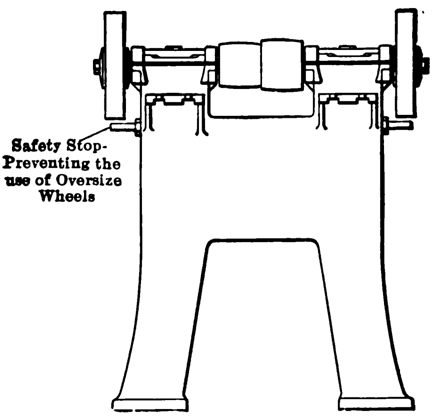


FIG. 51.—Device to prevent use of wheels above a proper size.

be maintained as it wears away in service, by means of a cone pulley on the spindle or by changing to a smaller size of machine with a faster running spindle. In the latter case where there are two or three grinders operated at different speeds there is only one pulley on the spindle and the danger of running the machine at the wrong speed is eliminated. At the same time it is essential that means be provided to prevent wheels over a fixed diameter from being mounted.

A safety stop which makes it impossible to mount an over-size wheel on the grinder spindle is shown in Fig. 51. In this case the safety stops are shown as applied to a two-speed machine, the stops being so positioned that a wheel too large for safe operation at the fastest speed of the spindle cannot possibly be mounted.

Before the wheel can be mounted the belt must be shifted to the slow speed pulley. When this is done, rods *A* and *B* slide back clear of the sides of the wheel.

OTHER SUGGESTIONS

Each machine should be marked with the number of revolutions and the size of wheel to be run upon it. In some shops a placard is hung

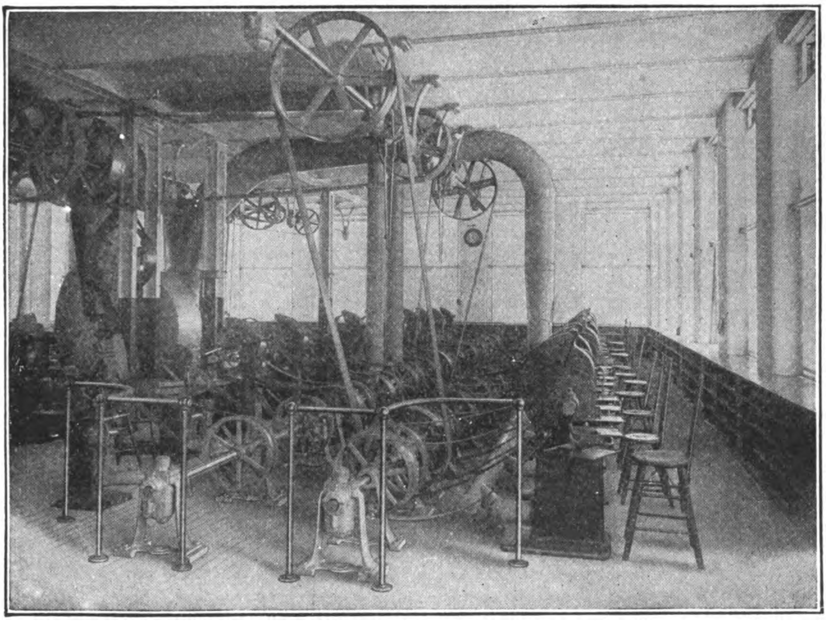


FIG. 52.—A polishing room with complete dust system.

over each machine, giving the machine number, number of spindle revolutions at which it is to be run, the diameter of the wheel in inches, and the diameter at which it is to be taken off. It also bears instructions that the foreman is to be notified when the wheel requires dressing.

All grinding machines in the department should be examined every morning by the foreman or his assistant to determine if the bearings are properly adjusted and oiled and the wheels in good condition. The man in charge should inspect each wheel carefully before it is placed on the arbor.

Competent men should be appointed to mount and true the wheels, adjust the rests and regulate the speeds.

DUST SYSTEMS

It is highly important that grinding and polishing rooms should be properly ventilated and well lighted and that the machines should be

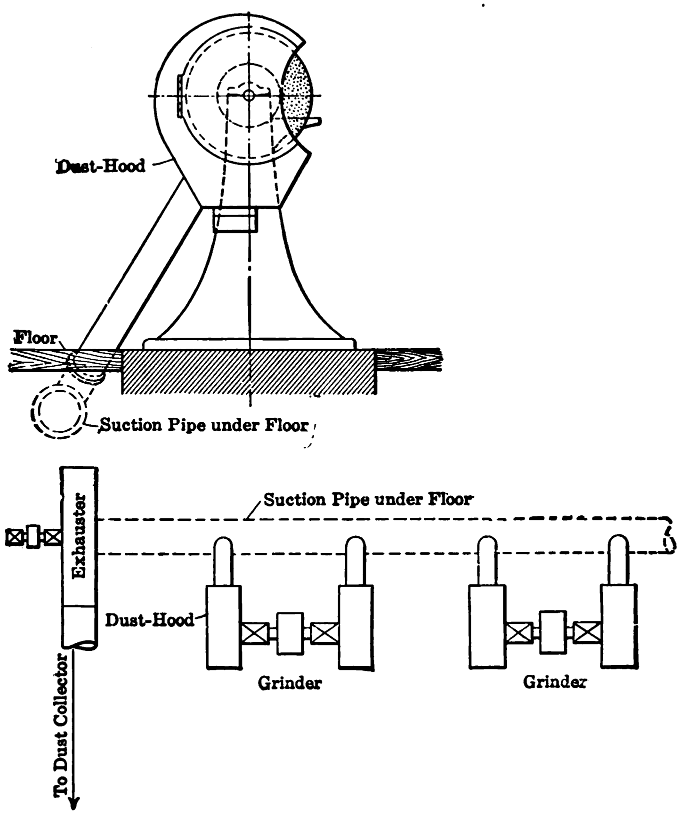


Fig. 53.—Practical dust system.

connected to an efficient dust system, not only for the preservation of the health of the workmen, but also to prevent unnecessary wear and tear on the machinery and belts.

Figure 52 illustrates a modern polishing department, with good dust system in the plant of the Brown & Sharpe Manufacturing Company, Providence, R. I.

Figure 53 shows the system in use at the Norton Company's plants. The main pipe, it will be noticed, is put in the ground.

CHAPTER VIII

TRAVERSE SPINDLE GRINDER ON SMALL WORK

The traverse spindle grinder is one of the most useful appliances to be found in the tool-room and on many classes of small work it is a valuable and almost indispensable manufacturing tool. Although primarily designed for watch factory purposes, it has taken its place to-day in other factories doing high-grade work, and will be found in the up-to-date tool-room along with other bench-lathe equipment.

TWO TRAVERSE SPINDLE ATTACHMENTS

Two types of traverse spindle grinders as made by the Pratt & Whitney Company are illustrated in Figs. 54 and 55. The first of these

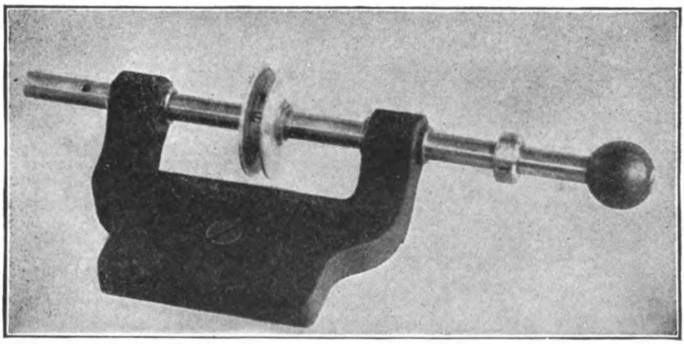


FIG. 54.—Slide rest traverse spindle grinder.

is adapted to be attached to the slide rest by a screw and nut, the latter passing into the tool post slot. It may be used for grinding or drilling holes, and general work. The slide rest screw locates the spindle at any desired point and it can be set at any angle.

The traverse motion of the spindle is controlled by a leather washer at the end or, better still, by the fingers engaging the sides of the pulley. The taper hole in the spindle has an included angle of 4 degrees, and the largest diameter of the hole is 0.2 inch.

Figure 55 shows the other type of traverse spindle which is so mounted on a grinding rest that it may be adjusted vertically, as desired, swung up entirely out of the way to permit gaging of the work, and returned to its proper position as determined by the stop. The spindle is carried in a rectangular frame which is supported at

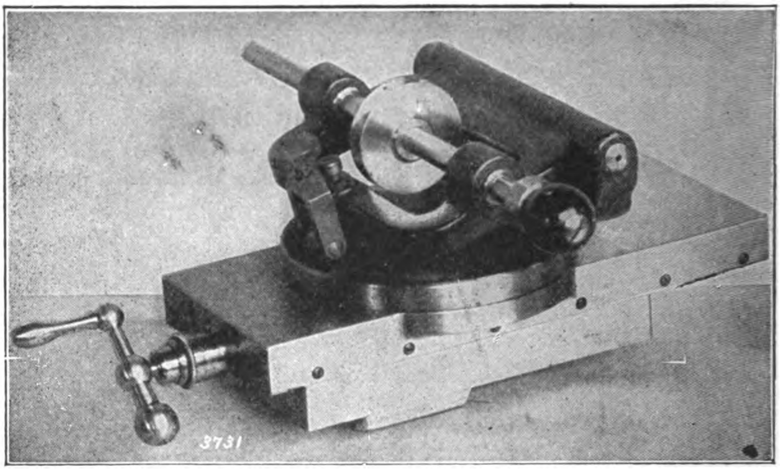


FIG. 55.—A grinding rest with traversing spindle.

three equidistant points to give it a rigid support on the top of the slide. There is one slide only, which is operated by a screw with friction micrometer. The spindle is set at any desired angle with the axis of

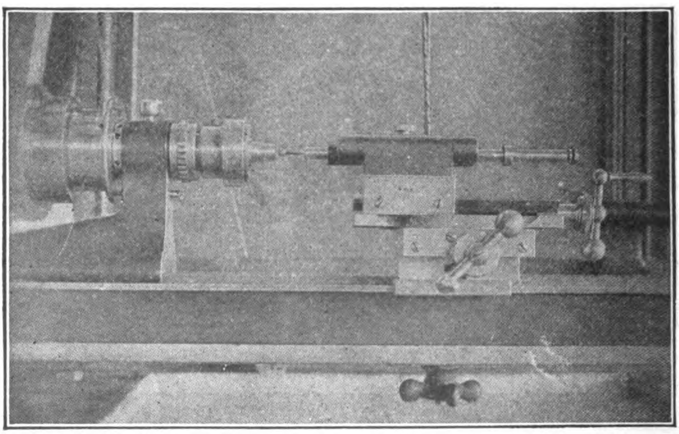


FIG. 56.—Grinding a small hole.

the work by means of the graduated circular base of the grinder head.

This attachment is particularly serviceable where precision grinding is to be done on a manufacturing basis.

The spindles in these traverse spindle grinders are ½ inch diameter, and run at speeds from 12,000 to 13,000 r.p.m. Both the bearings and the spindles are of hardened steel, ground and carefully lapped for straightness and fit.

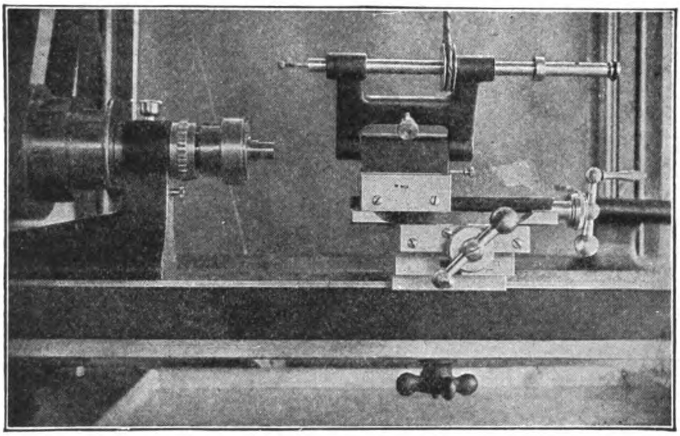


FIG. 57.—Grinding spindle swung up for gaging.

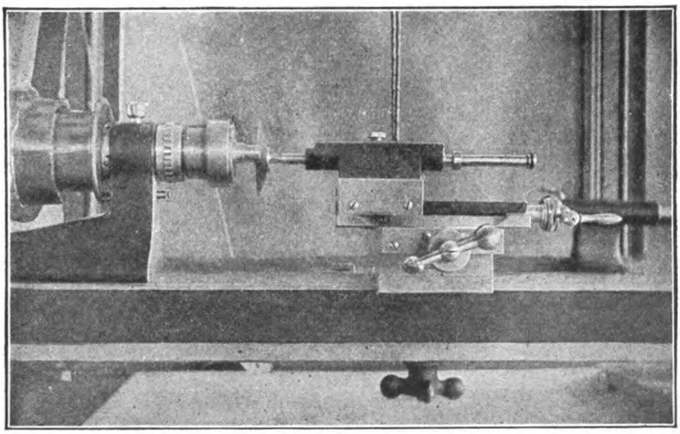


FIG. 58.—Grinding face and shoulders.

OPERATING THE TRAVERSE SPINDLE GRINDER

A few pictures of simple operations, with various traverse spindle attachments, intended merely to show the facility with which a single piece may be held and ground inside and out, may prove of interest.

Figure 56 shows the work held in a spring chuck and a small wheel in position for grinding the hole. Figure 57 shows the spindle swung back to allow the hole to be gaged.

Figure 58 shows the 3-inch disk wheel which will grind the diameter and face the shoulders of the work, or the rest may be placed on the offset shoe which is fastened to the back T-slot, as in Fig. 59, and brings the spindle at right angles to the head spindle. Although these

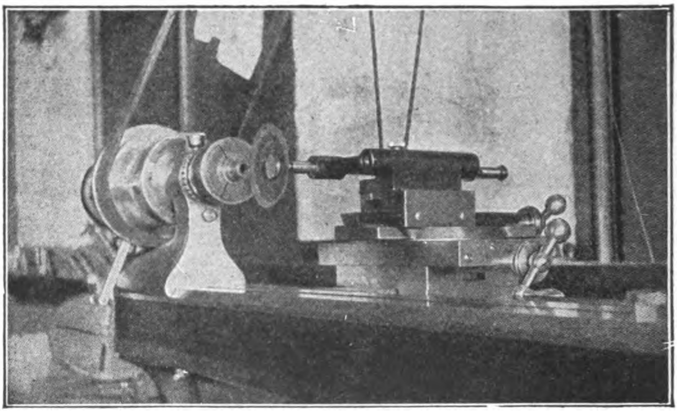


FIG. 59.—Grinding at right angles.

grinding fixtures seem light and delicate to the uninitiated, holes in 4-inch rings have been ground with them where 0.01-inch stock had to be removed, in one-half the time it took to do the same job on a universal grinding machine. The traverse spindle, when properly fitted, will run without a particle of oil, if kept clean.

Use clean tissue paper and alcohol to clean the spindle and clean out the bushings, being careful to keep oily fingers and belts from coming in contact with the spindle. After starting to grind, if the spindle shows any tendency to cloud up or stick, it may be necessary to have a little wad of paper to rub it with, keeping the spindle revolving and traversing, to reach as much of the surface as possible. Spindles which will run dry are very rare however, as are the men who understand making and using them.

CHAPTER IX

MACHINING CRANKSHAFTS AND OTHER AUTOMOBILE PARTS

In Chapter II some particulars were given relating to the use of the grinder in machining crankshafts, and the present chapter, originally contributed to the *American Machinist* by J. G. Spence, takes up the machining of multiple-throw shafts in detail.

The machining of automobile, agricultural machine and other crankshafts with more than one throw or crankpin presents an interesting problem. Since the introduction of drop-forged cranks, the art of finishing them has made wonderful progress. The machining of the crankpins is, of course, the difficult part of the problem. There are at present several methods of doing this work, these methods generally requiring special machines to make the pins. An exception is the method developed by the Norton Grinding Company, Worcester, Mass., within the last few years.

PRELIMINARY OPERATIONS

Figure 60 illustrates a typical four-throw automobile shaft of the so-called "five-bearing" type.

The forging comes from the drop-forger straightened and centered. The first operation is called "turn for cut-off," which means that both ends are turned for a short distance before the forging goes to the cut-off machine. After being cut off to the required length, the shaft is re-centered in a Hendy-Norton centering machine, which is inspected every day and kept accurate within 0.002 inch. This machine grips the shafts by the turned portion, which insures that the new centers will preserve the original line of center made by the drop-forger, thus throwing the responsibility of the pins "cleaning out" onto him.

ROUGH-GRINDING THE BEARINGS

The shaft is then taken to a 14×72-inch Norton plain grinder, where the four bearings *E F G H* are rough-ground to 0.035 or 0.040 inch oversize. Bearings *E F G* are ground by bringing forward a wheel with a face 2⅛ inches wide and using no lateral motion of the work. *H* is ground by bringing the wheel forward twice.

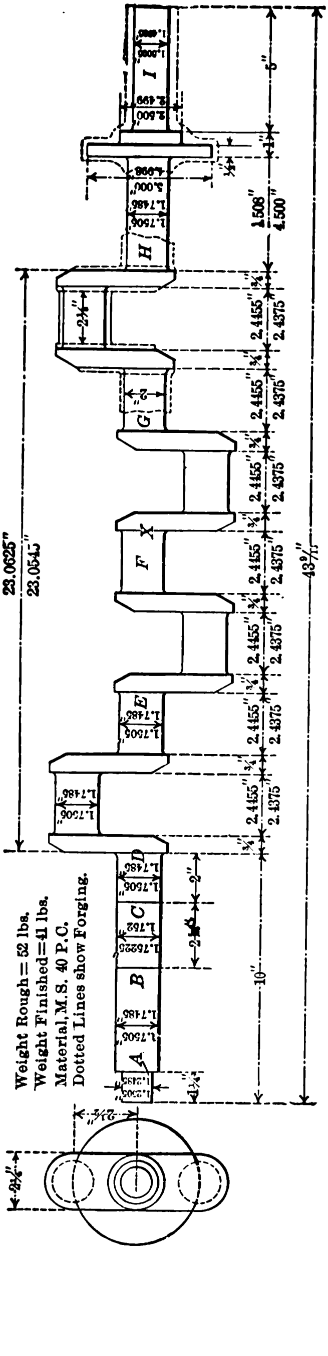


FIG. 60.—A four-throw crankshaft.

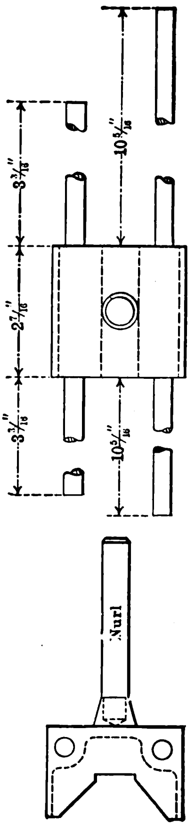


FIG. 61.—Length gage for locating bearing fillets.

MILLING WEBS AND ROUGH-TURNING FILLETS, ETC.

In the next operation, the right-hand end is rough-turned to 1.535 or 1.540 inches as far as the flange, and the left-hand end is rough-turned to 1.785 or 1.790 inches as far as the first "cheek." This is called "first turn."

Then the shaft is milled on the cheeks or webs in a vertical mill equipped with V-blocks which are designed to take any automobile

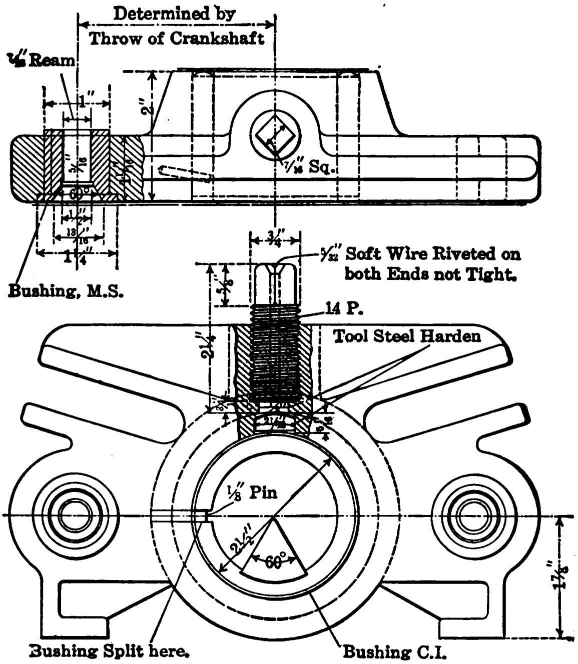


FIG. 62.—Center blocks for crankshafts.

shaft. Spacing bars (fastened to the front of the table) are made for each shaft and are adjustable to allow for sharpening the milling cutter.

After milling, the bearing fillets on *D E F G H* are rough-ground. In this rough-turning, the fillet shoulders are accurately spaced by means of the gage shown in Fig. 61. All distances are taken from the center-bearing fillet nearest the flange. It is marked *X* in Fig. 60.

Next the flange is rough-turned all over, and the shaft is ready to have the ends fitted to the center blocks, shown in Fig. 62.

The blocks are then put on a surface grinder by bringing forward a wheel 2¼ inches wide. These end fits are made 1.514 to 1.515 inches on the right-hand end and 1.764 to 1.765 inches on the left-hand end.

ROUGH-GRINDING THE CRANKPINS

The crank is now ready to have the pins rough-ground in a 14×72 Norton grinder set up for grinding crankpins. The rough-grinding is

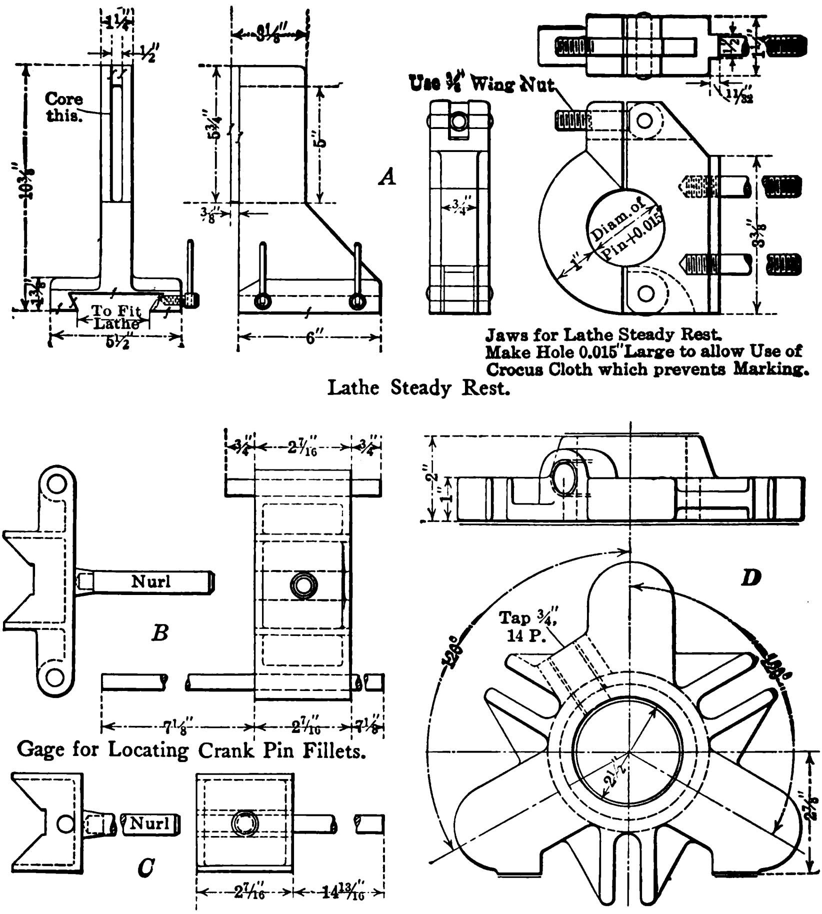


FIG. 63.—Crank grinding appliances.

done by simply bringing forward a wheel of the proper width and using no table traverse whatever. As will be seen in Fig. 60 the rough forging is ¼ inch larger in diameter than the finished pin. The pin in this particular shaft is rough-ground to 1.785 or 1.790 inches. This operation has been performed on a single pin, time and again, in 2 minutes, and occasionally in as short a time as 40 seconds. This means wheel-time only.

FILLETING OPERATION

After all four pins are rough-ground, the shaft is put into an ordinary lathe to have the pin fillets roughed out. The stock is removed by means of the common right-hand and left-hand round-nose tool of the proper radius. The pin is held steady by means of the special steady rest at *A*, Fig. 63. The fillet shoulders are accurately placed by the use of the gage *B*, all distances being relative to point *X*, Fig. 60.

The shaft is now straightened, if necessary, and returned to the grinder to have the pins finish-ground. Again, the wheel used has a face wide enough to make the pin without table traverse.

To finish the pin fillets to proper radius the lathe is again resorted to and the pin held steady as in the fillet-roughing operation. This fillet-finishing operation can be done on the grinder, if desired; in fact this is necessary when the shaft is hardened. We have made shafts both ways, although taking into consideration the extreme accuracy of radius and location of shoulders required by most engine builders, we prefer to use both grinder and lathe.

FINISHING OPERATIONS

After finishing the pin fillets, the center blocks are removed and the shoulder *A*, Fig. 60, is turned down. This is left large up to this time to allow as good a grip for the center block as possible.

The parts *A B C D E F G H I* and both of the flange diameters are then ground to the drawing limits. The fillets on these last-named parts are then finished to correct radius and the flange is squared smooth and to correct dimensions, the location being determined by the gage, *C*, Fig. 63.

After the shaft is inspected for running true and squared to length it is complete.

OTHER SHAFTS

Figure 64 shows a six-throw shaft similar in construction to the four-throw shaft of Fig. 60. This shaft is handled in exactly the same manner. In Fig. 63, *D* gives the style of center block used for the six-throw shaft. Figure 65 illustrates a shaft of the "three-bearing" type. This shaft is of 3½ per cent nickel steel. The lathe and milling times in Table 12 show the effects of this hard material, but the grinding time is not very much affected. Note the quantity of material removed in order to produce this shaft.

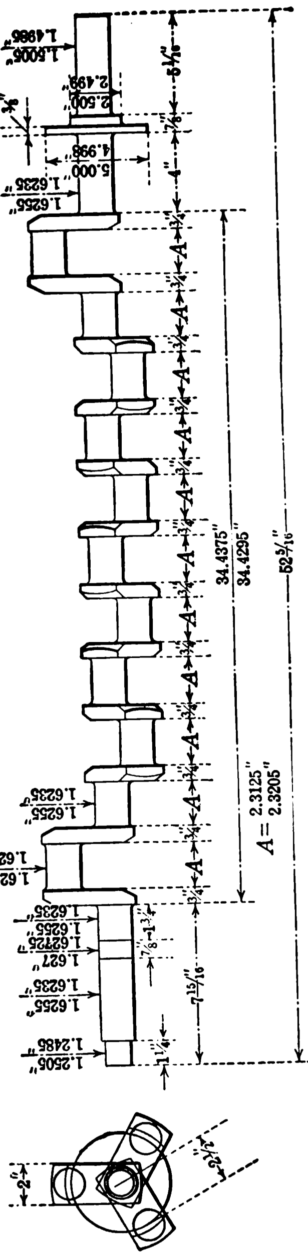


FIG. 64.—A six-throw crankshaft.

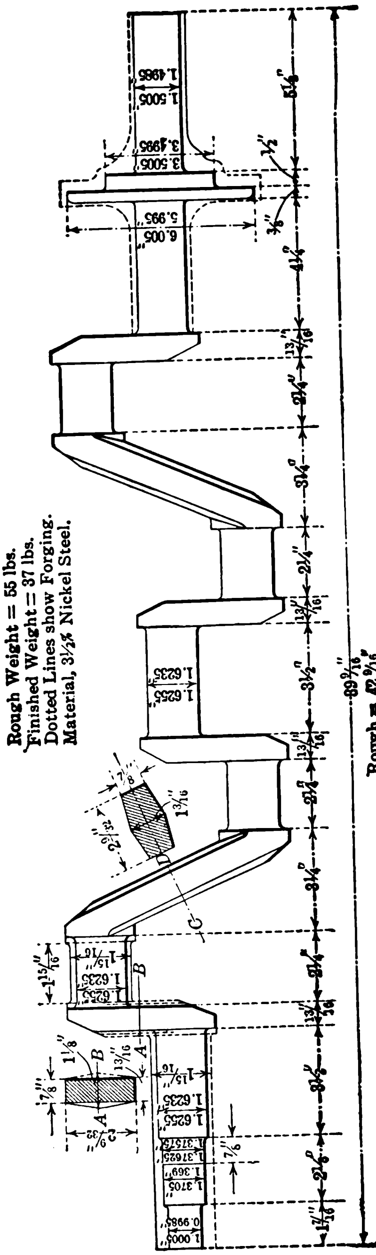


FIG. 65.—A nickel steel crankshaft.

SCHEDULE OF TIME REQUIRED TO MACHINE SHAFTS

In Table 14 of operation times, here included, there is a column marked "average time" and one marked "best observed time." The average time is taken from the time cards after the completion of a large number of shafts; the best observed time was picked up here and there, whenever conditions were favorable.

TABLE 14.—TIME REQUIRED FOR VARIOUS OPERATIONS ON CRANKSHAFTS SHOWN IN FIGS. 60, 64 AND 65.

	Fig. 60		Fig. 64	Fig. 65	
	Average time	Best observed time	Average time	Average time	Best observed time
Turn for cut-off	7	4	12	10	5
Cut-off and center	8	6	8	8	6
Rough-grind bearings	36	18	50	28	14
First-turn ends	17	10	18	17	12
Mill cheeks	47	30	90	31	22
Rough bearing fillets	65	35	70	60	30
Rough-turn flanges	36	20	40	48	30
Grind for center blocks	5	3	5	5	3
Rough-grind pins	31	12	42	36	12
Rough pin fillets	65	27	70	79	48
Straighten	20	1	20	20	1
Finish-grind pins	46	10	50	46	10
Finish pin fillets	40	15	40	40	15
Second-turn ends	7	5	12	10	7
Finish-grind bearings	51	36	70	46	30
Finish bearing fillets	36	15	40	30	12
Finish-turn flange	36	20	40	41	25
Square ends to length	7	4	12	8	4
Total time	560	271	689	563	286

All time given in minutes and includes handling.

The success of the system which has been described in this chapter and the various features of which are illustrated by the halftone and line engravings depends, like all others, on common sense. An operator who violates natural laws will produce a shaft in which the crankpins are out of line with the bearings and in which the pin fillets are not concentric with the pins themselves. But if he does not spring the shaft by too much pressure from the footstock center and learns the true duty of the back rest on his grinder, he cannot fail to produce correct shafts at small cost.

GRINDING AUTOMOBILE CYLINDERS

Many fail to distinguish between the boring of automobile and other light gas-engine cylinders and those for steam engines, overlooking the added difficulty due to the extremely thin walls in the case of the lighter engines.

With these thin walls the metal springs away from the boring tool where it is not backed up by connection with the jacket. Port holes

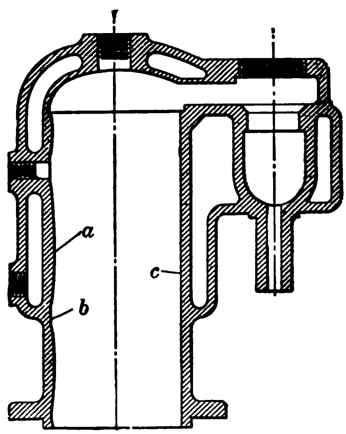


FIG. 66.—Inequalities in automobile cylinder.

also interfere with good boring and hard spots spring away from the boring tool, leaving high spots as at *a*, Fig. 66, when they spring back into place. These inequalities must be removed by the grinding wheel.

A soft spot will allow the tool to cut too freely and, if anything, cut below the correct depth (as indicated at *b*), leaving a depression in the walls, each condition being equally disadvantageous.

The speed of grinding cylinders depends on many elements beside the operator, the selection of the grinding wheel being one of the most essential. Cast iron varies to such an extent that makers of the machines carry in stock from 25 to 30 grits and grades so as to have the right wheels for the different varieties of iron in the cylinders. The best way is to try out a number of wheels and see which is best for the iron being used.

Although a soft wheel wears out faster than a hard one, it does the work in less time so that the lessened labor cost more than overbalances the cost for wheels. The soft wheel will also generally grind a truer hole than a hard wheel as it cuts down the high spots and has less tendency to follow any eccentricity in the cylinder bore.

Too much attention cannot be paid to the proper speed of the wheel as it is much more important than in any other form of machine. A low speed makes a good wheel appear to be too soft.

Cylinders 4 to 4½ inches by 9 inches long can be ground from rough boring in about 15 minutes each, removing 0.01 inch with a limit of 0.0005 inch.

TWO METHODS

While there may be said to be two methods of grinding cylinders, first by revolving the cylinder as we do with other internal grinding, and second by having the grinding wheel travel around the bore while the cylinder is held stationary, we can practically forget the first method and confine our attention entirely to the last.

With a perfectly symmetrical cylinder there is but little choice as to methods, but with the average cylinder, with its valve chambers and other side outlets and protuberances, the question of getting a running balance of sufficient accuracy to prevent "throwing" the cylinder every revolution, and consequently failing to produce a round hole, puts this method out of the question.

This leaves only the machine of the type shown in Fig. 3, in which the cylinder is bolted or clamped to an angle plate on the carriage of the grinder as in Fig. 67, and the grinding wheel travels around the inside of the cylinder, all the while revolving at its normal speed and cutting the metal as it travels. This does away with all questions of balance.

Unless the cylinder bore is connected with an exhaust system, as it always should be, both for accuracy and for the comfort of the operator, the grinding wheel must run through the combination of metal and abrasive which will collect in the bottom of the cylinder bore. This affects the accuracy of the work and tends to make the wheel glaze as well.

While water can be used direct in this type of machine it is not considered the best practice, as then the exhaust system cannot be used to advantage and the wheel must run through the collection of "mud" in the bottom of the cylinder bore.

Where it is thought best to cool the work during the grinding operation it is customary to run water through the cylinder jacket, in the case of a water-cooled engine, or on the outside of the cylinder if there is no water jacket. This does not interfere in the least with the use of the exhaust system.

Some engineers who have studied the question carefully feel that it is better not to cool the cylinder in grinding. This is because of the

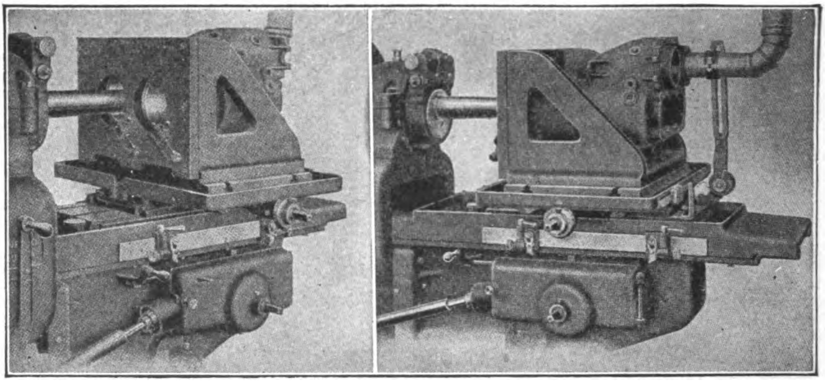


FIG. 67.—Holding automobile cylinders.

unpreventable unequal expansion under working conditions, owing to the unequal distribution of metal around the cylinder bore. The contention is that it is better to have the cylinder heated up, to the working heat if that were practicable, in order that it may be ground true while distorted to the same shape that it will assume when running.

CYLINDER GRINDING ALLOWANCES

Ideas as to the proper amount to allow for grinding varies widely, but it is coming to be understood that it need be much less than was formerly supposed necessary. This means the allowance for finish grinding where the hole is bored in a good machine or the piece rough-turned for grinding.

In internal work, such as gas-engine cylinders, there is no necessity for leaving more than ten one-thousandths of an inch (0.010) in most cases. This allows ample stock for truing up the hole and decreases the time required for grinding.

AUTOMOBILE PISTON DIAMETERS

The upper end of the piston is ground smaller than the back or lower end, on account of the heat of the explosion expanding it more at that end. Common practice seems to be to make the upper end about 0.0025 inch smaller per inch of diameter, than the cylinder. This small diameter usually extends back to the last ring on the front end of the piston. Some make the very front end even smaller than this.

The large diameter of the piston, i.e., the diameter back of the last ring, is usually about one-half the front end allowance less than the cylinder diameter or 0.00125 inch per inch of diameter.

Piston rings are usually given about 0.00025 inch side play in the grooves in the piston.

OVERSIZE STANDARDS FOR PISTONS AND RINGS

Many automobile engines are now made with cylinders cast in pairs, or *en bloc*, and an imperfection in one cylinder bore makes it necessary to throw away cylinders in which the other bores are in perfect condition, in fact, in better condition than any new cylinder which will come from the factory can be, because the old rings and pistons will not usually fit the new cylinder as well, and in any event the new cylinder is comparatively rough, and does not have such an excellent bearing and contact with the rings.

For that reason the ability to refinish a cylinder by the repair man is most desirable and means a considerable saving in time and money to the owner of a car. The advantages of being able to refinish cylinders are not confined to those which have become scored up in running, but apply equally in the case of ordinary wear, which is found in all engines after running 10,000, 20,000 or 30,000 miles.

USING OLD CYLINDERS OF ENLARGED BORE

Occasionally in refinishing a cylinder the scoring is so slight that an increase in diameter of perhaps 0.005 or 0.006 inch only is necessary to produce a perfect hole. But experience in regrinding hundreds of cylinders shows that very few will clean out with less than 0.010 or 0.012 inch of stock removed. When, however, the scoring is deep and the cylinder shows a great deal of wear 0.025 or 0.030 or even 0.040 inch has sometimes been removed in grinding before a satisfactory surface and hole accurately round and straight can be produced.

PISTON RING ALLOWANCES

Piston rings are usually made from a "pot" or sleeve, which is generally bored out on the inside, turned on the outside and cut off. They are usually finished by grinding, both on the sides and the outer surface. They are ground on the sides on a ring grinder, the grinding allowance being 0.008 to 0.012 inch, and from 35 to 45 rings being ground per hour to within a limit of 0.00025 inch. This is for 4- to 5-inch rings of the iron generally used. When the rings are cast separately and the iron is harder, fewer rings will be ground per hour. On 3- to 4-inch rings of the iron used in the turned and bored type, the output is 70 to 75 per hour.

INDIVIDUALLY CAST RINGS

Some builders of automobiles make piston rings differently from the usual way. Instead of casting the rings in a cylinder or pot, as it is

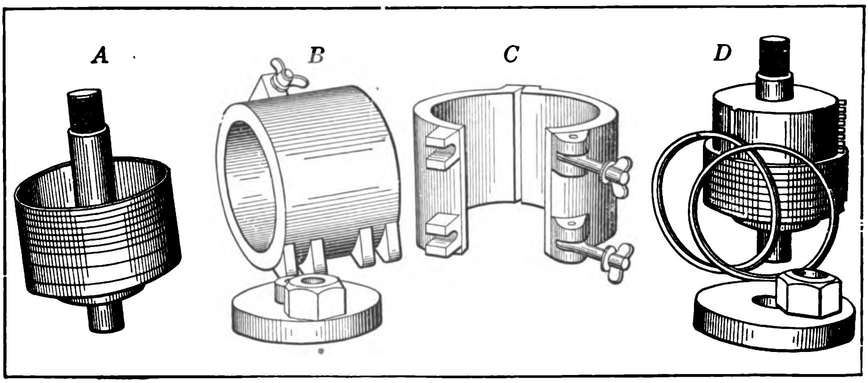


FIG. 68.—Fixtures for piston rings.

usually called, each ring is cast separately and finished entirely by grinding. The reason is that in order to have the metal soft enough to turn readily inside and out, it is difficult to secure an iron which has a satisfactory spring, and which will not take a permanent set. The individually cast rings are extremely stiff and it is impossible to set them, as, while being extremely elastic, they break.

These rings are first rough ground on the sides, slipped over the mandrel shown at *D*, Fig. 68, the heavy side of the ring going to the left and the thin side over the pin shown at the right of the mandrel. They are then rough ground on the outside, and after this the finished grinding is done on the sides.

The next operation is to cut the rings on a hand milling machine in the regular way, and after this they are placed loosely over the mandrel *A* and brought together by being clamped in the fixture shown in *B* and *C*. This is opened and put around the rings, drawing them together and also centering them on the mandrel. They are then clamped firmly in position by tightening up the other flange, and are ready to be ground in the usual way on the outside. The inside of the ring is not machined in any way, and all other operations except cutting are performed by grinding on the machines regularly used in such work.

AN ENGLISH PISTON RING GRINDING FIXTURE

A long experience on this class of work, where several machines were constantly engaged, showed that the greatest rapidity, coupled

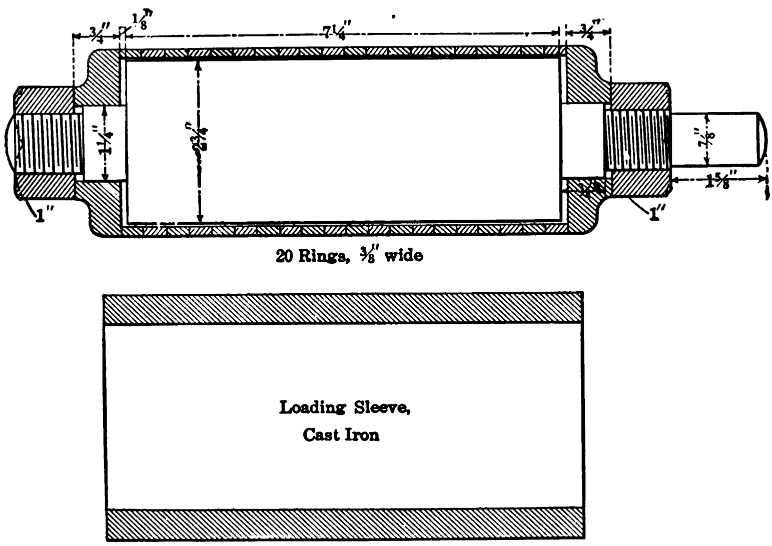


FIG. 69.—English piston-ring grinding fixture.

with accuracy, could be maintained by using a plain mandrel, nicely centered, and run on well-ground centers (a point often not receiving the attention its importance merits), threaded at either end, and having plain end plates, clamped by nuts, as shown in Fig. 69.

The cylinder, of cast iron, is bored and polished to provide a surface on which rings will slide. The mandrel end plates are turned to fit each size of cylinder. To load, the rings are sprung into the cylinder, with their splits alternately right and left, and the mandrel is inserted with one nut and plate removed, these being then replaced and tightly clamped. A convenient mandrel press having a lead-loaded nose, was used to remove the mandrel from the cylinder, the lead nose preventing the mandrel center being injured.

With this rig the first cost is extremely low, as is also maintenance. One mandrel may be used for a large range of sizes. All plates have standard holes, and the nuts are interchangeable.

Provided all centers are kept in good condition, the mandrel properly adjusted on the centers, and the usual details attended to, accurate work should be readily obtained and maintained.

MISCELLANEOUS OPERATIONS ON AUTOMOBILE PARTS

One job of especial interest shown by Mr. Darbyshire is the machining and grinding of the sleeves in the Knight silent engine as carried out by the Daimler Motor Company of Coventry, England.

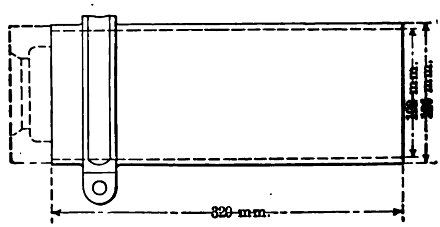


FIG. 70.—Approximate size of inner sleeve. Chucking face shown by dotted lines at end.

Of these sleeves it was formerly thought to be a necessity that they be a very close fit both in the cylinder and within each other so as to prevent the escape of any explosive gases; later practice has shown that this is not necessary, but the sleeves are still made to a fine limit to insure interchangeability. The castings are made of a special fine quality of gray iron and are cast with an extension piece on one end for convenience of chucking. They are first bored and turned on the end to suit the chucking fixture, as shown in Fig. 70, the edge of the bore being chamfered to an angle suitable for the grinding-machine centers. The operations of rough boring and turning are done simultaneously on a turret lathe fitted with a jig chuck, 1.5 mm. being left on the internal diameter and 1 mm. on the external, for removal by grinding and finish boring; the front end of the hole is also chamfered true with the back edge. The next operation consists of rough grinding the outer diameter which has to be to a fixed size so as to insure its fitting the special fixtures provided for finish boring and grinding; the rough grinding is done in a few minutes on a 10×50-inch Norton plain grinding machine fitted with revolving centers and using a 24K alundum wheel. The sleeves, after having the extension piece parted off, are now scored for lubrication and the ports and lugs milled out as shown in Fig. 71, they afterward being finish bored; for this purpose they are pushed into a stationary bushing and prevented from turning by having the lug clamped on the end of the bushing. This bushing is inclosed in a tank with a supply of water running constantly through

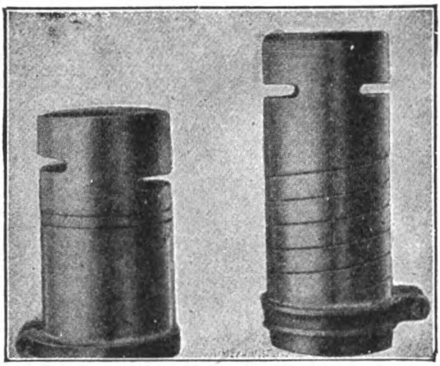


FIG. 71.—Sleeves for Knight silent engine.

it for cooling purposes, an ordinary cutter bar is used with supporting bushes at each end and two roughing tools and one finishing tool are used, 0.1 mm. to 0.2 mm. is lift in the bore for removal by grinding and the sleeves are bored at the rate of 5 per hour.

SLEEVE GRINDING OPERATIONS

For grinding the bore a special chucking device is fitted to a No. 3 Brown & Sharpe universal grinder work table. This consists of a revolving cylinder, with pulley in the middle, which runs in housings bolted to the table and is driven from the overhead work drum. The sleeves are merely pressed into this cylinder by hand, which shows that the previous rough grinding must be done very accurately. A full stream of water is kept running on the grinding wheel and the holes are ground straight and to size in some 20 minutes each. The last operation consists in grinding the external diameter, which is accomplished on a 10-inch by 50-inch Norton machine, the sleeves being hand pressed on to an ordinary arbor and the grinding being a matter of a few minutes. The point most worthy of note in this job is the cheap production when we consider the accuracy required and obtained, together with the sectional construction; the walls of the bore being very thin, necessitate the utmost care in every operation to prevent any springing.

CHUCKING PISTONS

For the grinding of automobile and gas-engine pistons there are various ways of chucking them. A method which was adopted proved very efficient and may be worth some little description. The pistons in question were for gas engines of various sizes but a similar ring would, of course, apply to those of a smaller size, as in the automobile trade; all that is necessary is that the mouth of the piston be bored to a fixed size and within reasonable limits. The piston shown in the sketch, Fig. 72, was first machined in a Potter & Johnston semi-automatic, being first held in a chuck by the blind end, the body was turned with two chips leaving 0.025 inch for removal by grinding and the mouth bored to size; it was then reversed and held in a draw-back chuck to have

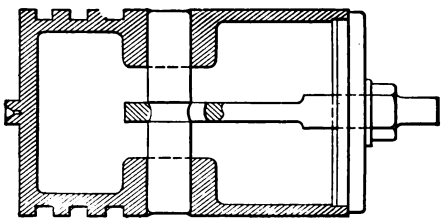


FIG. 72.—Gas engine piston, showing arrangement for chucking for grinding.

the grooves formed and was faced off to length, leaving a small tit on the end which was centered true with the body. The pistons were then drilled and reamed in a jig to receive the piston pin.

For grinding the piston an arbor was provided in the form of an eye-bolt with hardened center, the arbor was machined as shown to a close fit in the clamping washer and was threaded, the eye of the arbor getting a pull on a pin with a radial groove which was passed through the piston-pin bore. The piston shown was ground in 13 minutes on a Norton 10×50-inch grinder. The body of the piston was first ground to size and then each section between the grooves had to be reduced 0.001 inch successively to allow for expansion: It was suggested that 0.010 to 0.015 only be left for removal by grinding in future as the turning came out very accurate and if this suggestion has been acted on the grinding time would easily be reduced to about one-half.

The wheel used was a 24J+ alundum, running at a speed of 6000 feet per minute, the work speed was about 38 feet per minute. Heavy roughing cuts were taken up to the last 0.002 inch of material, the wheel was then trued up and a few finishing chips taken.

GRINDING HARDENED STEEL RINGS

Some hundreds of hardened rings were wanted which were to serve as gear-case liners for roller bearings. They were of the shape shown at *A*, Fig. 73, and had to be very accurate, and interchangeable. The outer diameter was to be a press fit in the gear case and the holes had all to be duplicated on account of the rollers. The rings were made from lengths of annealed steel tubing of a size which allowed of $^1/_{16}$ inch of material being removed from the outer diameter and the bore. These tubes were fed through the hollow spindle of a turret lathe and the rings were turned and bored, leaving 0.010 inch for grinding both internally and externally. The corners were then rounded and the rings cut off 0.010 inch over finished length, the rings then had a second

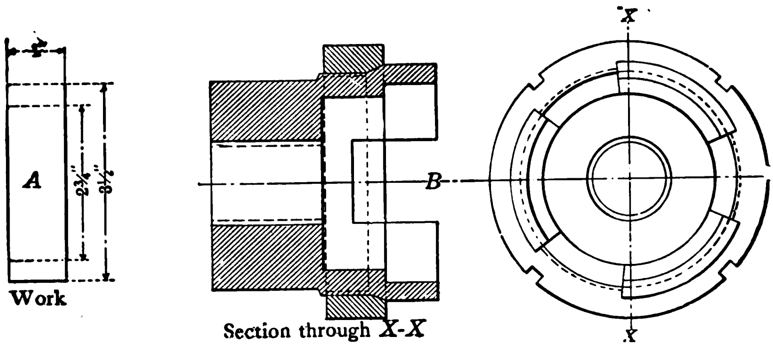


FIG. 73.—Adjustable spring chuck for grinding rings internally.

annealing and were afterward carbonized and hardened in the usual manner. It should be stated that this second annealing was found necessary owing to some scrap being made in the first batch that went through; owing to the want of annealing many of the rings had distorted so much in hardening that they would not clean up to size. The first grinding operation was to finish both ends to length, and for this purpose a Pratt & Whitney vertical-spindle machine was used. A number of the rings were first cleaned up on one end, and after these were all completed they were reversed on the chuck and the opposite end ground to length, the wheel being fed down to a dead stop; an alundum cup wheel of 30-grit grade K was used and the time occupied to grind the two ends was 35 seconds. Early experience had taught that even with the two annealings the rings were liable to go out of shape a little when the hard outer surface was ground, so that two operations of roughing and finishing were resorted to.

ROUGHING AND FINISHING OPERATION

Rough grinding internally was the next operation and for this purpose an adjustable spring chuck, shown at *B*, Fig. 73, was fitted to the universal head of a Brown & Sharpe grinder, a No. 8 Brown & Sharpe internal fixture was used with a wheel of 36-grit grade K, and the holes were rough ground to within about 0.004 inch of finished size, 7 minutes being consumed in the operation.

The rings were now strung on a parallel arbor which held ten rings and were held fast by a nut and washer while being ground. A 10×50-inch Norton machine was used carrying a 24J wheel and the ten rings were roughed down to 3.503 inches in 13 minutes including the setting. The rings were now allowed a day or two to season and were then placed on the same arbor and finished externally; any of those which had gone oval were eased off in the bore by means of a small wheel fixed on the bench grinding stand until they passed a free fit on the arbor, they were ground to a limit of 0.00025 inch + and − the time occupied being 16 minutes for the ten rings including setting. The same wheel was used as for roughing but it was nicely trued up. The last operation was finishing the bore, and for this a spring chuck was used similar to that for rough grinding but a 60-grit J wheel was employed. The holes were finish ground in 10 minutes to a limit of 0.00025 inch over size. A full stream of water was used in all grinding operations.

HOLDING GEARS FOR GRINDING

One of the many problems which have been brought out by the development of automobile manufacture, is the method of holding gears for grinding after hardening so that the hole may be ground concentric with the pitch line of the gear teeth. The problem is to hold the gear from some point or points which had a definite and fixed relation to the gear teeth when they were cut. If the outside of the gear blank were absolutely true with its axis of rotation on the gear cutter, the gear could easily be chucked from the outside by simply dividing up any inequalities as to roundness which the gear had undergone during the hardening process. Or, if the milling cutter be formed so as to cut the outer ends of the teeth at the same time it is finishing the curved tooth space, this method could be easily used.

In a similar way we can use the bottoms of the teeth perhaps more easily than in any other way, provided the finishing cutter goes clear to the bottom. But as the bottom of the tooth is merely for clearance, many gear men let the roughing or stocking cutter go deeper than the finishing cutter, so as to save the latter as much work as possible. Where this is done, it is not much safer to depend on the bottom of the teeth than on the outside, and it becomes necessary to hold gears by

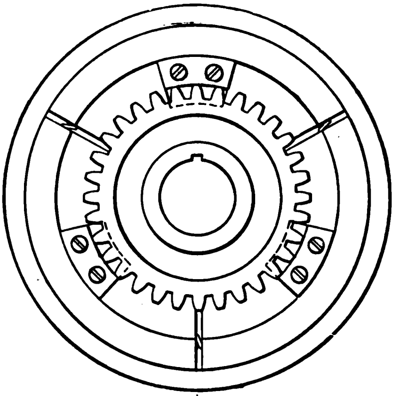


FIG. 74.—Detail for outside holding chuck.

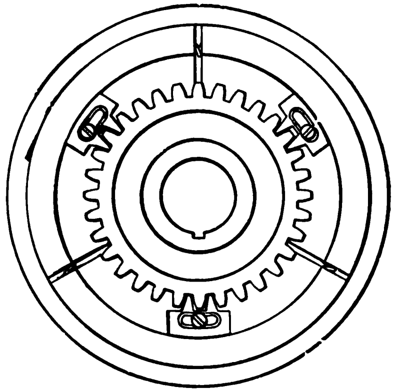


FIG. 75.—Detail of bottom holding chuck.

their curved faces, whether at the exact pitch line or not it is not so important.

Figures 74 to 77 show the three methods which have been mentioned in connection with the use of draw-in chucks, as made by the Heald

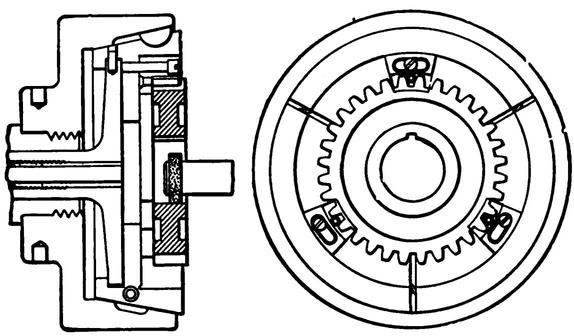


FIG. 76.—Detail of pitch line control.

Machine Co. Figure 74 requires no explanation whatever. In Fig. 75, where the gear is held by the points of the jaws reaching to the bottom of the teeth, the same general principle prevails except that the jaws are free to move in the direction of the slot, so as to accommodate gears of approximately the same diameter, although having different numbers of teeth.

Figure 76 shows a somewhat similar arrangement, the difference being that the holding portion of the jaw consists of a hardened-steel

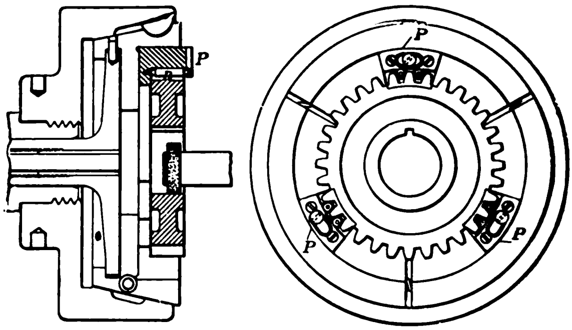


Fig. 77.—Detail of double-roll jaw.

roll, which fits in between the teeth at approximately the pitch line and holds them from this point. This is known as pitch-line control.

One advantage of the method of root control is that the chuck jaws bear directly on solid metal in a straight line with the web of the gear,

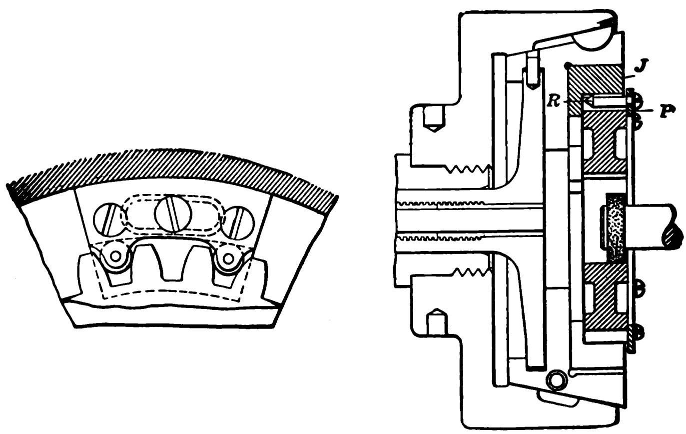


Fig. 78.—Holding by alternate teeth.

and that it is a very simple matter to maintain the accuracy of the contact point by simply truing them with a grinding wheel whenever it may become necessary.

The use of five jaws has been suggested and tried in some cases, with the idea of securing still greater accuracy, but the results obtained by using three jaws are so far ahead of the work usually secured in the average shop, that the three-jaw chuck is recommended for general use.

A NEW CHUCK WITH DOUBLE ROLLS

Working along this line, the Heald company has developed a chuck, using pitch-line control, and at the same time securing greater accuracy than heretofore when rollers were used. As will be seen from Fig. 77, each jaw carries two hardened-steel rollers having conical ends, and being held by loosely fitted conical recesses, which allow perfect freedom to the rolls *R*, and at the same time prevent them dropping out of place, unless the retaining plate *P* is removed. These rolls fit in between the teeth of the gear to be ground, adjusting themselves easily to any inequalities of the tooth surface, and seating against hardened-steel plates, which are inserted in the collet jaws when they are drawn down into place to hold the gear for grinding.

This method gives great latitude in the holding of gears by their curved faces, and in allowing for any distortion which may occur in hardening of the gears. It also allows the jaws to be maintained with great accuracy, as by removing the retaining plate *P*, and taking out the rolls, the hardened-steel plates, against which they bear, can be easily ground to remove any inaccuracy due to either wear or distortion, although the latter is hardly possible in a chuck of this description.

The latest development in holding gears by this method is shown in Fig. 78. This is simply a modification of the double-roller chuck, in which the two hardened rolls are spread so as to skip one tooth space.

This secures the double advantage of distributing the holding points more equally around the gear and of taking care of any distortion of the gear teeth which occurred in hardening. One of the most noticeable effects of this distortion is to produce a wide and a narrow space next to each other. This arrangement skips the wide or the narrow space, as the case may be, and is much more apt to hold the gear by spaces having approximately uniform width.

A still further modification of this idea is a chuck in which each of the three holding jaws carries three hardened steel rolls, placed far enough apart to fit in every third tooth space. This gives largely increased contact all around the gear, and in the case of gears which have become elliptical in hardening should give a more accurate chucking by dividing up their inaccuracy.

HOLDING BEVEL PINIONS AND GEARS

Figure 79 shows a form of chuck for holding bevel pinions by the bottom of the teeth. This has a single-pointed holding jaw, which is ground to the proper angle to hold the gear to be ground.

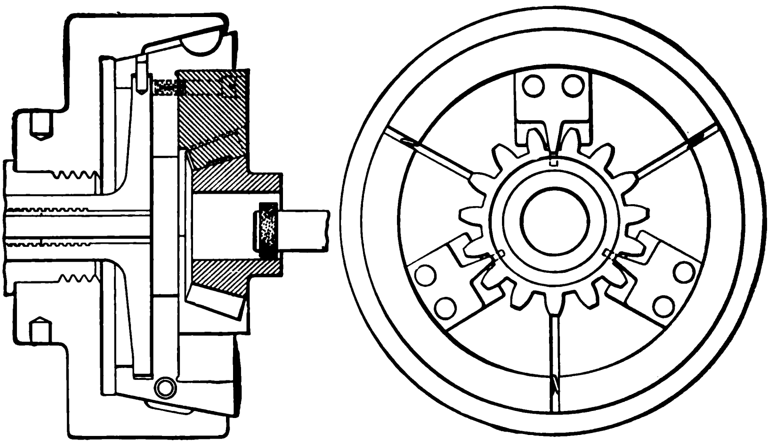


FIG. 79.—Holding small bevel gears.

The methods shown are the practice recommended by the Heald Machine Co., and should prove of value to those having internal grinding to be done.

CHAPTER X

GRINDING OPERATIONS ON TRACTOR PARTS

The illustrations that follow show something of the grinding operations on Holt Caterpillar parts. Much of this work has to do with the finishing of the bore of gears of various kinds and sizes, a number of types of which are seen in Fig. 80.

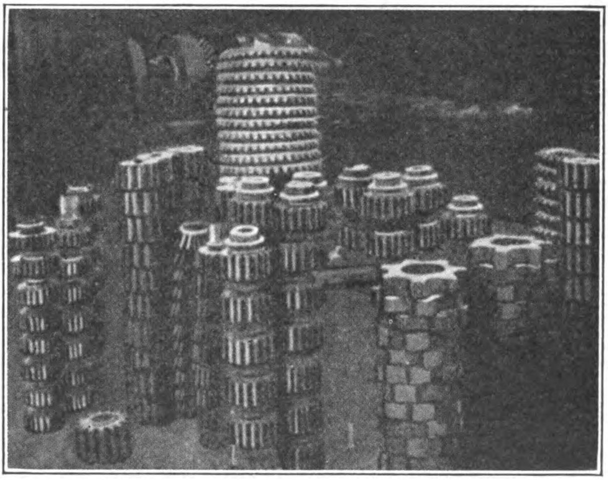


Fig. 80.—A variety of tractor gears.

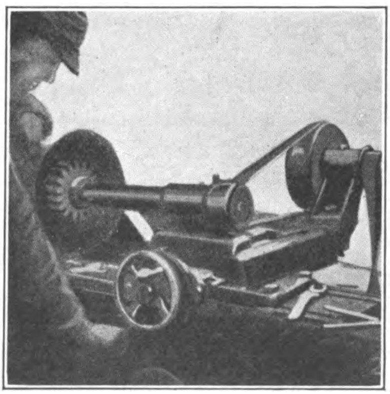


Fig. 81.—Grinding tractor gears.

The greater part of this work is handled in Heald internal grinders and in Fig. 81 one of them is shown with a spur gear undergoing finishing in the bore. This gear, Fig. 82, has a bore 3.874 inches in diameter by 2.5 inches long and the allowance permitted in the grinding of the bore is only 0.001 inch from the specified size and that must be on the plus side of the dimension.

Like so many others finished by the same method this gear is of mild steel casehardened, and the wheel used on the internal grinding machine spindle is a Norton alundum 46K or 46L. The wheel is 3 inches in diameter and is operated at a speed of 5500 revolutions per

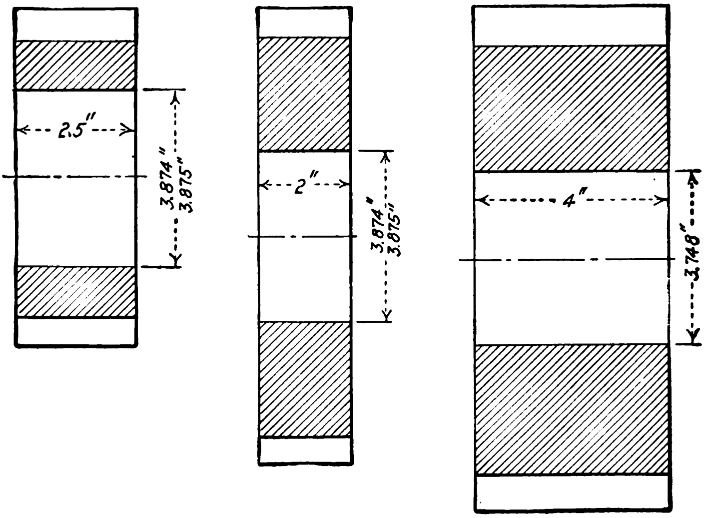


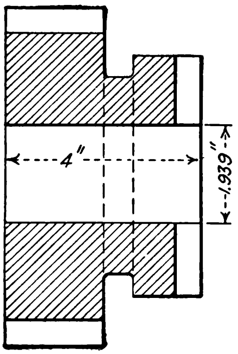
Fig. 82. Fig. 83. Fig. 84.
Dimensions of tractor gears bores.

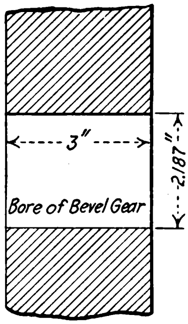
minute. The amount of material left for grinding out with the wheel ranges from 0.015 to 0.030 inch.

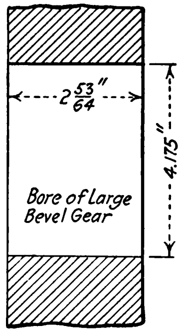
The work is rotated at 120 turns per minute and the wheel is traversed through the work at a rate equivalent to 24 inches per minute. The metal removed per pass of the wheel runs, say two or three thousandths and the rate of production is eight gears per hour ground to micrometer measurements and held within the limit of 3.874 and 3.87 inches.

Another and larger gear, Fig. 83, has a bore of practically the same diameter described but as the width is only 2 inches, better time of production is obtained, the number of gears of this size finished per hour being 10. The same grade of wheel is used as for the other gear and the same rate of feed and speed of rotation employed. The greater output on the narrow gear is precisely in proportion to its length of cut as compared with the other gear width. In another gear of 3.748 inches bore by 4 inches thickness (see Fig. 89) the rate of grinding is five per hour or half that on the gear having the 2-inch face.

A speed change gear with a clutch, Fig. 85, is handled on the same







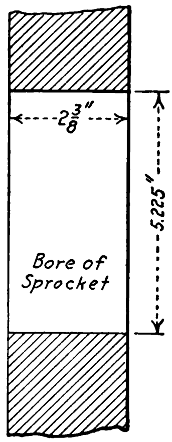


FIG. 85. FIG. 86. FIG. 87. FIG. 88.
Other tractor gears.

type of machine. This gear is of 1.938 inches bore and is ground out with a 1¾-inch wheel rotating at about 5000 feet peripheral speed per minute. The depth of the hole to be ground is 4 inches but the diameter is only half that of the last example cited and the rate of grinding is eight per hour.

There are various sizes of bevel gears to be ground out in this

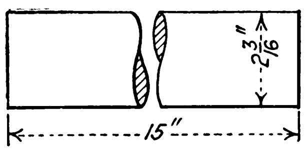


FIG. 89.—Caterpillar gudgeon.

manner. A typical example, Fig. 86, has a bore diameter of 2.187 inches and a depth of 3 inches. The wheel speed and feed, allowance for grinding, and limit of accuracy correspond to the data already given.

The large bevel gears shown stacked high in Fig. 80 are other interesting examples of internal grinding. They are 10.67 inches outside diameter and the bore, as shown in Fig. 87, is 4.175 inches in diameter by $2^{51}/_{64}$ inches long. An allowance of 0.003 inch is permissible in sizing this bore and the work is turned out at the rate of five per hour.

The counter main sprocket, Fig. 88, is a heavy steel piece ground internally on an engine lathe with carriage fitted up with an internal grinding-machine spindle; a 36K alundum wheel is used. The hole is

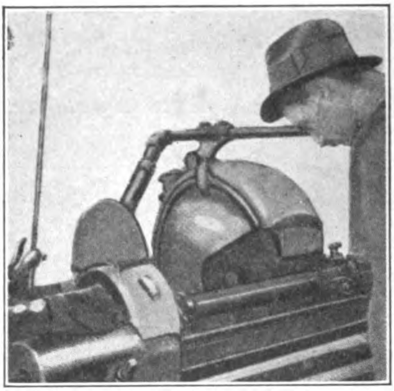


FIG. 90.—Grinding the gudgeon.

5.225 inches in diameter and the sprocket 2⅜ inches thick. Four of these sprockets are ground per hour, the amount of metal removed by the wheel ranging from 0.020 to 0.030 inch.

The gudgeon for "Caterpillar" truck wheels is made of rolled stock casehardened and is a plain, straight piece of work, Fig. 89, nearly 2 inches in diameter by $16^3/_{16}$ inches long, turned to within about 0.020

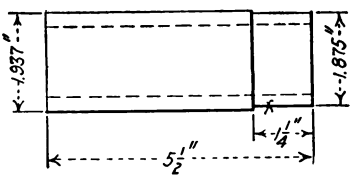


FIG. 91.—A tractor wrist pin.

inch of finished size. After casehardening it is taken to the grinding machine to be sized.

The piece is shown in Fig. 90 in the Norton 10 by 36-inch grinding machine with the operation just starting at the end. A 24-combination-L alundum wheel 20 inches in diameter by 5-inch face is used. The wheel spindle is driven at 1150 revolutions per minute. The work is rotated at 120 turns per minute corresponding to a surface speed of 60 feet.

The gudgeons are ground to the size required at the rate of 25 per hour, or in a little less than 2½ minutes each. A limit of 0.002 inch is permissible in the sizing of the gudgeon, which probably aids in keeping up the rate of production, although with the broad-faced

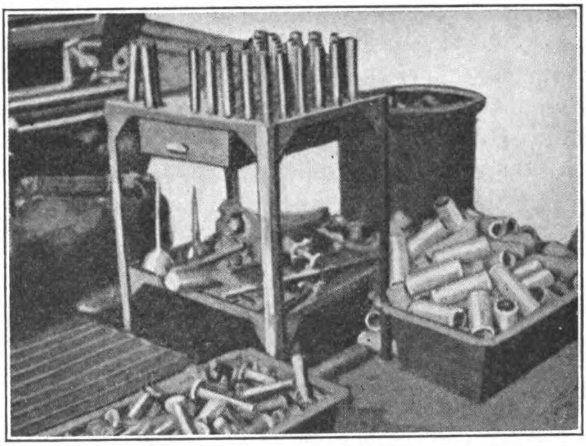


FIG. 92.—Some finished pins.

wheel there is relatively little wear and the work can be held closely to size with a minimum of effort.

A piece handled in large numbers in the grinding machine is the piston pin, or wrist pin, Fig. 91, made of seamless-steel tubing case-hardened and ground to finished size. This tubular part is of fairly

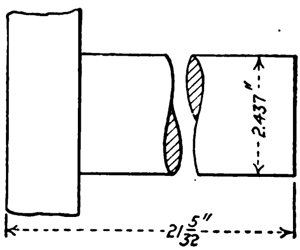


FIG. 93.—A reverse shaft.

heavy section through the walls, having over ¼ inch of metal at each side. It is turned down to within 0.012 to 0.015 inch of finished diameter, and then put into the grinding machine for finishing.

Here again a 24-combination-L alundum wheel driven at 1350 r.p.m. is employed, the wheel diameter being 18 inches, so that the surface speed is about 6250 feet per minute. The work is rotated at 120 turns per minute or at the rate of 60 feet surface speed.

The hollow piece is mounted on an arbor for grinding. It is held lightly, as only 0.005 inch is allowed from standard size. The piece has to be sized to two diameters as indicated. The larger or main size is secured by setting the stop to bring the wheel to position for sizing the body of the pin at one pass across the wheel surface. Then with the stop thrown out the wheel is fed straight in to give the smaller diameter, which is only $1\frac{1}{4}$ inches long, the wheel face in this case being $2\frac{1}{2}$ inches wide. The pins are finished at the rate of 16 per hour. A lot of them are shown in the tote pan in front of the grinding machine in Fig. 92.

The reverse shaft, Fig. 93, is made from a drop forging and finished

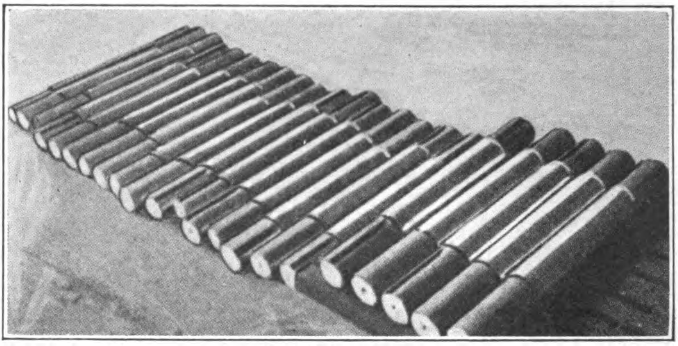


FIG. 94.—A lot of intermediate shafts.

by grinding to a limit of 0.001 inch for a length of 20 inches, the diameter being 2.437 inches. The wheel is alundum 24-combination-L, 20 inches in diameter by 5-inch face. The wheel is driven at 1200 revolutions or 6000 feet surface speed. The work is run at 100 revolutions per minute or 75 feet surface speed. The metal removed ranges from 0.030 to 0.060 inch and so two operations are made for each shaft. The lot of shafts is run through the roughing process, then the wheel is reset and the entire lot passed through the machine again for a finishing cut. The same wheel is used for both rough and finish grinding. The first grinding operation removes the metal to 0.006 to 0.010 inch of size and the work is handled through this process at the rate of 18 per hour, or say one in $3\frac{1}{2}$ minutes. In the second, or finish grinding operation 12 per hour are turned out, the time being increased to 5 minutes each, owing to the necessity for holding the work to the limit specified.

INTERMEDIATE SHAFTS

The shafts shown on the floor in Fig. 94 are part of a lot of such members made from nickel steel. As shown by the detail, Fig. 95, they have a body diameter of 2¾ inches and a total length of 23¾ inches. The ends are reduced somewhat for a distance of about 5 inches. The piece is known as an intermediate shaft and has to be ground all over.

The work is handled in a Norton 14×50-inch plain grinding machine. The wheel used is an alundum 24-combination-L, 20 inches in diameter by 5-inch face. It is driven at 1050 revolutions, 5500 feet per minute. The work is run at 100 revolutions, or 80 feet surface speed. The depth of metal removed averages 0.030 inch, and about 0.004 inch

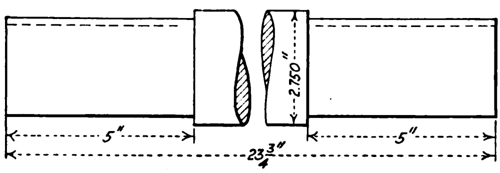


FIG. 95.—Dimension of shaft.

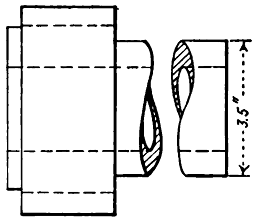


FIG. 96.—Sleeve gear details.

is taken off at each pass across the wheel. The rate of traverse of the work is about 72 inches per minute.

The time required for grinding the body and both ends complete is 15 minutes.

A gear and sleeve, Fig. 96, is ground on a Norton 10×36-inch machine, as shown in Fig. 97, with a 20×5-inch-face alundum wheel, 24-combination-L, run at the same speed as given for the shaft above, namely, 5500 feet peripheral speed per minute. The work is driven at 85 r.p.m., or for the 3¼-inch diameter approximately 80 feet surface speed.

Here, as before, the allowance for reduction by grinding is from 0.020 to 0.030 inch, and the time in grinding is about 10 minutes each.

The work, having a $2^5/_{16}$-inch hole clear through the sleeve, is mounted on an arbor for placing between the grinding-machine centers. It is held to within 0.001 inch limit of accuracy.

CHILLED-IRON CAMS

The cams for these motors are made of chilled iron with special foundry appliances that will be described later. A cam detail is reproduced in Fig. 98, which shows all of the dimensions of importance and gives an idea of the form to be finished by grinding.

These cams are handled on a Landis machine with cam-grinding attachment, the wheel used being a crystolon 46K running at 6000 feet per minute. The work is driven at 50 r.p.m., or practically 35 feet circumferential speed.

As the cams are cast in chills there is ordinarily little variation in the size of the work as it comes to the grinder. The amount generally left for removal by grinding from the casting is from 0.040 to 0.050 inch. The limit to which the ground work is held is 0.003 inch.

The wheel is applied by feeding in to the stop for depth and then

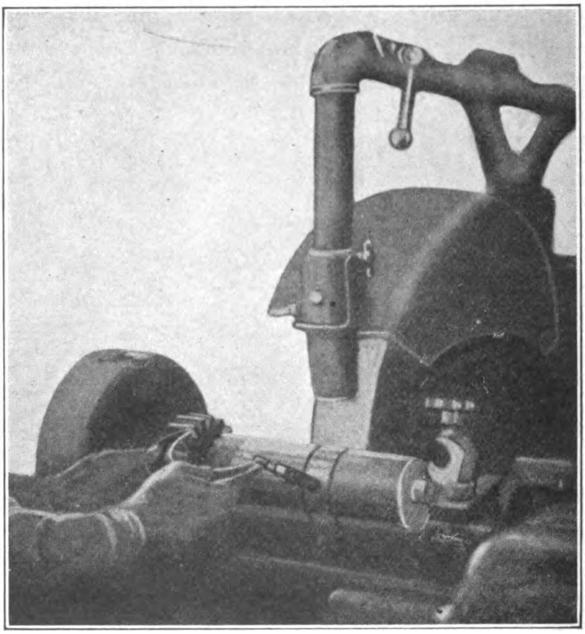


FIG. 97.—Grinding the sleeve gear.

feeding straight across the cam surface. The time required for grinding each cam is 3½ minutes only.

Another job finished on the Landis grinding-machine is a case-hardened mild-steel thrust-bearing washer (Fig. 99) 7½ inches in diameter by 0.325 inch thick, the limit of accuracy in thickness called for by the blueprint giving 0.003 inch leeway or a maximum thickness of 0.328 inch.

The washer is ground on the faces only. It is held on a magnetic chuck and a 14-inch wheel with 1¼-inch face applied. The wheel is a 36K alundum run at 6000 feet per minute. The work is driven at 150 revolutions per minute.

The total amount of stock to be ground from the face is about $^1/_{32}$ inch. The wheel removes 0.003 inch at each pass across the face and the job is completed at the rate of five washers an hour, or 12 minutes each.

A great many bushings of phosphor bronze, manganese bronze, etc., are finished in the grinding-machines department. A bushing for the small end of a connecting-rod is of manganese bronze. It is finished as in Fig. 100 to 2.812 or 2.813 inches, the limit being 0.001 inch. It has a length of $3^{11}/_{16}$ inches and is placed for grinding in a Norton 6×32-inch plain grinding machine.

In turning these bushings $^1/_{32}$ inch of metal is left for removing with the wheel, and this is done very rapidly, the bushings coming from the grinding machine at the rate of 60 per hour, or 1 minute apiece.

A 36K crystolon wheel is used, the wheel having a diameter of 14 inches and a thickness of 2 inches. This wheel is operated at a

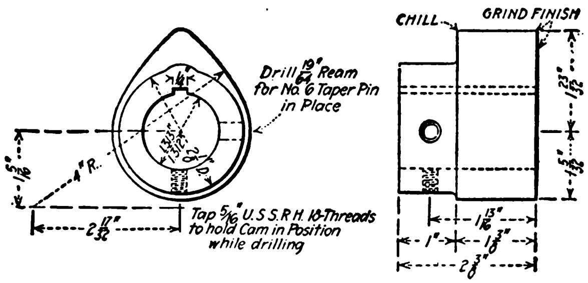


FIG. 98.—A chilled iron cam.

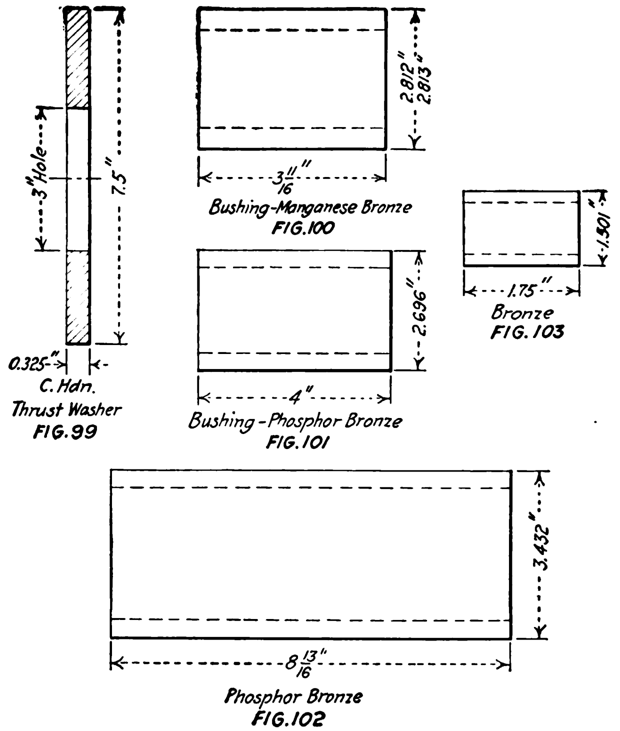
surface speed of 5500 feet per minute, corresponding to a velocity of 1550 r.p.m. The work is rotated at 100 turns per minute, or at a surface speed of 75 feet.

Another bushing, shown in Fig. 101, 2.692 inches in diameter and 4 inches long, of phosphor bronze, is ground under practically the same conditions and at the same rate. It is a bushing for the truck wheels of the "Caterpillar," and here again only 0.001 inch limit is allowed in finishing the piece. Sixty-five are ground in an hour.

A longer bushing, Fig. 102, is also held to the limit of one thousandth of an inch. This piece of work has a length of $8^{13}/_{16}$ inches and a diameter of 3.432 inches, so its total surface area figures out at almost exactly three times that of the connecting-rod bushing referred to above. The time required for grinding is in exact proportion, or 3 minutes each.

It is ground with a 14 by 2-inch crystolon 46K wheel operated at 1650 revolutions per minute or at a surface speed of 6000 feet. The metal to be removed averages from 0.015 to 0.035 inch and the wheel removes about 0.003 inch at each pass.

The small bushing, Fig. 103, is 1.501 inches diameter by 1.75 inches long; it is ground with a 46L crystolon wheel of the same size as given above. The wheel is run at 5000 feet per minute and removes from 0.015 to 0.025 inch of metal. The stop is set and the wheel position then remains unchanged except when dressed. One pass is



Figs. 99–103.—Washer and bushings.

made across with the work and the bush sized at the one cut. Although the piece is held to the limit of 0.001 inch the bushings are ground at the rate of 110 per hour.

The surfacing of cast iron gear case covers is accomplished on the Pratt & Whitney vertical spindle surface grinder. A 24H crystolon wheel is used here which is run at 1150 revolutions per minute. The wheel having a diameter of 14 inches, the peripheral velocity is about 4400 feet per minute.

The castings have about $^1/_{16}$ inch to be removed in the grinding operation and are passed three or four times under the edge of the ring wheel in the process. The table is operated at the rate of six forward and backward movements per minute so that only approximately one minute is consumed in the actual surface grinding operation.

CYLINDER OPERATIONS

A drawing of the cylinder for the 75 horse-power caterpillar is shown in Fig. 104. The length of bore proper in this cylinder is 12 inches and the counterbore is 2½ inches deep so that the total length machine in boring through the cylinder is 14½ inches. The high and

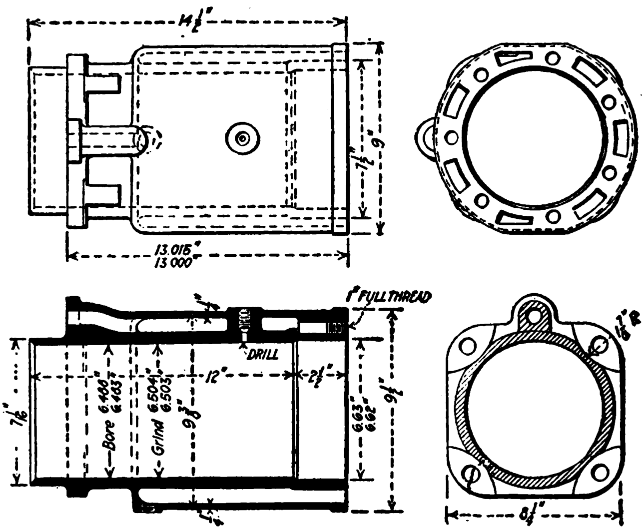


FIG. 104.—A tractor cylinder.

low dimensions to which the boring is held are respectively 6.488 and 6.483 inches, leaving from 0.015 to 0.020 inch for grinding, the five thousandths limit of accuracy in the boring process being restricted in the grinding to a limit of one thousandth only. The figures for the latter are, as noted in Fig. 104, 6.504 and 6.503 inches.

GRINDING CYLINDERS

The grinding of the cylinders is performed on the cylinder grinding machine shown in Fig. 105, the time required for the operation being 25 minutes.

The method of locating and supporting the cylinder casting in the machine will be obvious from an inspection of the illustration, and requires no description.

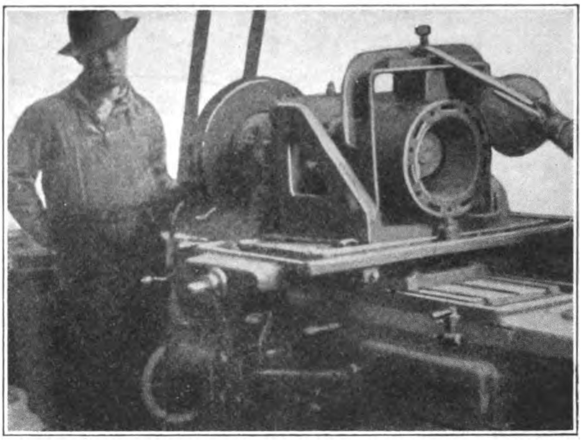


FIG. 105.—Grinding the cylinder.

The wheel used for the grinding operation is a crystolon 30J 5 inches in diameter by ½-inch face. The wheel is run at 5000 r.p.m., equivalent to a peripheral velocity of 6500 r.p.m. The revolving head, which carries the wheel spindle, makes 75 turns per minute, so that the travel around the bore is at the rate of 110 feet per minute. The work is traversed past the wheel at 2 feet per minute, or one complete forward and back movement in that time.

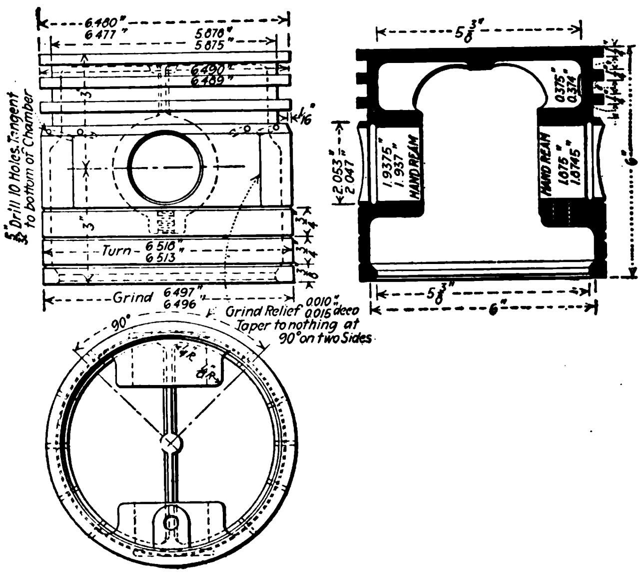


FIG. 106.—A tractor piston.

PISTON WORK

The pistons, Fig. 106, are carried through a number of operations before they reach the grinding department. When they reach the grinders there is some fifteen to twenty thousandths to come off under the wheel, which is removed at one pass of the wheel, the feed or traverse being operated by hand after the wheel has been set to depth. The grinding of this outer diameter is done on a plain grinder with a 14 by 1¼-inch wheel driven at 6000 feet per minute. The wheel is an alundum 26K and the work is driven at 100 revolutions per minute. The feeding across the work by hand is performed at a slow rate of travel, say 2½ to 3 minutes for the movement clear across the surface. The rate of production is 14 per hour.

CRANKSHAFT WORK

A typical crankshaft manufactured by this company is illustrated by Fig. 107. This is a chrome-nickel steel shaft for a 7½ by 8-inch

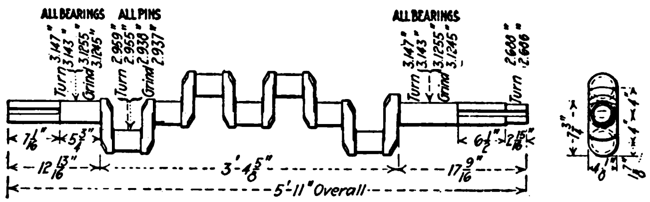


FIG. 107.—Heavy tractor crankshaft.

motor and is machined from a drop forging. The drawing is dimensioned for both turning and grinding limits and it will be noted that the turning is held to 0.004 inch and the grinding to 0.001 inch, the amount left by the turning tools for removing by grinding ranging from 0.018 to 0.025 inch.

The drop-forged crankshafts are, in the rough, about ¼ inch over finished size all the way around. The roughing of the main bearings and the second or finishing cuts are attended to in the engine lathe. The roughing cut is taken with a depth of chip of ⅛ inch, leaving $^1/_{16}$ inch on a side for the next cut. The feed is $^1/_{16}$ inch per revolution. The work is turned at 60 revolutions per minute and 0.022 is left for grinding. Crankpin turning operations are illustrated by Fig. 108, the lathe fixtures carrying the work off center the amount required to suit the throw. The same amount of metal is left for grinding as on the bearings.

The pin-roughing operation leaves $^1/_{32}$ inch or more on a side for a second turning cut, which leaves the specified amount for finishing by grinding.

The work is rotated at 90 turns per minute and the feed is about $^1/_{16}$ inch per turn. The first-roughing lathe on main bearings and the crankpin lathe take care of all of the work on the webs.

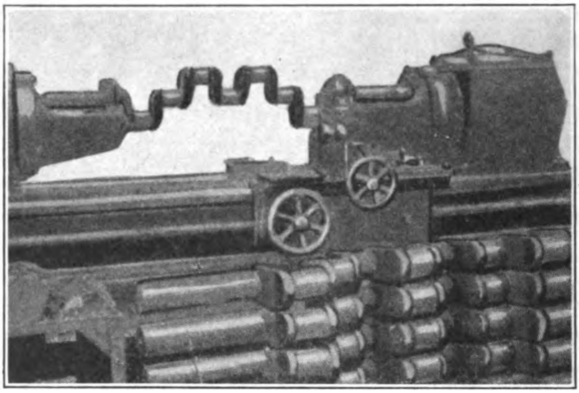


FIG. 108.—Crankshaft turning.

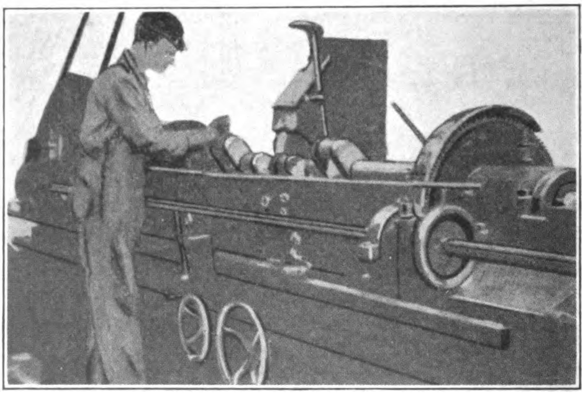


FIG. 109.—Grinding crankshaft.

Roughing the main bearings is done in 1½ hours. The second turning cut is taken on 10 shafts in a day of 9 hours. The crankpin lathe turns 24 pins, four pins to each of six shafts, in one day's time.

The journals are ground in a 16×72-inch machine with an alundum 36M combination wheel measuring 26 inches in diameter by 3 $^9/_{32}$-inch face. The wheel is driven at 950 r.p.m., or at 6500 feet surface speed. The shaft is rotated at 60 turns per minute equivalent to 50 feet surface speed of work. The time required for grinding bearings is 50 minutes per shaft.

The pins are ground as in Fig. 109 on a crankshaft grinding machine with an alundum 36L silicate wheel 42 inches in diameter and $3\,^9/_{32}$ inches wide.

The wheel is operated at 550 r.p.m., this figuring out at 6000 feet peripheral velocity. The crankshaft is driven at 35 turns, or 30 feet per minute. The four pins on each shaft require about 30 minutes for actual grinding, the total time, including putting in the shaft, setting, etc., and removing when ground, averaging 50 minutes.

The pins are ground before the main bearings. Then, if desired,

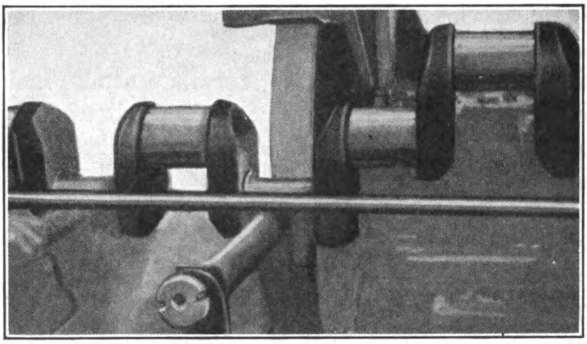


FIG. 110.—Grinding a crankpin.

they are wrapped for the protection of the surfaces while the crankshaft is handled for grinding the bearings.

The close-up view in Fig. 110 illustrates the manner of applying the wheel to the grinding of the pins.

The length of pin is $3^{15}/_{16}$ inches. The wheel is $3^9/_{32}$ inches across the face. The pin, therefore, exceeds the wheel width by only $\frac{5}{8}$ inch. The wheel is fed bodily in to a depth to size the pin and to clean up the fillet on one side, then fed into the other side to grind the other fillet. The limit of accuracy here as in the case of the grinding operation on the main bearings is 0.001 inch. This limit refers particularly to the shaft illustrated in Fig. 107 and shown in the different stages of manufacture in the various machines illustrated above. In certain other types of shafts only one-half thousandth inch is allowed for variation in main journals and pins.

CHAPTER XI

ROLL GRINDING[1]

There are two methods commonly employed in grinding rolls. In one the roll is supported on centers, one in the head and one in the footstock of the machine. The other method is to grind them on their own bearings revolving on their own neck bearings in specially designed pillow blocks or roll neck bearings. The first mentioned method is usually employed on light rolls that can be supported on centers without difficulty. For example, rolls up to 20 inches diameter and 60 inches long on the face are commonly handled by grinding on the centers and there have been cases where rolls as large as 30 inches in diameter and 120 inches long on the face have been successfully ground by this method. But the better way for the larger type of rolls is to support them on neck bearings in the same manner that they are supported when in use in the rolling mills.

It does not always follow because a roll is round and concentric with its axis and ground while rotating upon its own journals, that it is practically a perfect roll. The degree of perfection depends largely upon the accuracy of the center holes on which the journals or necks are turned; that is whether these journals are round and in line with each other. A frequent cause of error is found in the imperfection of the lathe spindles on which the necks were turned, or the eccentricity of the center point in the rotating spindle. Careful tests with a good indicator reading to thousandths would probably show nearly every roll lathe to have a spindle bearing not round and a center point not true; also, an examination of the center holes in the rolls will show that very few are true.

It is customary for all mechanics who grind really accurate work in tool making, machine building, etc., to grind on two dead centers, which is the only method of obtaining accurate work.

With view to ascertaining the truth, certain tests have been conducted in connection with both methods of grinding—that is, grinding with the roll supported on two dead centers and grinding with the roll turning on its own journals—which resulted in the following conclusions:

[1] Howard W. Dunbar in *American Machinist.*

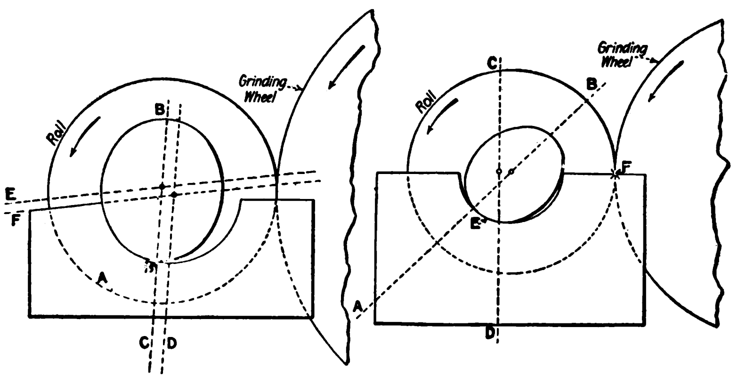
1. If the necks or journals are prefectly round over their entire length and if the two necks are in perfect line with each other, the grinding of the roll when rotating on the necks will give perfection; not otherwise.

2. Not a single roll examined had necks that were round or in line.

3. Not a single roll examined had round center holes on which to produce round journals or necks.

4. When the center holes were scraped to remove the imperfections, the necks could be made round only by grinding them while rotating on these perfected holes and on two dead centers, which were also ground perfectly round.

5. When the center holes were near enough round to grind the necks perfect when rotating on perfect center points, the body of the



FIGS. 111–112.—When roll necks are not round.

hole could be ground perfectly round and concentric with the necks while rotating on the same centers.

6. A grinder rigid enough to grind perfect necks on centers is also rigid enough to grind perfect bodies on centers.

The illustrations, Figs. 111 and 112, show some of the things that occur when grinding a roll which rotates on journals that are not round. Referring to Fig. 111, the journal is shown oblong in shape in order to illustrate what may happen. The bearing *A* may be a perfect half-circle of a diameter equal to the largest diameter of the journal *B*. As the roll turns in the direction of the arrow and the grinding wheel is pressing against the roll body, the axis will assume the position shown; that is, one side of the center of the bearing, or at *C*. When the roll is rotated one-fourth of a turn, its axis will have moved toward the grinding wheel at *D*. It will also have dropped from *E* to *F*.

The raising and lowering of the axis of rotation cause a variation of distance from the cutting face of the wheel to the bearing point of the journal.

Referring to Fig. 112, when the line across the greatest diameter *AB* is in the position shown, the axis is moving to the left toward *CD*, the position it will assume when the roll has made a part of a rotation. During this movement of the axis to the left, the journal is rolling on the part of the box marked *E* and for an instant is not really turning on its axis. This causes a high place where the wheel cuts during that movement.

When this roll is put to work in its housings, if the boxes of the housings are of the same size as the box used to grind in, this same motion will occur; but when the axis moves to the left and the journal rolls on the part *E*, the work being rolled will not be at *F* where the grinding wheel has cut the roll, but rather at *C*. Now, when the high place on the roll at *F* (caused by this movement of the axis to the left while grinding) shall have reached *C*, or the point where the work is done, the distance from the working face of the roll and the supporting surface of the journal will be greater than *C;* therefore there will be greater pressure on the work, causing a "thin" place. To grind successfully on centers, the center must be big and strong and made of good material. The center holes in the ends of the rolls must be perfectly round, true and large enough to engage a sufficient surface on the center to insure the roll being supported without springing the center and to present a large surface for wear. Center holes should have a drilled clearance hole for the point of the center.

The most successful practice is to use center holes of 60 degree angle or some other angle more obtuse than 60 degrees as a preventive against breakage of the center point. Care should be taken that the center holes are round, and they should be guarded against damage in the mills. This is extremely important. In truing up the roll necks (which is always done in order to keep them round and concentric with the roll face) the two methods are also employed. The most common method, however, is to support the roll on centers, although specially designed neck bearings have been made, making it possible to grind the necks while they are revolving on their own bearings. This operation of grinding necks requires that the corner of the wheel be trued to a radius in order to produce the fillet which takes the thrust of the rolls when they are in operation in the rolling mill. Such fillets range from 3/8 inch to 3 1/2 inches.

The ordinary type of cylindrical grinder is commonly employed for producing rolls of small diameter and light weight. The method is no different from that ordinarily used in grinding cylindrical work.

A notable difference between this machine for comparatively small rolls and a special machine built by the Norton Grinding Company for handling the larger rolls is this: In their regular machine the work is supported on a moving table and travels in front of a fixed wheel, whereas in the larger type of machine the work is fixed on the work base and the wheel is traveled back and forth over the surface being ground. The latter method is more convenient in handling large rolls of several tons' weight. When the work table becomes so heavy that it is not an economical proposition to move it, the work should be fixed and the lighter member, which is the wheel, reciprocated. Also in the machine for large-roll grinding, th operator is positioned on a carriage opposite the wheel so that he can with ease control the operation of the machine and at the same time see the point where the wheel comes in contact with the work. Where the work is small, this, of course, is not a matter for consideration, as the operator can look over the moving table and down to the point of contact of wheel and work. The large-roll grinder referred to is designed exclusively for the finishing of rolls for rolling mills. This machine employs the method of moving the wheel back and forth over the face of the roll, being dressed. The wheel is supported on a carriage upon which the operator stands, where he is in full view of the wheel and can readily see the point where it comes in contact with the work. Although this wheel is moved instead of the work, it is just as much fixed in relation to the work being ground as though it were mounted upon a stationary base. The essential elements of this machine for the dressing of large rolls are a work-carrying base with supporting heads, in the form of centers or journal rests or pillow blocks; means for revolving the work; a base for supporting the wheel (which must be adjustable in and out from the work); and the necessary control mechanisms, adjustments and conveniences consistent with the design.

Rolls are usually revolved at a surface speed ranging from 100 to 200 feet per minute, and the wheel is revolved usually from 4500 to 6000 surface feet per minute. The table travel or wheel travel is regulated so that the distance of travel for every revolution of the work is just slightly less than the width of the wheel in order to obtain the maximum production.

The Norton wheels that have proved successful on chilled-iron rolls are 24-combination-J crystolon, 20-24 grade K crystolon, 16-20-24 L crystolon. For steel rolls, 80J alundum is very successful. The latter wheel is especially good for a fine finish free from scratches, but is not as good a producer as the 24-combination-K alundum. The 24-combination-L-and-M alundum wheels have also been successful in production on steel rolls when a fine finish is not important.

It is common practice in rough grinding rolls to remove as much as 4 cubic inches of material a minute. The wheel wear, of course, depends upon many things, such as the proper use of the wheel, material being ground, etc. The following are typical examples of relative wheel wear to metal removed, the finishing operation being included:

1. In removing 1802 cubic inches of stock on chilled-iron rolls in 15½ hours, 167 cubic inches of wheel were worn from the diameter of a 20-24J crystolon wheel.

2. In removing 685 cubic inches of stock on chilled-iron rolls in 8½ hours, 113 cubic inches of wheel were worn from the diameter of a 16-20-24K crystolon wheel.

FORMED ROLLS

The forming of rolls is accomplished either by special attachments on the machine or by certain changes in the machine construction. It is possible to make a concave or a convex face on the roll. It is possible to taper the roll from one end or from both ends, or to grind the roll perfectly straight.

Some work, especially rolling ribbon stock, requires that the face of the roll be crowned slightly. There are two methods of producing a crown on the small rolls: First, by forming the desired shape in the face of the wheel, then feeding the wheel straight in against the roll face; second, by means of an attachment on the machine for controlling the movement of the wheel slide, so as to produce the desired shape as the wheel travels back and forth across the roll face. Tapers, or irregular forms of this nature, are not very great as compared with the diameter of the roll. For instance, on small rolls for rolling ribbon stock the crown may be from 0.001 to 0.015 inch high. On large-diameter rolls, 36 inches in diameter and 90 inches long, the taper may amount to $^1/_{16}$ inch in length of the roll face.

CHAPTER XII

GRINDING REAMERS, CUTTERS AND OTHER TOOLS

A few illustrations are presented in this chapter showing methods of grinding cutters on the Cincinnati cutter and tool grinder.

SHARPENING PERIPHERAL TEETH OF A SIDE MILLING CUTTER

Figure 113 shows the "set-up" for grinding the peripheral teeth of a side-milling cutter with a cup wheel, while Fig. 114 illustrates a similar operation as performed with a disk wheel. In both cases the tooth rest is mounted upon the swivel head on the table of the machine.

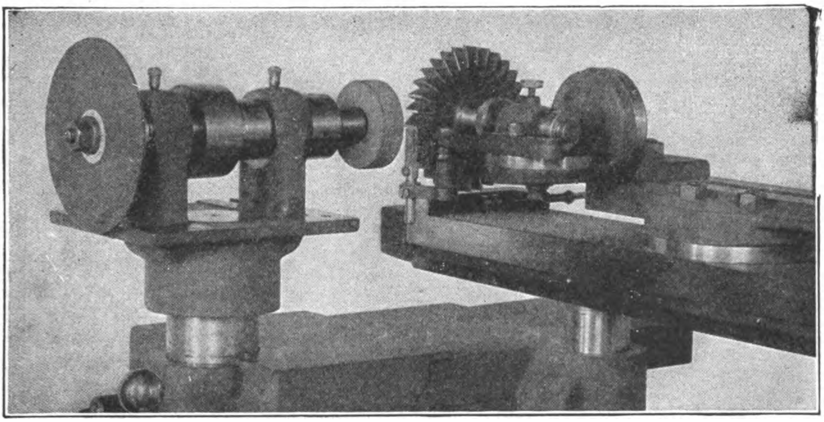


FIG. 113.—Sharpening peripheral teeth of a side milling cutter with a cup wheel.

There is a centering gage for this machine which is used upon the table as shown in Fig. 117. This gage is the same height above the table as the work centers. There are centering lugs on the rear side of the wheel head whose faces are on a line with the spindle so that when the table is adjusted to bring the gage to these lugs the work centers will be central with the spindle. The gage thus forms a means by which the cutter may be set central with the wheel spindle if desired, and the tooth rest set to the same height as either work centers or wheel spindle whatever their relative positions may be. A micrometer adjustment is provided for the table elevating device, and this micrometer dial in connection with the centering gage (from which initial settings are made) enables the work center and the tooth rest to be set in the proper vertical relation to the wheel spindle for obtaining any desired degree of clearance.

Referring again to Fig. 113, the top of the tooth rest when adjusted for this operation is set below the centering gage an amount required for the desired clearance as determined by a table used with the machine. The knee is swung around on the column slightly (to 89½ degrees) to bring the "up" side of the wheel in contact with the cutter tooth. If the wheel strikes the tooth next to the one being ground the table should be elevated until the tooth clears the top of the wheel. The knee is easily set around to any desired angle as there is a large graduated collar and index pointer at the bottom of the knee bearing on the column.

USING THE DISK WHEEL

When using the disk wheel as in Fig. 114, the work center is set level with the wheel spindle by means of the centering gage, the micrometer

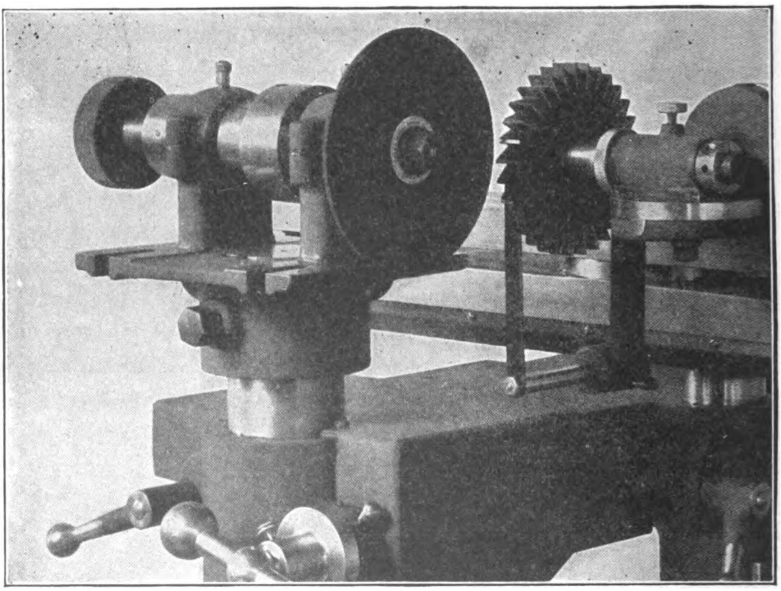


FIG. 114.—Sharpening peripheral. A side milling cutter with a disk wheel.

dial set at zero and the table then lowered to bring the work center the required amount below the spindle center to give the desired clearance. This amount, of course, varies with the diameter of wheel used. The tooth rest is of fixed type and its height is such that the face of the tooth being ground is the same height as the center of the cutter.

In all cases whether a cup or a disk wheel is used, the "up" side of the wheel should do the cutting, as this reduces the tendency to draw the temper of the cutting edge, permits faster grinding and prevents the forming of a burr on the edge of the tooth, which results when the grinding wheel runs in the opposite direction.

The cutter is held by hand against the tooth rest with sufficient pressure to prevent it from being lifted by the action of the wheel.

Of the two types of wheels shown in Figs. 113 and 114 the cup form is preferable for this operation as it gives a straight line clearance with a stronger cutting edge than is obtainable when grinding with a disk wheel sufficiently small to clear the adjacent teeth.

SHARPENING LEFT-SIDE TEETH OF A SIDE MILLING CUTTER

Figure 115 illustrates the method of sharpening the side teeth of a side milling cutter with a cup wheel, which, as already pointed out,

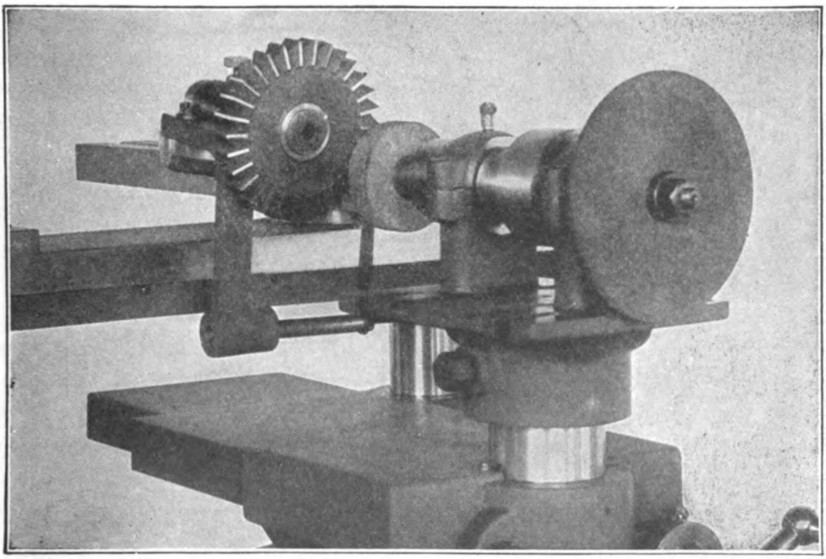


FIG. 115.—Sharpening side teeth of side milling cutter with a cup wheel.

gives a straight line clearance and a strong cutting edge. The cutter is held on the work spindle of the swiveling head and the head is depressed to an angle corresponding to the desired angle of clearance. The knee is set to 90½ degrees so that the up side of the wheel will touch the work while the down side will clear. The tooth rest is fastened to the swiveling head. Its height is fixed so that the face of the tooth being ground is the same height as the center of the cutter.

The teeth on the right side of the cutter are ground in similar fashion, except that the cutter is reversed and the knee set to 89½ degrees. The tooth rest is also reversed and the grinding is done on the side nearest the operator.

In both cases the table must, of course, be elevated until the tooth next the one being ground clears the top of the wheel.

SHARPENING A SPIRAL MILL

A disk wheel is seen in operation on the spiral mill in Fig. 116. Here the tooth rest is secured to the wheel head and its contact point

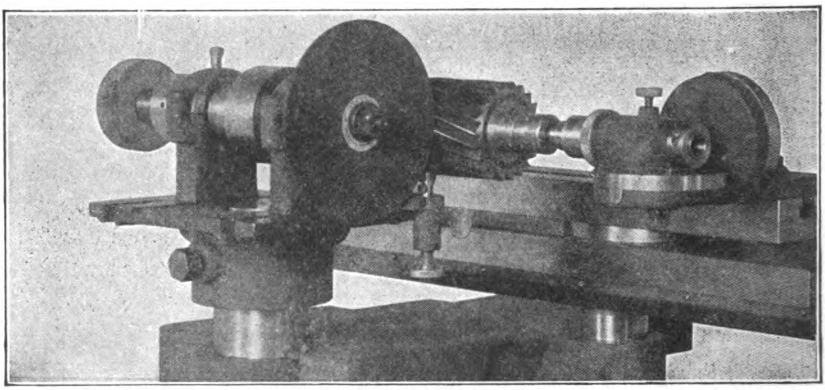


FIG. 116.—Sharpening a spiral mill with a disk wheel.

is set to the height of the work centers by means of the centering gage after the table has been lowered to bring the work centers the necessary distance below the wheel spindle for the desired clearance.

SHARPENING A REAMER WITH THE CUP WHEEL

The hand reamer in Fig. 117 is supported between centers on the table and ground with a cup wheel, the knee being set ½ degree off the 90-degree mark to bring the up side of the wheel in contact with the work. The table is brought to proper height for grinding, the tooth rest adjusted to the gage, the micrometer dial set to zero, and the table then elevated the amount required for clearance. The grinding operation may then be accomplished. As in the case of the cutter-sharpening process, if the wheel interferes with the reamer tooth next to the one being sharpened, the table must be raised until the tooth clears the top of the wheel, this must be done before setting the tooth rest and adjusting for clearance.

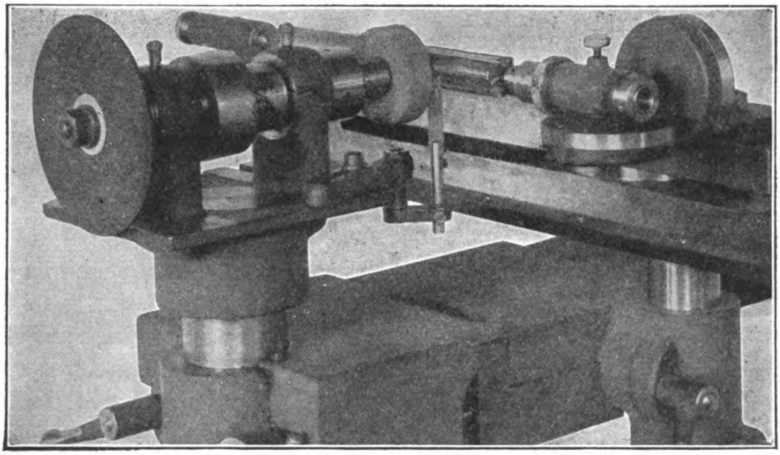


FIG. 117.—Grinding a reamer with a cup wheel.

GRINDING A SNAP GAGE

Figure 118 illustrates surface grinding work on the Cincinnati cutter grinder. The regular surface grinding attachment for this machine

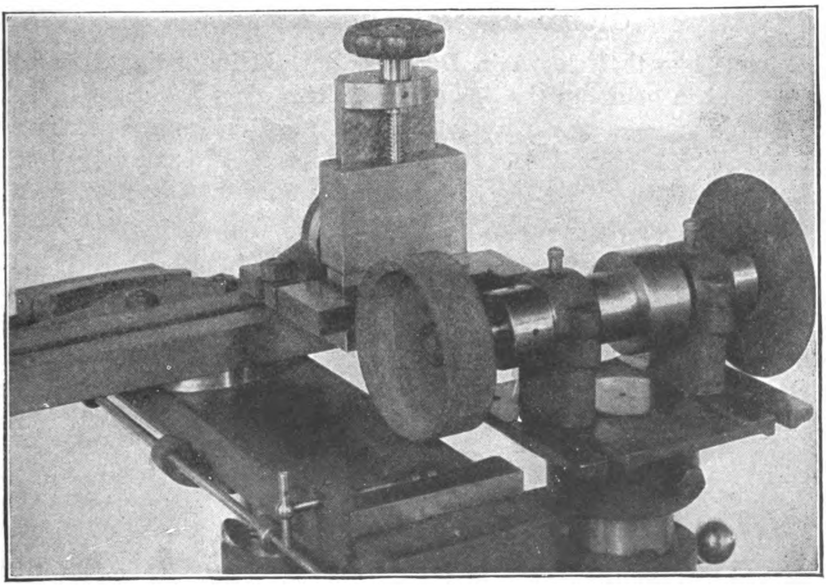


FIG. 118.—Grinding a snap gage on the cutter grinder.

when mounted upon the table allows the work held in its jaws to be presented at any desired angle with the axis of the wheel head by making the necessary adjustments of the swivel vise, the table and the long slide.

The snap gage is held in the vise jaws and grinding is done with a cup wheel. The best results are obtained when the center of the work is the same height as the center of the spindle. By reversing the wheel on its spindle or by using a double-edge cup wheel which cuts on both sides, the opposite jaw of the gage may be ground. In this manner gages up to 13 inches may be ground without rechucking.

SHARPENING TWIST DRILLS

Drills should be ground so as to cut the right size and with as little power as possible.

In order to have the drill in condition to cut the right size, the cutting lips must be of equal length and form equal angles with the axis of the drill. Both of these conditions must be observed or the drill will cut oversize. Thus in *A*, Fig. 119, the point is central but the angles are not alike. In *B*, the angles are equal but lips are not of equal length. In *C*, the angles are unequal and the lips also. In all three cases the drill will cut oversize as indicated, and one lip will do practically all of the work, so that it will dull rapidly and require an extra amount of grinding to keep the drill in condition to cut.

GAGING AND MODIFYING THE LIPS

A gage like that shown in *D* will be an aid in getting the angles correct and in grinding the lips central. This gives the usual lip edge angle of 59 degrees. At *E* is shown a method of determining if both of the lips are alike, but it does not give the angle. *F* is a suggestion by Professor Sweet for relieving the drill back of the cutting edge, making it similar to a flat drill in this respect.

For drilling brass, or for any thin stock where the drill goes through, it is best to grind the cutting edge parallel with the axis of the drill. This does away with the tendency for the drill to draw into the work. *G* shows how this is done.

It is sometimes necessary to thin the point of the drill to get best results. This requires care in grinding but it can be done as shown in *H*.

THE PROPER CLEARANCE

The best all-round clearance is 12 degrees, though for softer metals 15 degrees can be used. The 12-degree angle referred to is at the cutting edge, but this should increase back of the cutting edge so that the line

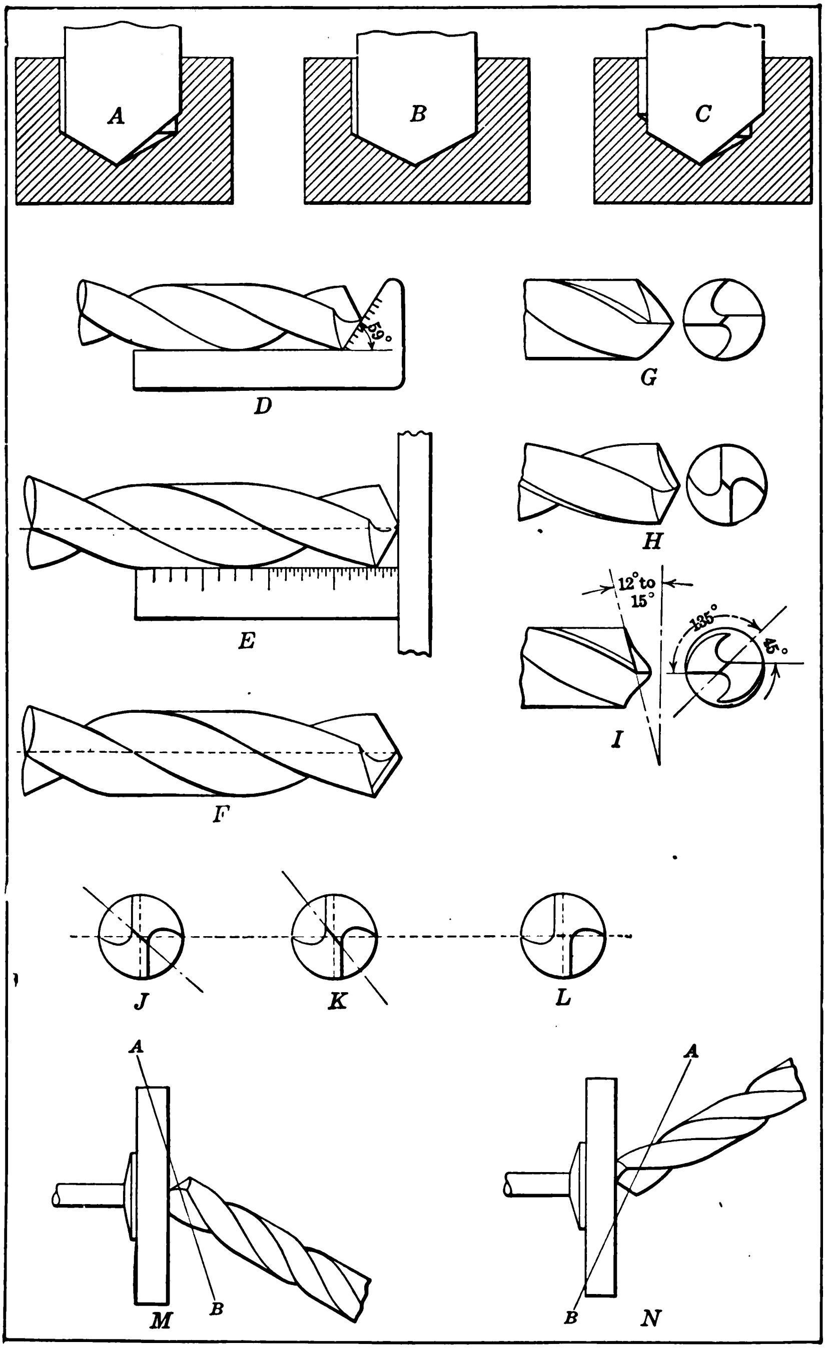


FIG. 119.—Details of drill grinding.

across the web will be 45 degrees with the cutting edges. This is important, as it not only saves power but prevents splitting of the drill in severe service. The point of the drill should look like *G* or *H*. At *I* is the clearance angle and the right angles for the drill point.

The angle of 59 degrees has been mentioned as the usual one for the lip edge. Twist drills are customarily made so that their cutting edges are straight when ground to this angle. If the drill is ground to a lesser angle, the lips are left hooking and are likely to produce a crooked and irregular hole.

The grinding lines of the drill are placed slightly above center as in *J*, *K*, and *L*, to allow for the proper angle of the point which indicates the extent of the clearance. Both *I* and *J* show the proper angle across the point or web, while in *K* the angle is too sharp and will cause the drill to cut rank. The angle in *L* runs backward and shows an entire lack of clearance.

MEASURING THE CLEARANCE

If the drill is placed as in *E*, and rotated with its point against the plane surface, the scale will indicate at once the amount of clearance, at the same time showing whether the lips are of equal length as already pointed out.

This question of proper clearance is a most important one, and it is, of course, impossible to grind a drill by hand so that the clearance will be just right.

A principle employed on some drill grinders to give the clearance to the lips is represented by *M* and *N*. Here the axis about which the drill swings in the grinding of the two lips is shown at *A–B* and it will be seen that the method results in grinding the lip behind the cutting edge, to the form of a truncated cone, the apex of which is at the point of intersection of the axis *A–B* with the wheel face. This gives a gradual increase in clearance from the outside of the drill to the center.

CHAPTER XIII

BUFFING AND POLISHING

The old strapping machine, consisting of two flanged pulleys carrying a canvas belt loaded with glue and abrasive on the outer side, has long been used for finishing irregular surfaces, especially on brass work. It is often called a strapping or strap buffing machine.

The straps or grinding belts run at from 2000 to 2500 feet per minute in most cases. The later development of this type of grinding is in the belt grinder. In some of the later types of machines the belt is of emery or other abrasive cloth, carefully cemented into an endless belt and run at about 7000 feet per minute.

At the point where the grinding is done, the belt runs over a flat metal plate which supports both the belt and the work and produces remarkably flat surfaces. The belts usually run on top of or over, a specially prepared leather belt which acts as a cushion.

BAND POLISHING MACHINES

Polish wheels were formerly of wood with the abrasive carried on a leather strip or band pegged to the wheel. They were covered with glue and rolled in emery or other abrasive.

The later practice is to use a wheel of a steel casting about 12 inches in diameter and 2½-inch face. The face is covered with a strip of cloth carrying the abrasive so that they can be changed from one grade to another or renewed when worn, with very little difficulty.

The grinding bands are graded as follows:

No. of cloth:	00	0	½	1	1½	2	2½	3	3½
Grade of abrasive:	Flour	120	90	80	70	60	46	36	24

Polishing machines are made in two styles, one to be used while standing and the other sitting down. Sitting machines have spindles 32 inches from the floor, and standing machines, 42 inches from the floor.

A 12-inch wheel is run about 1850 r.p.m., making a surface speed of about 5500 feet per minute. With an individual motor three horsepower is allowed for one of these machines.

FACTS ABOUT POLISHING[1]

There are many varieties of polishing wheels in use, the principal kinds being known as wooden wheels, compressed wheels, canvas and muslin, sea-horse and felt wheels. To equip a polishing room with the right wheels requires the assistance of a polisher who has had a wide experience in polishing and is familiar with the various methods employed as well as the best abrasives. For good work, and economy in abrasive, glue and labor cost, wheels and methods must be selected to suit the work.

WOODEN WHEELS

A few years ago, the wooden wheel covered with leather and turned to fit the piece to be polished, was universally used. At the present time, the wooden, leather-covered wheel is used largely on flat surfaces and on work where it is necessary to maintain good edges. When this kind of a wheel is made with a double coating of leather, it makes a first class finishing wheel.

COMPRESSED WHEELS

Compressed wheels, or wheels having a steel center are made with surfaces of leather, canvas or linen. Many tool shops are equipped with these wheels exclusively. They answer all purposes and are safer and more economical than wooden wheels.

They are also used largely on cutlery and for polishing chilled plows. The compressed wheel is of strong construction, is very durable and easily kept in balance.

CANVAS AND MUSLIN WHEELS

Canvas and muslin wheels are used extensively for polishing stoves, shovels, plows, brass, cast iron and steel. For roughing out and dry fining on irregular pieces, they have proved very satisfactory. They hold the abrasive well and require no washing off, as they can be cleaned with a buff stick or an abrasive brick.

Many concerns, such as plow-, shovel- and hoemakers, buy the canvas and muslin and make their own wheels.

SEA-HORSE WHEELS

Sea-horse wheels are very expensive, most concerns buying the hides and making their own wheels.

Where a high-grade polish is required, there is probably no wheel

[1] W. F. Ford, in *Grits and Grinds*.

which can compare with the wheel made of sea horse. They are largely used on guns, pistols and cutlery.

FELT WHEELS

Felt wheels are largely used by stovemakers for finishing surfaces. Bull neck wheels are also used for this purpose.

The felt wheels are made from white Spanish and Mexican felt and are extensively used for finishing on certain classes of work.

CARE OF POLISHING WHEELS

Polishing wheels should be kept in perfect balance and running true at all times. A wheel out of balance wastes time, glue and abrasive, and will not do as good work.

The most efficient glue and the best abrasive are the cheapest in the long run.

The glue pots should be kept clean and the glue properly cooked before using.

It is also important to heat the abrasive before applying.

The wheels should be kept properly cleaned and thoroughly covered with the abrasive.

The wheels should be selected for the particular work the same as in grinding and only the wheel best adapted should be used at all times.

POLISHING OPERATIONS

Polishing operations are usually divided into three classes: roughing, dry fining, and finishing or oiling.

The abrasives used for roughing usually run from numbers 20 to 80. For dry fining, from numbers 90 to 120. The numbers used for finishing run from 150 to XF.

For both roughing out and dry fining, the polishing wheels should be used dry. For finishing, the wheels are first worn down a little and then oil, beeswax, tallow and similar substances are used on the wheel. This, together with the abrasive, brings up a fine finish.

SPEED OF BUFFING WHEELS

Wood, leather covered......	7,000 feet per minute.
Walrus	8,000 feet per minute.
Rag wheels.................	7,000 feet per minute.
Hair-brush wheels..........	12,000 feet per minute.
Ohio grindstone............	2,500 feet per minute.
Huron grindstone...........	3,500 feet per minute.

CHAPTER XIV

THE MAGNETIC CHUCK

Magnetic chucks have come to be a very necessary part of the equipment of any surface grinding machine, whether plain or rotary. Credit for these belongs to O. S. Walker of Worcester, whose first patent was granted on July 21, 1896. These are now being made by others.

Before their coming it was customary to bed thin work in wax on the platen of a grinder in order to finish the flat sides. Other flat work had to be held in "fingers" on special fixtures, and on account of their being very thin and easily sprung, it was difficult to secure really accurate work.

The magnetic chuck holds the thinnest pieces of iron or steel firmly, draws down any slight spring in the work and prevents springing when strains are released during the grinding operations.

The chuck face is divided into magnet poles, separated by babbitt or other non-magnetic metals, and coils of insulated wire form these into electromagnets when current is applied. For rotary work, the electric current is supplied by brushes running against insulated contact rings on the outside. Current can be supplied from any incandescent lamp socket on a direct current circuit.

Alternating current cannot be used.

A No. 0 chuck having a face 10×14 inches uses about one-half as much power as a 16 candle-power lamp. A No. 1¼ with a face 12×6 inches takes the same current as a 16 candle-power lamp.

Chucks are made with plain and duplex bases and arranged for straight and taper work.

Figure 120 shows a few adaptations of the magnetic chuck for holding work. The aligning strip *M* in No. 1 is on the back of the chuck for squaring the work against. The edge of *G* just matches this so that the two form a squaring device as shown. No. 1 shows plain work that is easily held. In No. 2 the lower edge is not square and the long side *A* must be out so that the magnetic pull on the angle side holds the piece against the squaring edges.

In No. 5, where a number of pieces are held at one setting, it is sometimes desirable to lay strips of non-magnetic materials, such as brass, or pasteboard in between them. In this way the magnetism of the chuck seems to get an independent grip on each piece. Sometimes, on heavy work, an adjustable finger, as at N, is set against the last piece or row of pieces.

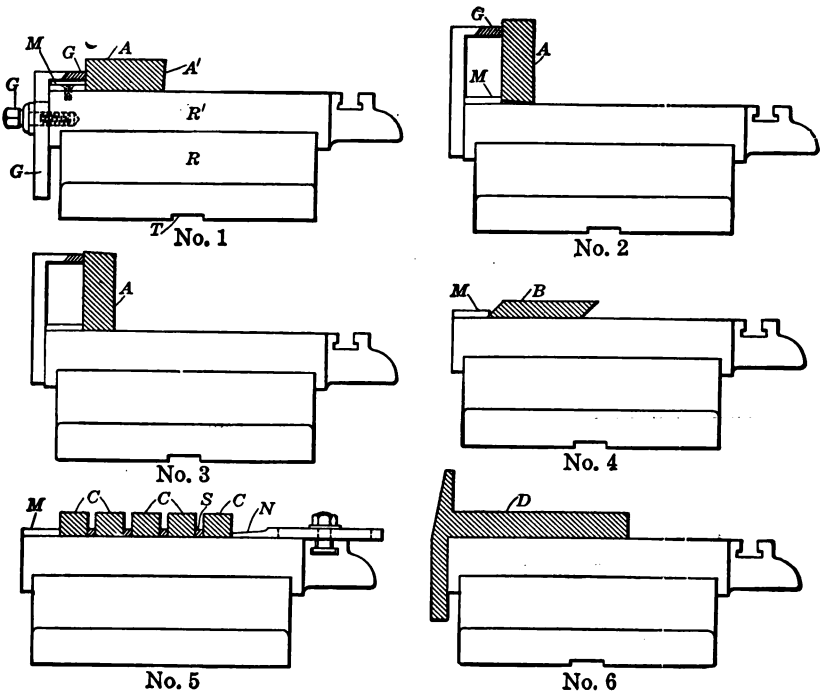


FIG. 120.—Back rests for magnetic chucks.

No. 6 shows another form of squaring device, which is itself held in place by the magnetism of the chuck.

DEMAGNETIZING THE CHUCK AND THE WORK

Iron and steel in contact with magnets retain some of the magnetism, which is sometimes more or less of a nuisance in getting small work off the chucks.

To overcome this the chucks are often furnished with a duplex or demagnetizing switch, which simply reverses the direction of the current, and when this is done a few times the magnetism will disappear and the work will be easily released.

This does not demagnetize the work, but demagnetizers are made for this purpose. These are only necessary where the remaining magnetism is objectionable in the work itself. These are sometimes arranged to be worked automatically from the countershaft.

Magnetic chucks are made for use with water, but in most cases require a current of air to be blown through the chuck to prevent the entrance of water and the formation of moisture in the chuck interior from the constant heating and cooling of the coil chamber. Some of the later chucks do not require this.

ARRANGING JIGS ON MAGNETIC CHUCKS

In Fig. 121 will be seen an idea of how magnetic jigs can be arranged on the chucks. The work *W* is all outline in each case. The holding

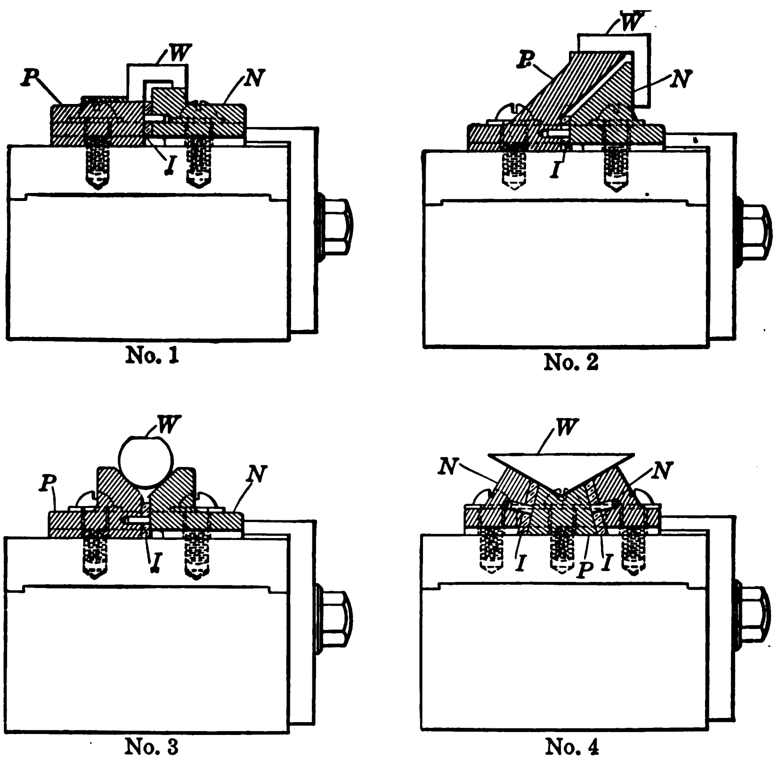


FIG. 121.—Magnetic jigs for special work.

pieces are *N* and *P*, negative and positive, separated by non-magnetic materials *I*, and are air-gaps in the case of No. 2 to hold an angular piece by each leg.

A round bar can be held in *V s* as in No. 3. In No. 4 the central piece is positive and there are two outer, negative poles.

As an example of the way in which small and thin pieces can be handled in some such way is shown in Fig. 122. The disk *J* not only makes it easy to locate the rings *I* so as to be firmly held and also assists in holding the work. The whole plate being attracted to the chuck acts as a locating disk and anchors the pieces against any side strains. These plates can also be made to hold small stampings which are too small to be held in any other way.

It is well known that it is only the small or thin work which is hard to hold. By using this perforated disk, or any similar device, the

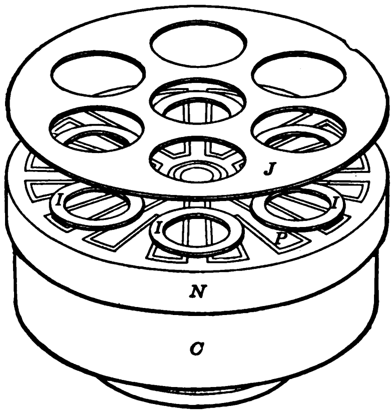


FIG. 122.

combined holding power of all the pieces assists in holding the separate ones. In some cases, a loose ring only is provided which encircles all the pieces of the work, while in others, a ring with internal teeth or notches is used to locate the work. These disks or rings can be removed with the work and remounted without loss of time.

HINTS FOR USING MAGNETIC CHUCKS

The chucks should not be taken apart.

Nothing but iron or steel can be held on the chucks.

The holding power depends on the amount of work surface in contact with the chuck.

Work can be held on edge by using adjustable back rest.

Very thin work can be held for grinding on the edges by laying it against the back rest and backing it up with a parallel strip.

Thin work will not hold as well as thick work.

In packing a number of small pieces on a chuck at one setting, it is better to separate them a little with strips of non-magnetic material.

Do not plug up the vent holes in the chuck.

Keep water away from the switch, the brushes and the interior of the chuck.

Magnetic chucks do not take the place of all other chucks.

Do not use water on chucks except where they are made for it.

Chucks are usually wound for 110 or 220 volts *for direct current only.*

A number of chucks, mandrels and driving devices of a special nature are shown by the accompanying engravings.

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