MACHINE SHOP WORK

COMPREHENSIVE MANUAL OF APPROVED SHOP METHODS INCLUDING THE CONSTRUCTION AND USE OF TOOLS AND MACHINES, THE DETAILS OF THEIR EFFICIENT OPERATION, AND A DISCUSSION OF MODERN PRODUCTION METHODS

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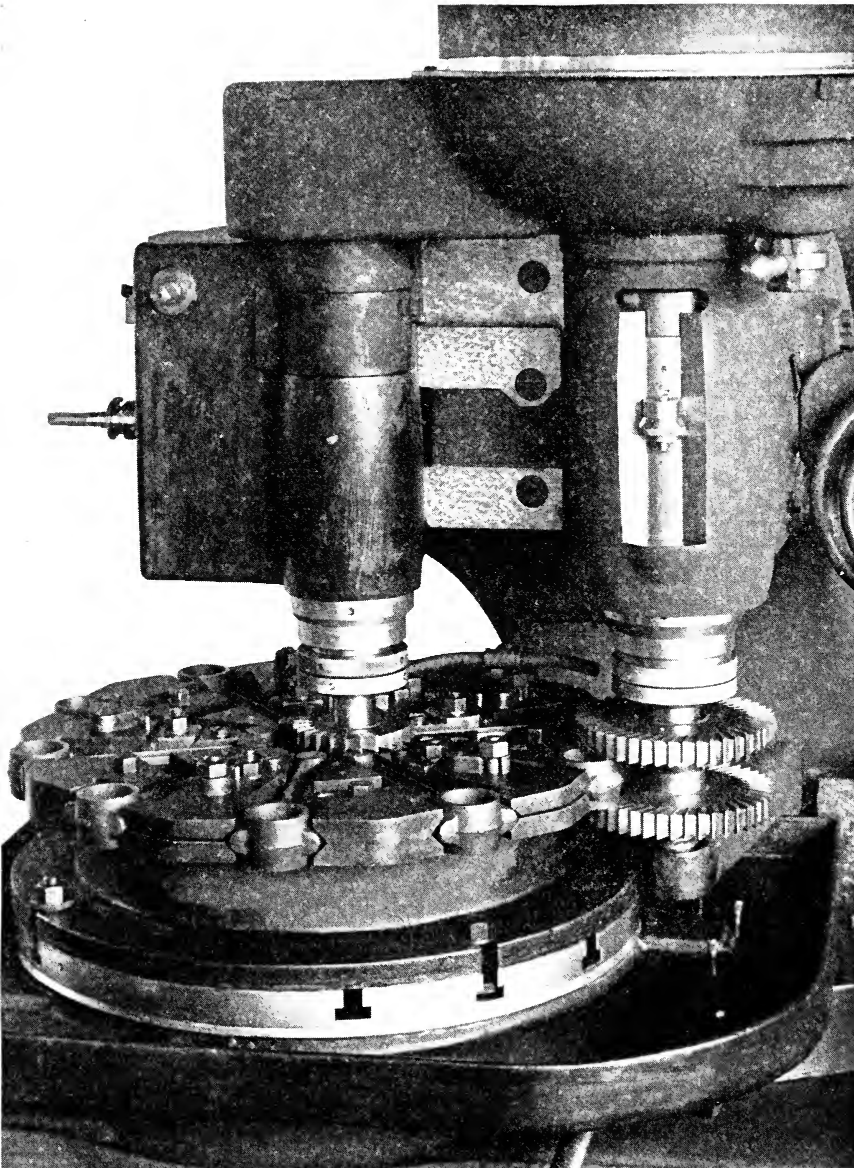
INTRODUCTION

MARVELOUS accomplishments in the mechanical world have become so common in this day and age that we scarcely realize the slow process of evolution which machine shop work has been undergoing during the last century. Barely a hundred years ago Watt, the father of the steam engine, had to be satisfied with engine cylinders which were three-eighths of an inch out of true because neither the machines nor the workmen could do better. Our present day machinist, on the other hand, must make his error two hundred times as small to meet the requirements. He also must deal with machines and mechanical problems which would have staggered his untried and unskilled brother of the previous century.

¶ And it is not only the workman who has progressed in accuracy. There are myriads of machines which have been built to facilitate the manufacture of all parts that go to make up a mechanical device—speed lathes, milling and stamping machines, die presses, and the jigs, tools, and dies which go with them—and all of these contribute mightily to the accuracy and speed of manufacture. One of our best known automobiles is made with such precision from radiator cap to differential that the parts are shipped "knocked down" to distant points and are assembled with practically no fitting—a truly marvelous performance and one which necessitates an exactness in the duplication of parts which would have been impossible even ten years ago.

¶ The tale of this development of machine shop work is an interesting one and should appeal not only to the technically trained man who desires the best advice on the correct mechanical process to follow, but also to the man who wants to know how to "do things" or at least how things are done. It is the hope of the publishers that this book will satisfy a real demand and prove of sterling value in its field.



VIEW OF BECKER CONTINUOUS MILLER MILLING CONNECTING-ROD FIXTURE
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

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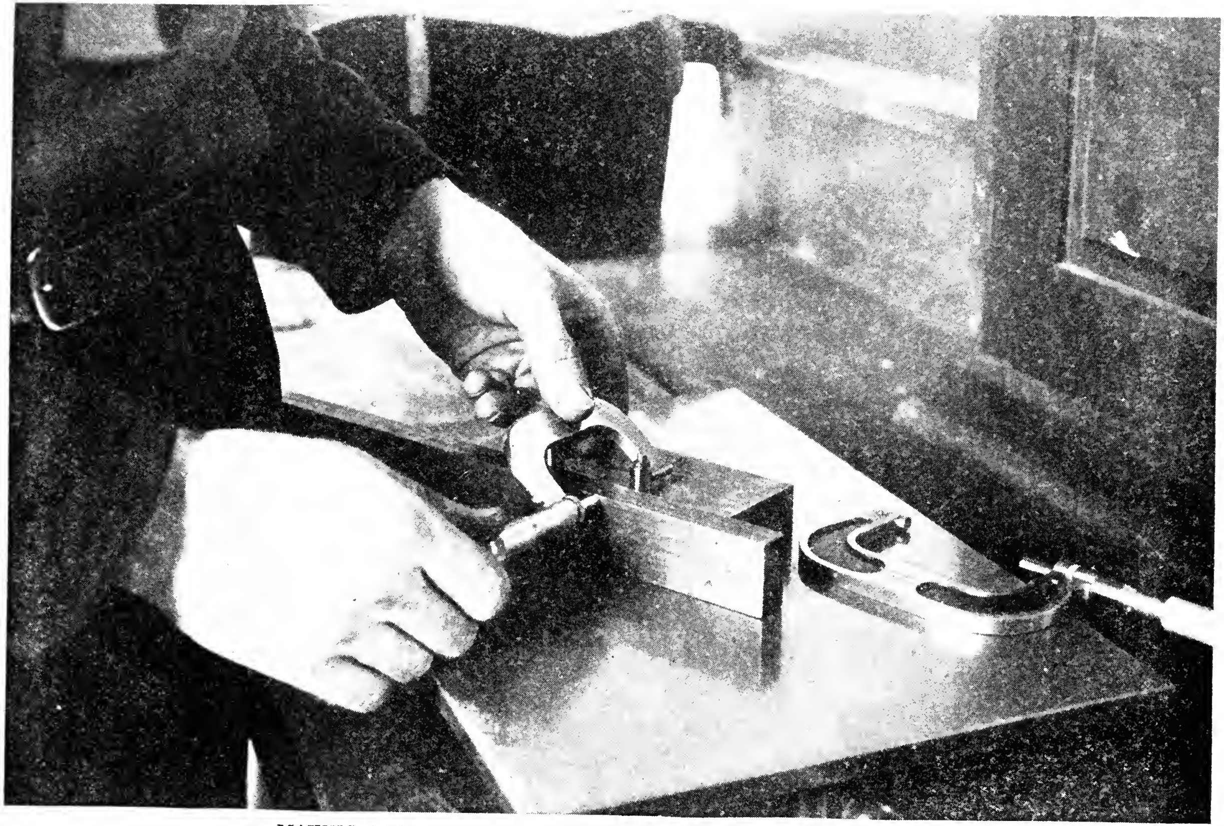


MAKING ACCURATE MEASUREMENTS WITH MICROMETER CALIPER

MACHINE SHOP WORK

PART I

HAND-OPERATED TOOLS

Simultaneous Use of Hand Tools and Machines. Machine shop work is usually understood to include all cold metal work in which a portion of the metal is removed to make the piece of the required shape and size either by power-driven or hand tools. However, there are some branches of cold metal work, such as sheet-iron work and coppersmithing, that are not usually included in machine shop work.

As the hand-operated tools are much simpler, and as the operations performed with them are in every case more typical, their description and use should precede that of power-driven tools. It should be clearly understood, however, that machine shop practice involves the use of both classes at the same time. Even hand tools are not used in the same order on different classes of work; it is, therefore, impossible to describe them in the order of use. Simplicity of construction and operation will be the guide for treatment in the following pages.

MEASURING TOOLS

ANGULAR MEASUREMENT

Surface Gage. The surface gage is used in laying out work for the bench, lathe, or planer. The ordinary form consists of a heavy base, an upright which is firmly attached to the base, and a scriber or scratch awl. In the universal gage, the upright is pivoted at the base so that it may be used at any angle. In some forms the base is grooved in order that the gage may be used on cylindrical work as well as on flat surfaces, Fig. 1.

To use the gage, the part of the work to be laid out must be prepared so that lines drawn on the surface will show distinctly. A rough or unfinished surface is covered with chalk, a finished or bright surface should be copper-plated by applying a thin coating of copper sulphate solution with a brush or a piece of waste. In use, the work and the gage are then placed on a true surface and the scriber adjusted to the desired height. The lines are drawn by moving the surface gage along on the true surface, keeping the point in contact with the work. After scribing the lines, it is well to place light prickpunch marks at frequent intervals along the lines,

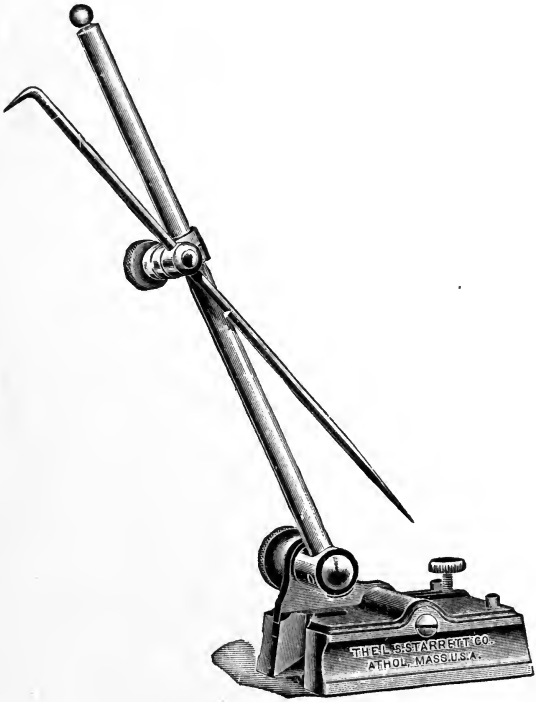


Fig. 1. Universal Surface Gage
Courtesy of the L. S. Starrett Company, Athol, Massachusetts

so that the position may be located if the chalk or copper sulphate becomes effaced.

Straightedge. The straightedge consists, in its simplest form, of a thin flat piece of steel, often unhardened, with accurately finished straightedges. The very small sizes used in fine work are occasionally made with a hardened knife edge. A non-conducting handle is sometimes used with the small sizes to prevent distortion from the unequal heating due to handling. The short lengths used for ordinary shop purposes have one edge beveled and are thick enough to avoid bending, Fig. 2. The larger sizes, from 3 to 10 feet or more in length, are usually made of cast iron with one finished edge. The metal is so distributed as to combine lightness with great rigidity, the tendency of the ends to drop being resisted by the truss-like form of the casting shown in Fig. 3. The flat form is used, in connection with the scriber, to draw accurate straight lines on plane surfaces. All styles are used to test the truth of plane surfaces by placing the straightedge on the surface to be tested in not less than the six positions shown in Fig. 4.

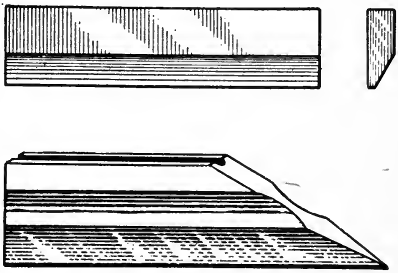


Fig. 2. Steel Straightedge

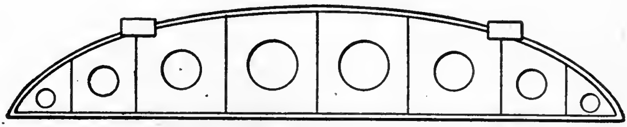


Fig. 3. Cast-Iron Straightedge

Keyseat Rule. For drawing lines and laying off distances on curved surfaces, such as shafts, a combination of two straight-

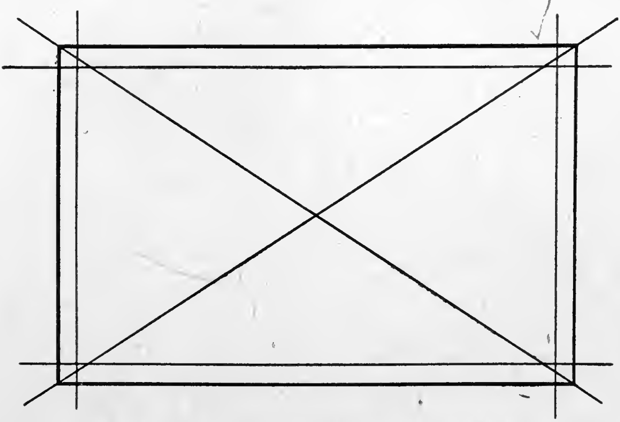


Fig. 4. Diagram Illustrating Use of Straightedge

edges, or a straightedge and a rule, is used. This is often called a keyseat rule because its chief use is laying out keysways on shafts.

However, many machinists call it a box rule. It is usually made in one piece, although some manufacturers provide clamps by which the two separate pieces are held at right angles to one another.

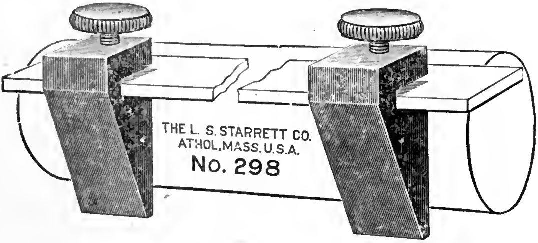


Fig. 5. Keyseat Rule
Courtesy of L. S. Starrett Company, Athol, Massachusetts

A more simple combination is shown in Fig. 5, the second scale being represented by two special clamps.

Flat Square. The simplest form of square, called the flat square, Fig. 6, is a combination of two straightedges at right angles. This is a useful form where the square is laid on the work. One blade is usually graduated on the inner edge, and the other on the outer edge.

Try Square. The try square, Fig. 7, consists of a beam and a blade at right angles. The beam is much thicker than the blade

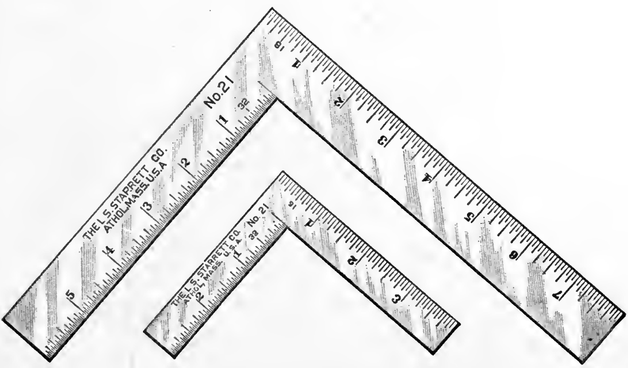


Fig. 6. Thin Steel Squares
Courtesy of L. S. Starrett Company, Athol, Massachusetts

and somewhat shorter. Try squares are made both unhardened and hardened. The unhardened form has graduations on one edge and is termed a graduated try square. The hardened type always has a hardened blade, sometimes a hardened beam as well, and is not graduated.

The try square is used as a guide to draw lines at right angles to each other and to given surfaces; to erect and test perpendiculars to plane surfaces; to test the truth of a given surface at right angles to another surface; in short, wherever an accurate layout or test of 90 degrees is required. When used for testing the relation of two surfaces, the beam is pressed closely against the correct surface, and the blade is brought carefully down to the surface under consideration. This does not prove more than that a line at the particular point tested is or is not at right angles to the true surface. By using the blade as a straightedge parallel to the true surface, errors in that direction may be corrected and the surface be made plane.

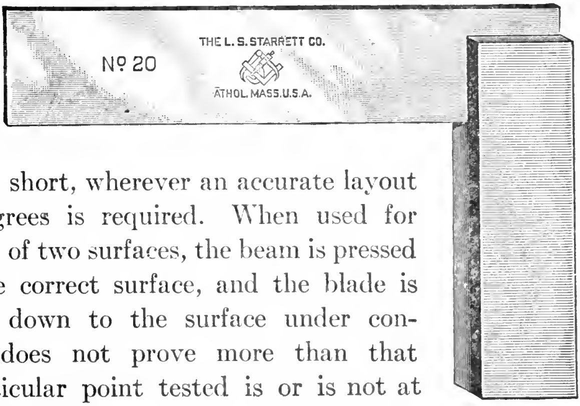


Fig. 7. Steel Try Square

Bevel. In many cases it is necessary to test the relation of lines and surfaces which are not at right angles to each other. For

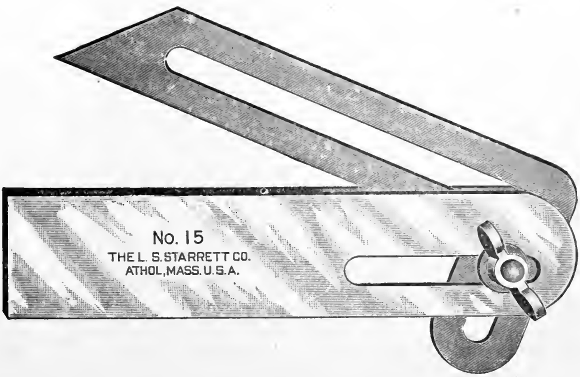


Fig. 8. Universal Bevel
Courtesy of L. S. Starrett Company, Athol, Massachusetts

this purpose a bevel is used in which what corresponds to the blade of the square is made adjustable. Its construction is seen in Fig. 8: its use is similar to that of the square.

Protractor. The bevel can be adjusted only by direct application to lines or surfaces having the proper angular relation. It often happens that such adjustment is not feasible and, therefore, a registering device, in the form of a graduated arc, is applied to the bevel, making what is known as a protractor, Fig. 9. This tool can be used to find the angular relation in degrees or to produce that relation by setting to the proper point on the graduated arc.

Center Square. As the center of a circle is found at the intersection of any two diameters, an instrument for readily finding that point is a great convenience. In Fig. 10 is shown a combination straightedge and square, called a *center square,* which accomplishes this result. As one edge of the rule bisects the angle of the square, it is evident that a line drawn by that edge passes through

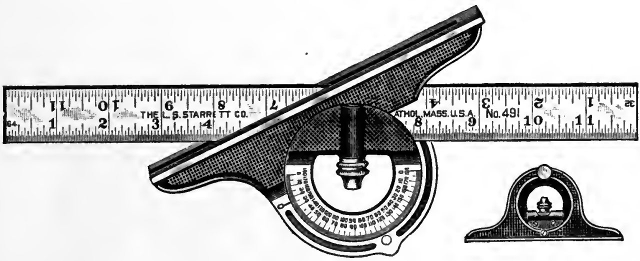


Fig. 9. Protractor
Courtesy of L. S. Starrett Company, Athol, Massachusetts

the center of any circular piece to which the square is applied. Locating centers in the ends of round bars or circular work of any kind is the principal use of this tool.

Combination Set. The center square, bevel, and protractor are furnished in a combination set as shown in Fig. 11. The ability to change the length of the blade is one of the great benefits of this construction.

LINEAR MEASUREMENT

The testing tools thus far described are used for comparing the angular relation of lines and surfaces and may be called tools for angular measurement. We now turn to the consideration of instruments for measuring distances and sizes, or tools for linear measurement.

Carpenter's Rule. The most common tool for linear measurements, and one which hardly requires description, is the so-called carpenter's, or two-foot, rule. This is very convenient for the machinist in making measurements which are not required to be very accurate.

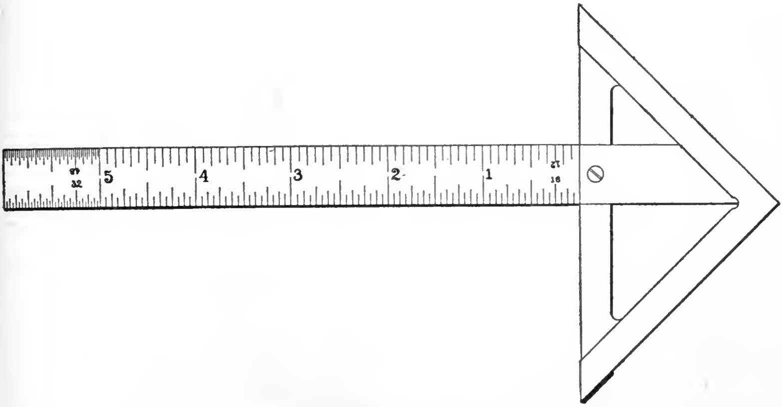


Fig. 10. Center Square

Steel Rule. For work of greater refinement, the standard steel rule, Fig. 12, is used. This is in reality a graduated straightedge and, as such, forms a part of several tools already described. The most common form of steel rule is flat, varying from 1 to 48 inches in length, and carefully hardened and ground. The grad-

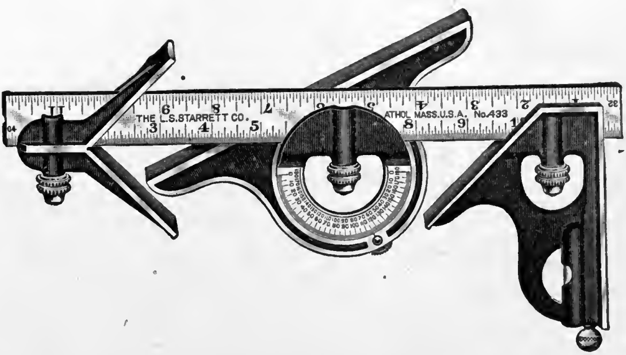


Fig. 11. Combination Set
Courtesy of L. S. Starrett Company, Athol, Massachusetts

uations in the better class of rules are cut with a dividing engine, although the lines may be etched on the surface with a fair degree of accuracy. A thin and somewhat narrower form, called a flexible rule, is made in sizes from 4 to 36 inches. What are known as narrow rules are obtainable from 4 to 36 inches and are of great convenience in certain cases. Besides these shapes, square rules are made in sizes from 3 to 6 inches in length, and the triangular form varies in length from 3 to 12 inches. Steel rules with the English system of graduation can be obtained with the inches divided in eighths, sixteenths, thirty-seconds, sixty-fourths; twelfths, twenty-fourths; tenths, twentieths, fiftieths, and hundredths. Special rules are made with graduations especially adapted to such uses as gear blank sizing, etc.

The ends of flat rules are sometimes graduated, making what might be called a very short rule with a handle. Flat rules are

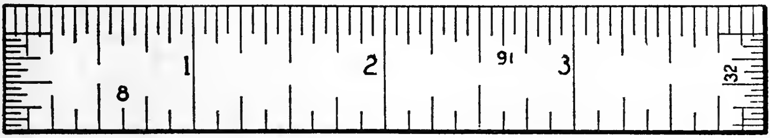


Fig. 12. Steel Rule

sometimes graduated with metric divisions as fine as one millimeter, and from 5 centimeters to 1 meter in length.

Dividers. For transferring and comparing distances, dividers are commonly used. They are classified according to the style of joint and the length of the leg. The most simple joint is the friction and, like all frictional devices, is hard to set accurately. Lock-joint dividers can be moved freely to approximately the right position, the joint locked, and the adjusting screw used for the final setting.

Wing dividers, Fig. 13, are of about the same construction as the lock joint, except that the fastening is made on the wing instead of at the pivot. The best of all forms has a spring adjustment as shown in Fig. 14. In this type, a spring tends to open the dividers, and the legs are closed against the spring by a nut working on a screw which is fastened to one leg and passes freely through the other. The length of dividers varies from $2\frac{1}{2}$ to 10 inches.

The distance to which dividers can be opened is generally about equal to the length of the leg. For distances above 10 inches, trammel points, Fig. 15, are convenient. They consist of hardened steel points attached to metal sockets and can be used on rods of any length. One point may have a spring adjustment and, in that case, can be set in the same manner as a pair of wing dividers.

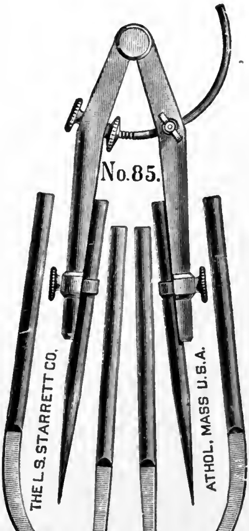


Fig. 13. Wing Dividers

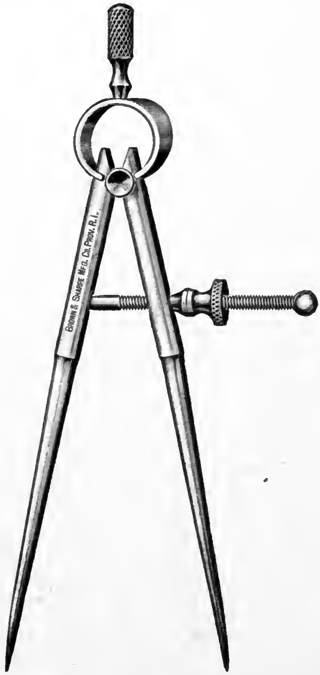


Fig. 14. Tool-Makers' Dividers
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Calipers. *Outside and Inside Calipers.* Instead of having straight legs with sharp points, caliper legs are bent and have blunt points. As distances are to be measured both outside and inside of solid bodies, we have outside and inside calipers. The legs of outside calipers have a large curvature so that the calipers may be passed over cylinders of their greatest capacity.

Inside calipers, Fig. 16, are much like dividers in general appearance, the ends being bent outward slightly and the points rounded. The same styles of joints used in dividers are used in calipers, and

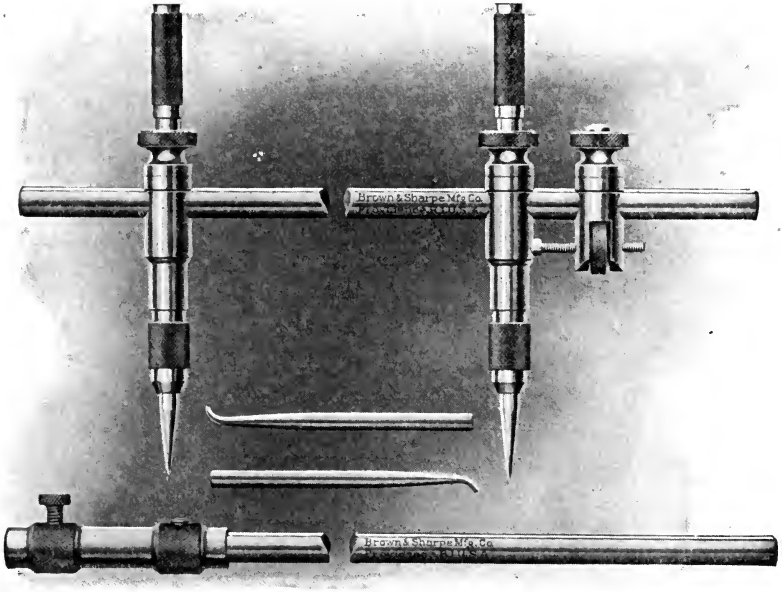


Fig. 15. Steel Beam Trammels
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

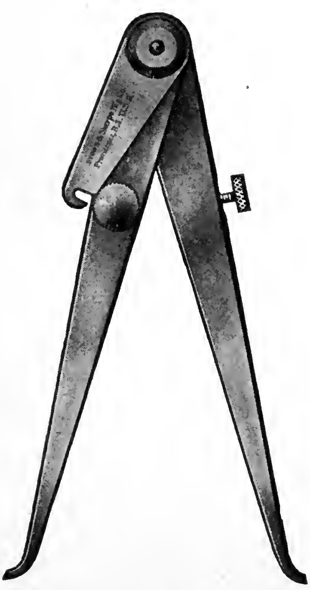


Fig. 16. Brown and Sharpe Inside Transfer Calipers

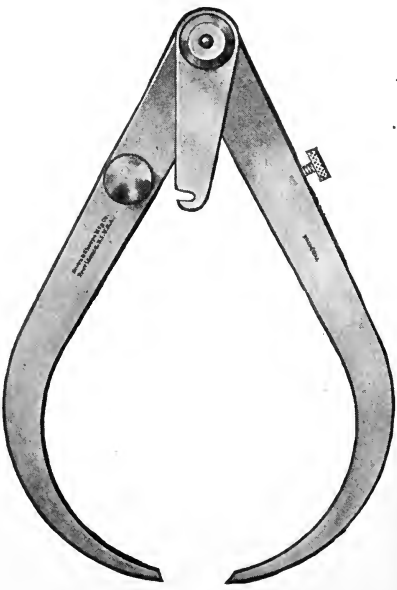


Fig. 17. Brown and Sharpe Outside Transfer Calipers

the size of calipers is also designated by the distance from the joint to the end of the leg. Spring calipers are made in sizes from $2\frac{1}{2}$ to 8 inches, while the other styles vary up to 24 inches.

Transfer Calipers. As it is sometimes necessary to make measurements behind shoulders and in chambered cavities where the ordinary calipers could not be removed after setting, it is necessary to have calipers so arranged that they may be set, changed to clear the obstruction, and then reset accurately in the first position. This is accomplished by transfer calipers, Fig. 17, in which one leg is temporarily fastened to a stub or false leg. After setting, this leg may be moved away from the stub, the calipers withdrawn, and the leg again placed in contact with the stub; the points will then be found to occupy the same position as when first set. Small curved legs may be used in place of points or trammels in calipering large objects.

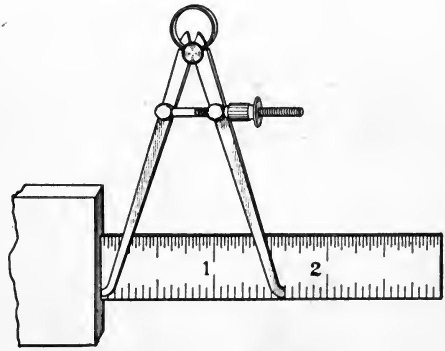


Fig. 18. Setting Inside Calipers

Both dividers and calipers are usually set by means of a scale. In setting dividers, place one point in a graduation of the scale and move the other until it falls easily into another graduation which gives the required distance. Outside calipers are often set by placing one leg against the end of the scale and moving the other until it is opposite the middle of the graduation giving the required length. As the graduations are not mathematical lines but have an appreciable width, this last precaution is one of great importance. Inside calipers are set by placing both the scale and the caliper toe against a plane surface, as shown in Fig. 18; the other toe is then set the same as the outside caliper.

Caliper legs are comparatively slender, spring easily, and care must be taken in using them to see that the contact with the object being tested is very light. It is an easy matter to spring calipers of common sizes as much as one-sixteenth of an inch unless a gentle touch is used in handling them.

Caliper Square. The caliper square is made by attaching a movable blade to the common square. In the ordinary forms it closely resembles a steel rule with two arms extending from it at right angles, one fixed near the end and the adjustable arm sliding along the scale with a clamping device for adjusting this movable arm. In order that the movable arm may be set accurately, caliper squares, Fig. 19, as at present constructed have two clamps for the movable arm. The one carrying the thumb nut is to be first clamped in approximately the right position, the clamp on the movable arm being secured after the adjustment has been made by the nut.

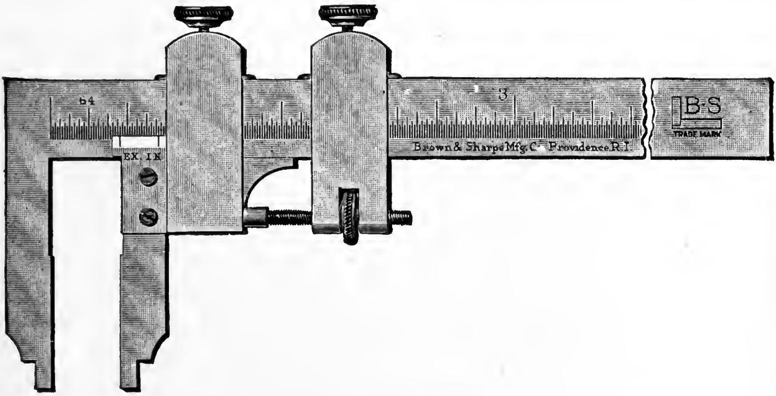


Fig 19. Caliper Square
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

The sizes used vary from 3 inches up, and are limited only by the length of rule obtainable.

Micrometers. For measurements which are required to be more accurate than can be obtained by the preceding forms of calipering devices, the micrometer caliper, Fig. 20, is used. The accuracy of its measurements is determined, not by direct setting to two lines, but by finely dividing the pitch of the measuring screw and furnishing means for reading these subdivisions. It is a registering as well as an indicating caliper, and thus serves the purpose of a common caliper in combination with a rule, but with a much greater degree of accuracy.

The micrometer caliper consists, essentially, of a crescent-shaped frame carrying a hardened steel anvil *B* at one end and a nut of fine pitch at the other, the axis of the nut being at right angles to the face of the anvil. The outside of the nut *A* forms a projection beyond the crescent that is called the *barrel.* The measuring screw consists of a fine-pitched screw to fit the nut, combined with a measuring point *C*, having a face parallel with that of the anvil. Firmly attached to the outer end of this screw is a thimble *D*, fitting closely over the barrel; the edge of this thimble is beveled so that graduations placed on the edge come very close to the barrel. A reference line is drawn on the barrel parallel to its axis and graduated to represent the pitch of the screw. The chamfered edge of the thimble is so divided that the movement of one division past the reference line on the barrel indicates a movement of the measuring

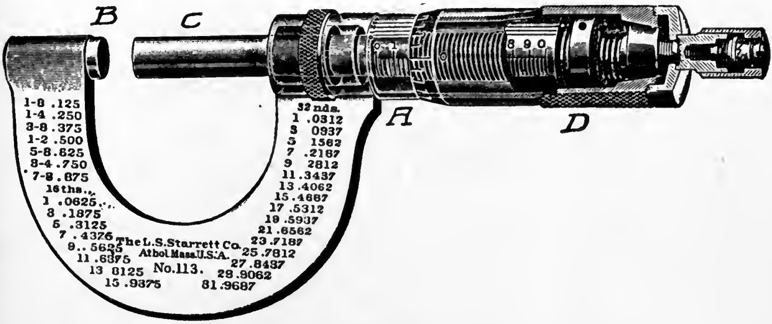


Fig. 20. Transparent View of Micrometer Caliper with Friction Stop
Courtesy of L. S. Starrett Company, Athol, Massachusetts

point of one-thousandth of an inch. For example: if the pitch of the measuring screw is one-hundredth of an inch, there should be 10 divisions on the thimble, if one-fiftieth of an inch, 20 divisions; if one-fortieth of an inch, 25 divisions; if one twenty-fifth of an inch, 40 divisions. Measuring screws having a pitch of one-fortieth of an inch are usually used, and every fourth division on the barrel lengthened and numbered to indicate tenths of an inch, as shown in Fig. 21.

In using the micrometer caliper, it should not be set at the size required and pushed over the work, but should first be opened, then screwed down until the measuring point *C* and anvil *B* are in contact with the work; the size may then be read from the relation of the thimble to the reference line on the barrel. The proper degree of pressure to be applied to the screw is acquired only after extended practice, and some manufacturers place a friction device on the thimble so that undue pressure cannot be exerted.

The micrometer caliper will not only indicate that the work is too large or too small, but will also show exactly the amount by which it differs from the desired measurement. This is a great improvement over the rigid form of calipers, and enables the workman to judge more accurately the progress of the work. As the micrometer caliper is rapidly coming into favor in spite of its cost, it has been described more at length than the common forms previously considered.

The range of motion of the measuring screw is usually limited to one inch, but various devices give the micrometer caliper a

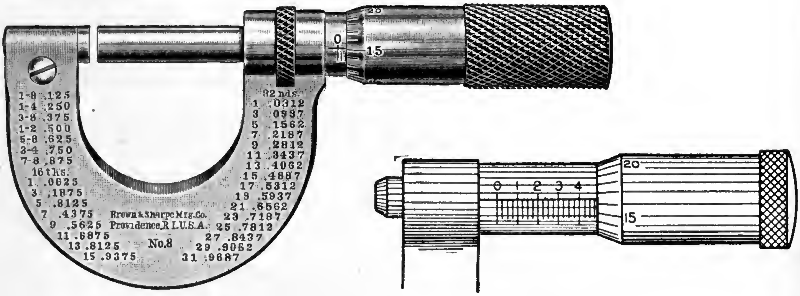


Fig. 21. Ordinary Micrometer Caliper Showing Typical Reading

larger range of action. Micrometer calipers may now be purchased in combinations or sets, with a range from zero to 20 inches.

The application of the micrometer principle to inside measurements is not in general use, but is easy to arrange, and makes a very simple instrument, as shown in Fig. 22. It consists of an ordinary micrometer head, except that the outer end of the thimble carries a contact point, attached to a measuring rod which may be of any length. The shortest distance that can be measured with this device is about 2 inches, but there is hardly any limit in length, as the rigidity of the rod is easily provided for. It is evident that such rigidity is harder to obtain in the curved shape necessary for outside measurement and thus limits this form to about 20 inches, as above stated. The contact points in the outside type are parallel plane surfaces, and in the inside form they are rounded points of small radius. Outside micrometers are provided with contact points of varying forms for measuring paper, threads, walls of tubes, etc.

Reading the Micrometer. Reading in thousandths. As stated, the micrometer screw has usually forty threads per inch and the thimble has twenty-five divisions on its circumference. The barrel is divided to correspond to the pitch of the screw with each fourth division numbered. In reading the indicated measurement, first note the highest number visible on the barrel and call it hundreds

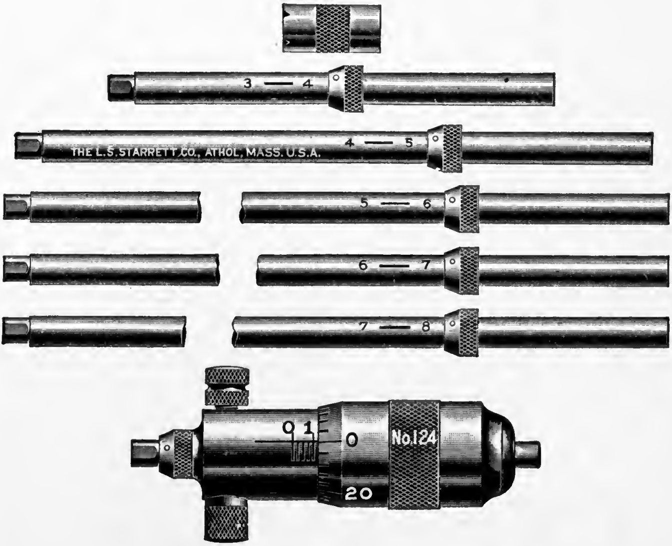


Fig. 22. Inside Micrometers
Courtesy of L. S. Starrett Company, Athol, Massachusetts

of thousands—in Fig. 21 it is 400 thousandths or .400; then read the short divisions on the barrel, calling the first division 25 thousandths, or .025; the second, 50 thousandths, or .050; and the third, 75 thousandths, or .075. In Fig. 21 the third division is the last one visible. Now read the number indicated on the thimble, that is, the number that has passed the line running lengthwise. In the figure it is 16; or $16\frac{1}{2}$ if the reading is to be finer than thousandths. Add this reading to the readings of the short divisions, thus: $75 + 16\frac{1}{2} = 91\frac{1}{2}$; this is $.091\frac{1}{2}$. Adding the .400 to this we get $.491\frac{1}{2}$. This means that the distance from the anvil to the measuring point is

$\frac{4915}{10000}$ of an inch, or .4915 inch. If the micrometer caliper is a good one, we may be sure the distance is between .491 inch and .492 inch.

Reading to Ten-Thousandths. In reading measurements finer than thousandths, use is made of a Vernier. The following description tells how to read a ten-thousandths micrometer: As applied to a micrometer, the Vernier consists of ten divisions on the sleeve which occupy the same space as nine divisions on the thimble. The difference of width of one of the ten spaces on the sleeve and one of the nine spaces on the thimble is one-tenth of a space on the thimble. In Fig. 23 at *B*, the third line from the zero on the thimble coincides with the first line on the sleeve. In opening the tool by turning the

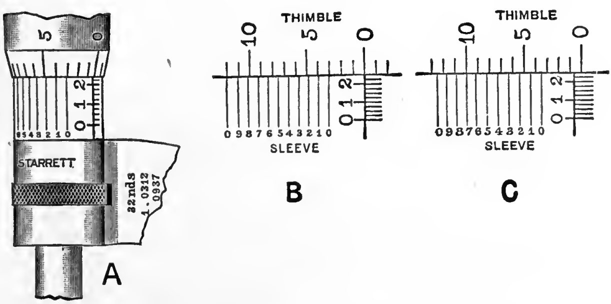


Fig. 23. Diagrams Showing How to Read Micrometer Caliper

thimble to the left, each space on the thimble represents an opening of the tool equal to one-thousandth of an inch. If the thimble be turned so the lines marked *5* and *2* coincide, the tool will have been opened two-tenths of one-thousandth, or 2 ten-thousandths. At *C* the thimble has been turned until line *10* matches with line *7* on the sleeve. The tool has therefore been opened 7 ten-thousandths. Therefore, first note the thousandths as in reading the ordinary micrometer, then observe the line on the sleeve which matches with a line on the thimble. If it is the second line, marked *1*, add one ten-thousandth to the previous reading; if the third line, marked *2*, add 2 ten-thousandths, etc.

Vernier Calipers. A common use of a Vernier is its application to a caliper square, termed a Vernier caliper. Fig. 24 shows a representative tool.

How to Read the Vernier. The following text represents the L. S. Starrett instructions for reading their tool:

The scale of the tool is graduated in fortieths, or .025 of an inch, every fourth division, representing a tenth of an inch, being numbered. On the Vernier plate is a space divided into twenty-five parts and numbered 0, 5, 10, 15, 20, 25. The twenty-five divisions on the Vernier occupy the same space as the twenty-four divisions on the scale.

The difference between the width of one of the twenty-five spaces on the Vernier and one of the twenty-four spaces on the scale is, therefore, $\frac{1}{25}$ of $\frac{1}{40}$, or

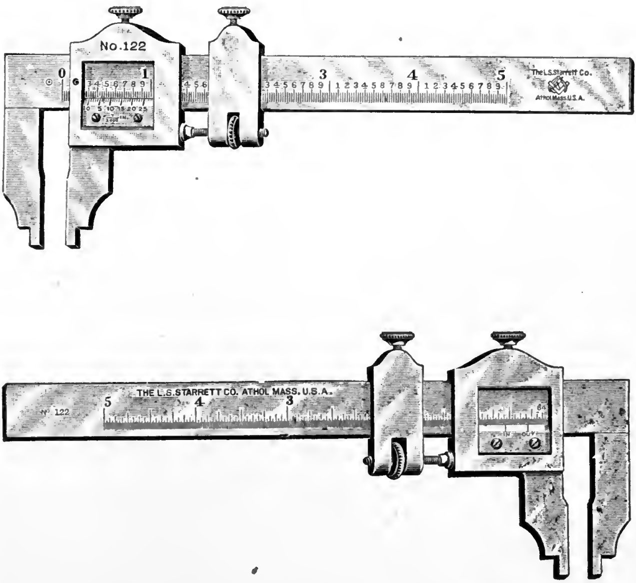


Fig. 24. Front and Back View of Vernier Caliper
Courtesy of L. S. Starrett Company, Athol, Massachusetts

$\frac{1}{1000}$ of an inch. If the Vernier is set so that the 0 line on the Vernier coincides with the 0 line on the scale, the next two lines will not coincide by $\frac{1}{1000}$ of an inch; the next lines will be two thousandths apart, and so on.

To read the tool, note how many inches—tenths, or .100, and fortieths, or .025—the 0 mark on the Vernier is from the 0 mark on the scale; then note the number of divisions on the Vernier from 0 to a line which exactly coincides with a line on the scale.

In Fig. 25 the Vernier has been moved to the right one and four-tenths and one-fortieth inches (1.425″), as shown on the scale, and the eleventh line on the Vernier coincides with a line on the scale. Eleven thousandths of an inch are therefore to be added to the reading on the scale, and the total reading is one and four hundred and thirty-six thousandths inches (1.436″), which is the distance the jaws of the tool have been opened.

In making inside measurements, the width of the jaws, as given in the list, is to be added to the apparent readings on the side having the Vernier to allow for the space occupied by the measuring points. No such allowance is necessary when using the back side, without Vernier, as the two lines marked "in" and "out" indicate inside and outside measurements.

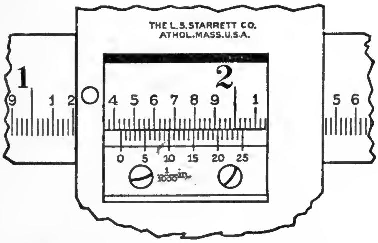


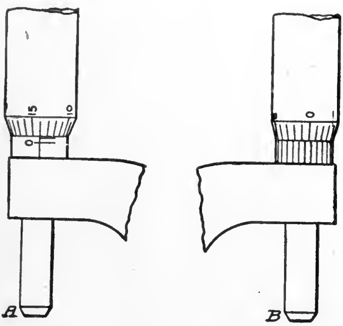
Fig. 25. Enlarged View of Vernier

EXAMPLES FOR PRACTICE

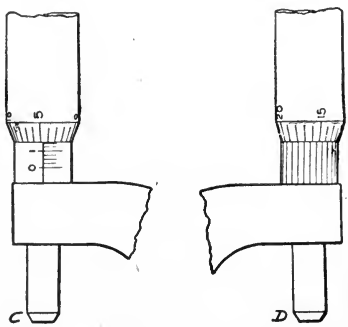
1. A micrometer caliper shows a reading of .463; how many times must the thimble be turned to produce a reading of .587? (Assume 40 threads per inch.) Ans. $4\frac{24}{25}$ times

2. What are the readings of the micrometer calipers shown in Figs. 26 and 27? Ans. .039

3. State the readings of the micrometer calipers shown in Figs. 28 and 29. Ans. .1546



Figs. 26 and 27. Positions of Caliper for Example 2



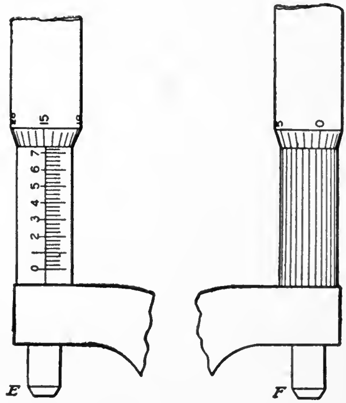
Figs. 28 and 29. Positions of Caliper for Example 3

4. Give the readings of the micrometer calipers shown in Figs. 30 and 31. Ans. .7398

5. Sketch the front and back of a micrometer caliper when the reading is .6327.

6. What is the reading of the Vernier and scale when in position Fig. 32? Ans. 6.36

Fixed Gages. While the adjustable tools just described are available for a large range of work, gages of one dimension, or fixed gages, are used to a considerable extent, especially in shops where work of a duplicate character is produced in large quantities. These may be used for standards to which adjustable gages may be set, or used directly in connection with the work in the same manner as an adjustable gage. One form of such gages for comparisons of length is a steel rod with the ends carefully ground so that the distance required may be quickly and accurately determined. In one form the ends are parallel plane surfaces, and in another the ends are sections of a sphere of the same diameter as the length of the rod. Both these forms are illustrated in Fig. 33. Another form of gage for the same purpose consists of hardened and ground steel discs, Fig. 34, to which calipers and similar tools may be set, and which may be used also to test the size of holes by direct application. For the latter purpose, handles are provided by which the discs can be conveniently manipulated.



Figs. 30 and 31. Positions of Caliper for Example 4

Plug and Ring Gages. Plug and ring gages, Fig. 35, furnish accurate and convenient standards for the production of duplicate parts of machines. The same result is attained by the caliper gage, Fig. 36, which combines the two gages in one piece. In this form the external gage has parallel plane surfaces and the internal gage is a section of a cylinder. In sizes above 3 inches,

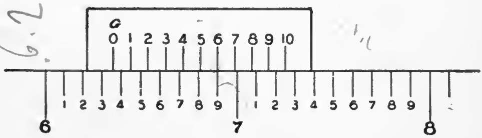


Fig. 32. Position of Vernier for Example 6

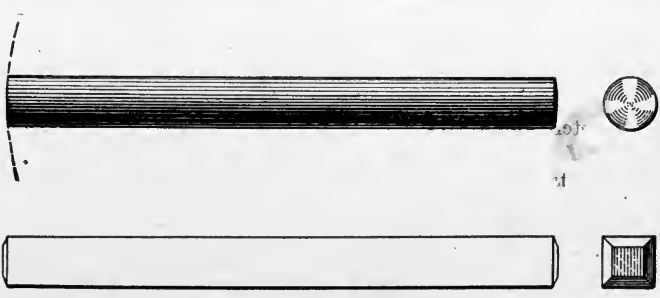


Fig. 33. End Measuring Rods

the caliper gage is usually made in two parts, making the tool easier to handle.

As is indicated by the cost of these gages, the exact duplication of such exact sizes in quantities would mean a cost that would be prohibitive in machine construction. The limit of error in the standard gages just described is never over one ten-thousandth of an inch at a standard temperature, which is usually taken as 70° F. Ordinary machine parts do not require such accuracy, and it is usual to allow a limit of error which is in accordance with the class of work being produced.

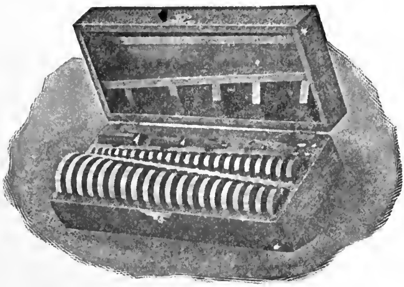


Fig. 34. Set of Ground Steel Disc Gages
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Limit Gages. For testing sizes and dimensions, both at the machine and in the inspection department, combination fixed gages,

Fig. 35. Typical Plug and Ring Gages
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

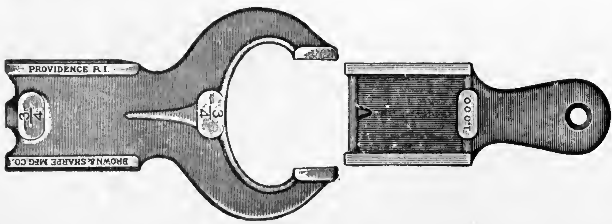


Fig. 36. Caliper Gages
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

known as limit gages, are employed. These are made both for external and internal measurements. The external gage, Fig. 37, is for testing pieces supposed to be .250 inch in diameter. As indicated by the figures on the gage, the piece is allowed a variation of .0005 inch over and .001 inch under the nominal size. The words "go on" and "not go on", stamped near the ends, indicate clearly how the

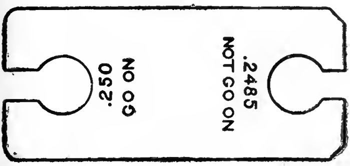


Fig. 37. Limit Gage with Jaws Opposite

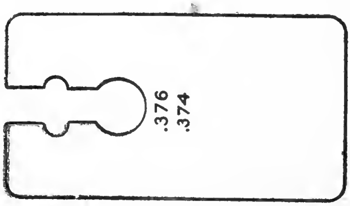


Fig. 38. Limit Gage with Jaws in Series

gage is used. A more convenient arrangement of this gage is shown in Fig. 38, in which the work must enter the first parallel opening, but must not pass through the second. In this form, one motion tests the piece for variation above and below the standard. Fig. 39 shows a limit gage for holes, the end marked "go in" being required to pass into the hole, while the other end, marked "not go in", must not enter. An arrangement of the internal limit gage similar to the external gage of Fig. 38 is shown in Fig. 40, and has the same advantages.

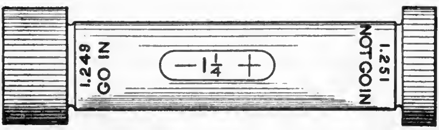


Fig. 39, Limit Gage for Holes

In some classes of work no variation is allowed over the standard size, and in other classes no variation is allowed under the nominal size. The amount of variation allowed in any case is governed by the class of work and the intended use of the piece. As these allowances are not uniform, such gages are not kept in stock but are made only to order.

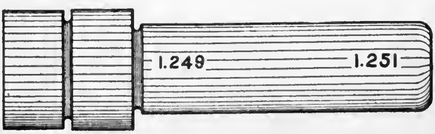


Fig. 40. Limit Gage for Holes with Limits in Series

For many years gages of an entirely different character have been used in the measurement of wire, small rods, and sheet metal. The sizes have been designated, not by the diameter or any definite unit, but by a number or letter in a purely arbitrary manner. Even in the same gage, the sizes do not advance in any regular order.

The matter is still further complicated by the fact that in one gage large numbers indicate large sizes, while in another, the smaller numbers mark the large diameters. Another source of annoyance lies in the fact that such gages are cheaply made and cannot be relied upon to be duplicates of one another. Most of these gages had their origin in days when refined measurements were not common, but since the use of the micrometer caliper has become almost universal, there seems to be no good reason why all sizes should not be expressed in thousandths of an inch, thus avoiding the troubles incident to the use of the arbitrary gages.

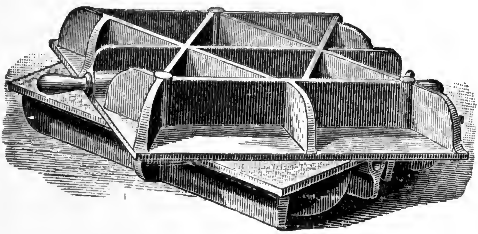


Fig. 41. Cast-Iron Surface Plate
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Surface Plates. For the production of accurate plane surfaces the use of the straightedge is not sufficient. Such surfaces should be compared with standard surfaces, called surface plates, Fig. 41. A surface plate is a cast-iron plate strongly ribbed on the back to prevent distortion, and supported on three points to insure a uniform base. Their production and use will be described under the head of "Scraping". They may be had in sizes varying from 3 inches by 4 inches to 36 inches by 72 inches.

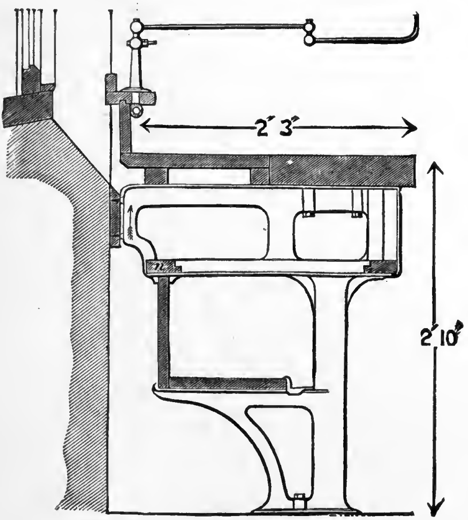


Fig. 42. Work Bench
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Work Bench. The machinist's bench at which hand work is ordinarily performed should be of substantial character, about 2 feet 10 inches from the floor and 2 feet 3 inches wide, Fig. 42. For the sake of economy it is usual to have a $2\frac{1}{2}$- or 3-inch plank at the front to which the vises are fastened and on which all the heavy work is done, while the rear of the bench is made from 1-inch lumber. Maple and birch are preferred as materials for a bench, although ash makes a very good substitute.

Work Vises. In order that work may be held rigidly for the performance of hand operations, the machinist uses what is termed a vise. They are made in a great variety of forms and sizes, but all

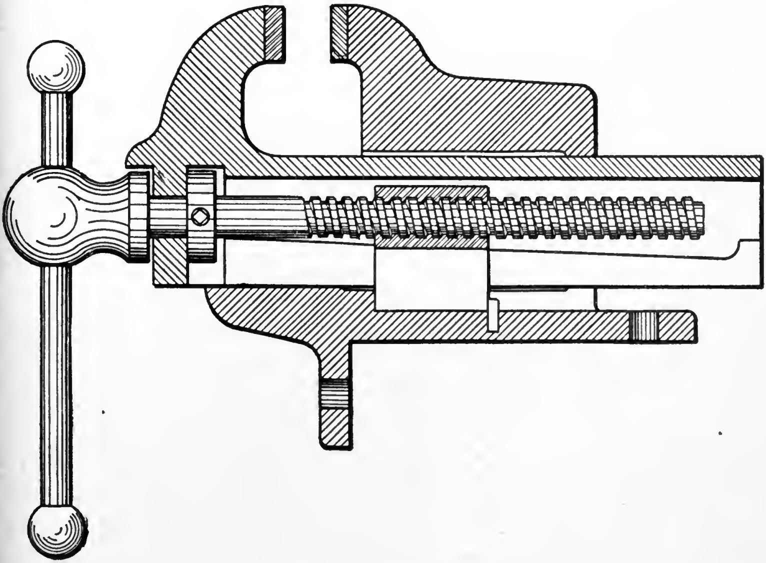


Fig. 43. Bench Vise

consists essentially of a fixed jaw, a movable jaw, a screw, a nut fastened to the fixed jaw, and a handle by which the screw is turned in the nut and the movable jaw brought into position. The sectional view, Fig. 43, shows these parts clearly and also a device, present in some form in all vises, by which the movable jaw is separated from the fixed jaw when the screw is backed out of the nut.

In the machinist's vise, both jaws are made of cast iron with removable faces of cast steel. These may be checkered to provide a firm grip for heavy work, or may be smooth to avoid marking the surface of the plate operated upon. When holding soft metal, even the smooth steel jaws would mar the surface; and in such cases it is customary to use false jaws of brass or Babbitt metal, or to fasten leather or paper directly to the steel jaws. The screw and handle are made from steel and the nut from malleable iron.

The common method of fastening a vise to the bench is by means of the fixed base shown in Fig. 43, although a swivel base such as is shown in Fig. 44 is preferable. The vise shown in Fig. 44 also has a swivel jaw, which enables it to hold tapered work securely. This swivel jaw is provided with a locking-pin, which fixes the jaws

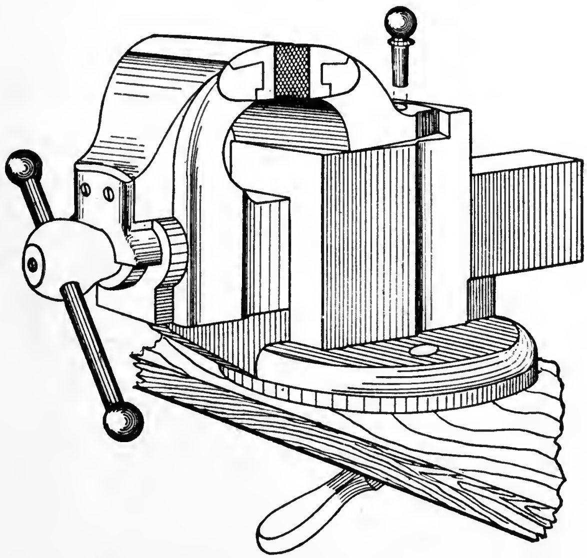


Fig. 44. Swivel Work Vise

in a parallel position. The height of the vise from the floor depends somewhat on the class of work to be performed, but a general rule is to have the top of the jaws about $1\frac{1}{2}$ inches below the point of the elbow when standing erect beside the vise.

HAMMERS

Classification. The machinist uses hammers of three shapes: ball peen, cross peen, and straight peen, Fig. 45. The ball peen is the most common; it varies in weight from 4 ounces to 3 pounds. The cross peen and straight peen hammers vary from 4 ounces to 2 pounds and are used principally in riveting. Hammers are made from a good grade of tool steel, hardened, and drawn to a blue color at the eye and a dark straw on the face and peen. The eye is elliptical in shape, and the handle is fastened by driving wedges, either wood or iron, into the end of the handle, thus spreading it to fill the eye. The handle is of hard wood, preferably hickory, and of a length suited to the weight of the hammerhead. When the handle is properly inserted, the axis of the head stands at right angles to the axis of the handle.

Soft Hammers. Soft hammers are used for striking heavy blows where the steel hammer would bruise the metal or mar the surface. They are made of rawhide, copper, or Babbitt metal, and vary in weight from 6 ounces to 6 pounds. They are subject to

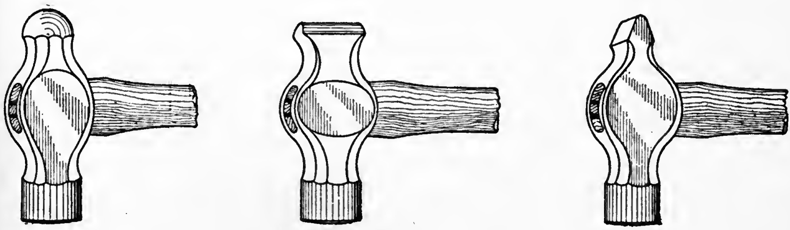


Fig. 45. Hand Hammers

rapid wear, but are indispensable in setting up and taking down machinery. Those of metal are so constructed that the soft metal can be recast in the handle.

CUTTING TOOLS

Chisels. The simplest form of metal-cutting tool is the chisel. The several types in common use are shown in Fig. 46.

Flat Chisel. The flat chisel is used for snagging castings, for chipping surfaces having less width than the edge of the chisel, and for all general chipping operations. It is the form most commonly used, and is often called the cold chisel. Generally it has a cutting edge about an eighth of an inch wider than the stock from which it is forged.

Cape Chisel. The cape chisel is used for cutting keyways, channels, etc., and also for breaking up surfaces too wide to chip with the flat chisel alone. Channels are driven across such a surface, leaving raised portions or "lands" to be removed by the flat chisel. The cutting edge of this chisel is usually an eighth of an inch narrower than the shank, and the part just in the rear of the cutting edge is made thin enough to avoid binding in the slot. As this weakens the chisel, it is made comparatively thick in the plane at right angles to the cutting edge.

Diamond Point. The diamond point chisel is made by drawing out the end of the stock to about $\frac{5}{16}$ inch square, and grinding the end at an angle with the axis of the chisel, leaving a diamond-shaped point. It is used for drawing holes, making oil grooves, and cutting holes in flat plates.

Round Nose. The small round-nosed chisel is cylindrical in section near the cutting end, the edge being ground at an angle of 60 degrees with the axis of the chisel. When used to "draw" the starting of drilled holes to bring them concentric with the drilling

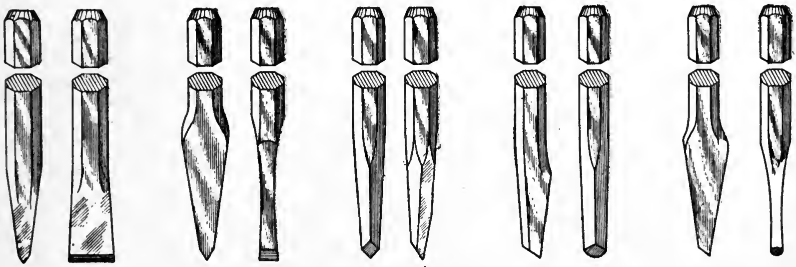


Fig. 46. Hand Chisels

circles, they are called center chisels. The round-nosed chisel is also used for cutting channels, such as oil grooves and similar work. The larger sizes of round-nosed chisels are of the general shape of the cape chisel with one edge rounded, making a convex cutting edge. Large round bottomed channels and all concave surfaces are the proper work of the round-nosed chisel.

All the accompanying forms should be made from a good grade of tool steel, carefully forged, hardened, and tempered to a purple color. The stock generally used is octagonal, and the chisels for heavy work are about 8 inches long and $\frac{3}{4}$ inch in diameter.

Cutting Edge of Chisel. The two bevels forming the cutting edge of a chisel should make with each other as small an angle as is possible without leaving the cutting edge weak. If the angle is too small, the chisel will soon become dull, while if large, more force will be required to drive it. The best angle for cutting cast iron, all things considered, is about 70 degrees, while for wrought iron and mild steel a slightly smaller angle, say 60 degrees, will be better. When there are two bevels, they should be alike in width and form equal angles with the center line of the chisel. Small round-nosed chisels and some slotting chisels are ground one-sided, that is, with but one bevel like a wood chisel. The angle between the surfaces which form the cutting edge should be the same, whether these surfaces are both bevels, or one a bevel and the other the straight side of the chisel. In a one-sided chisel, therefore, the angle that the bevel forms with the center line of the chisel should be twice as large as in one having two bevels.

To cut well, chisels should be sharp and, therefore, should be ground at once when they become dull. This may be done on an emery or carborundum wheel, not finer than No. 60, care being taken to avoid heating, which draws the temper and spoils the tool.

Fig. 47. Bench Chipping

Chipping. Chipping is a term applied to the removal of metal with the cold chisel and hammer. The degree of accuracy required varies. The piece is held in a vise, and the method of working is to grasp the chisel firmly with the left hand, holding the cutting edge to the work and striking the head of the chisel with the hammer, keeping the eyes on the edge of the chisel to watch the progress of the work, Fig. 47. The lower side, or bevel of the chisel, is the guiding surface and is held at a very slight angle with the finished portion of the work, the cutting edge only touching. Raising or lowering the shank of the chisel increases or decreases the inclination of the guiding bevel and causes the chisel to take a heavier or lighter cut. If the hand is carried too low, the chisel will run out before the end of the cut; while if the hand is raised too high, the progress will be slow, owing to the resistance offered by the metal to separation. The depth of the cut taken with a cold chisel should never be more than an eighth of an inch.

When chipping wrought iron or steel, a piece of waste saturated with oil should be kept on the bench and the edge of the chisel frequently thrust into it. This lubricates the surfaces in contact and preserves the cutting edge of the chisel. While lines are used as guides in chipping operations, it is never advisable to bring the surfaces too near them with the chisel; sufficient stock must be left so that the surfaces may be finished with a file. This is especially to be observed in chipping keyways with a cape chisel; an ample margin for filing should be left both on the sides and on the bottom.

FILES

Characteristics. The file differs from the chisel in having a large number of cutting points instead of one cutting edge and in

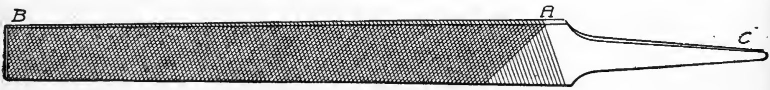


Fig. 48. Hand File

being driven directly by the hand instead of by the hammer. As hand power only is used, it is evident that the amount of metal removed at one stroke will be small, and the amount removed by a single tooth will be exceedingly small.

Files are made from cast or crucible steel and in manufacture pass through the successive processes of forging, annealing, grinding, cutting, hardening, and tempering. They have three distinguishing features—length, kind or name, and cut or coarseness of teeth. Length is measured from the heel *A* to the point *B*, Fig. 48, the tang *C* not being included. These lengths vary from 3 inches to 20 inches.

Classification of Style and Cuts. There are many kinds of files manufactured. Those in common use are shown in section in Fig. 49

as follows: *A*—flat file; *B*—hand file; *C*—warding file; *D*—square file; *E*—three square or triangular file; *F*—half round file; and *G*—round file.

The cut of files is in two styles—single and double; and each style has several grades of coarseness, viz, coarse, bastard, second-

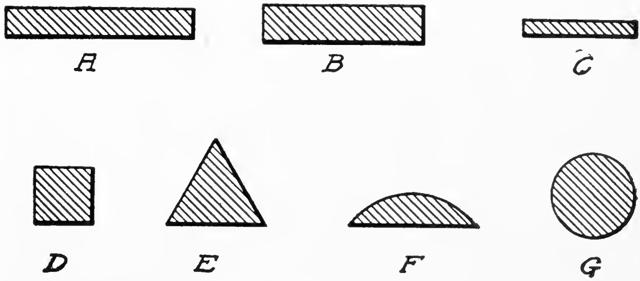


Fig. 49. Cross-Section of Files

cut, smooth, and dead smooth. The last two grades are sometimes called fine and superfine. As is shown in Fig. 50, the coarseness of each style varies with the length—the longer the file the coarser the cut.

Convexity of Files. If the cutting surface of a file were perfectly flat, the number of teeth or cutting points engaged with the work would depend on both the width of the file and the width of the piece being filed. To force as many cutting points as would be contained in such a large area deeply enough into the metal to enable each to remove its share of the stock would be beyond the power of the man pushing the file. To avoid this necessity for great pressure, files are usually "bellied" or made slightly convex in the direction of their length, so that, theoretically, the file and the work are in contact only on a line as long as the width of the file. This enables the file to be forced into the metal sufficiently for the teeth to bite, and thus avoids dulling the teeth, which always occurs when the file is allowed to glide over the work without sufficient cutting.

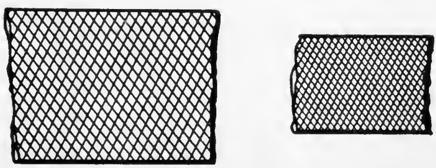


Fig. 50. Diagram Showing Coarseness of Files

This convexity of files also serves another purpose. The pressure applied to the file to make it bite bends the file more or less, Fig. 51, and if the file in its natural state were perfectly flat, when cutting it would be concave; and this would prevent the production

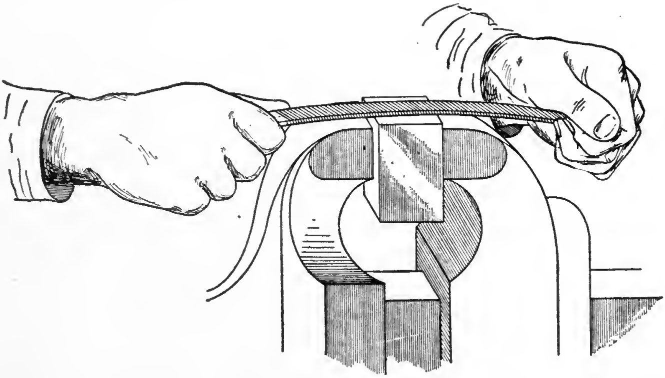


Fig. 51. Bench Filing

of a flat surface as it would cut away at the edges of the work, leaving a convex surface. Such files might, however, be used on convex surfaces.

Height of Work for Different Classes of Files. Work for filing is usually held in a vise, and, under ordinary circumstances, the

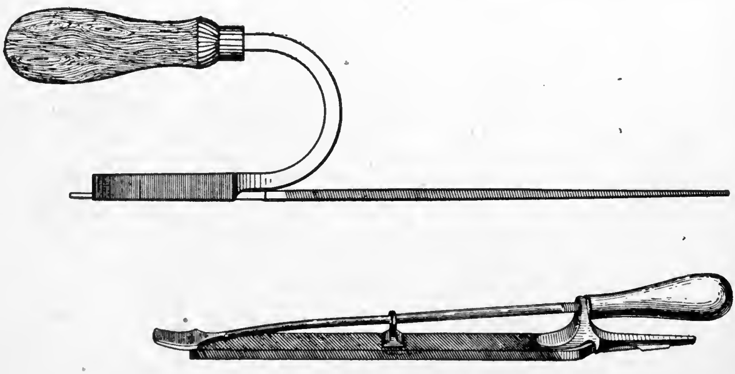


Fig. 52. Special File Holder

surface of the work should be about the height of the elbow. For fine work with small files, where close observation is of more importance than pressure on the file, the work should be higher than this, the height increasing with the refinement of the work. On the other hand, for very heavy filing, where great pressure is absolutely necessary, the work should be several inches below the point of the elbow, so that the weight of the body may be used to good advantage, and also because the workman naturally stoops a little when exerting a great pressure on the file.

File Handles. The handles commonly attached to files are of wood and are made to fit the hollow of the hand. The handle is driven onto the tang of the file, a ferrule on the handle preventing it from splitting. Care should be taken to have the axis of the handle parallel with the file. A good way to prepare the handle for the tang is to heat the tang to a dull red, the file proper being kept cool by a piece of wet cotton waste, and the hole in the handle burned out until the tang is almost in the position it is designed to finally occupy. After cooling the tang, very little driving will be required to securely fasten the handle to the file.

Fig. 53. Bench Filing Position

When filing surfaces of such size that the handle as ordinarily applied would interfere with the use of the file, the tang may be bent up to an angle so that the handle will clear the surface. Various forms of holders are used for filing under these circumstances, the simplest forms being shown in Fig. 52.

Correct Filing Position. The correct position for filing is about as follows: feet about 8 inches apart and at right angles, the left foot being in line with the file; stand back from the vise so that the body may follow the file slightly; grasp the file handle with the right hand, fingers below, thumb on top of, the handle. For coarse filing, place the ball of the thumb of the left hand on the point of the file, and for fine filing grasp the point of the file with the thumb and forefinger of the left hand, Fig. 53. When holding the file in one hand, as is often done in light work, the forefinger should be on top of the file, pointing in the direction of its length, as is shown in Fig. 54. This allows free movement of the hand and wrist, pressure being applied principally by the forefinger.

As file teeth or cutting edges point toward the end of the file, it is evident that the file can cut only when moving in a forward direction. On the return stroke, the pressure should be relieved; otherwise the teeth will be dulled when drawn back over the surface.

Choice of Files Depends on Work. The kind of metal being worked determines in a great measure the character of the file to be used. Cast iron, especially if the scale has not been previously removed, is particularly hard on a new file, as the glassy character

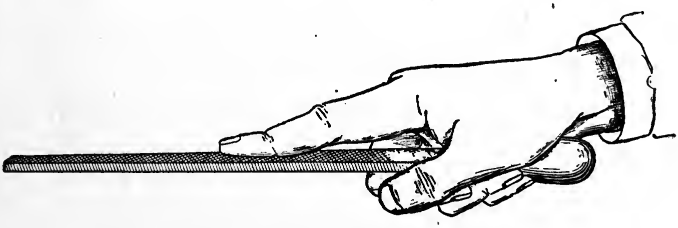


Fig. 54. Position for Single Hand Filing

of the scale tends to dull the cutting edges. New files should never be used on such a surface. It is found that on tool steel, and on hard materials generally, a second-cut file is better than the bastard. This is because if pressure enough is exerted to cause the coarse teeth of the bastard to bite into the work, the teeth, being comparatively long, are very likely to be broken off. In the second-cut file, the teeth are shorter and present more cutting points in a given area, thus preventing excessive duty being imposed on a few teeth.

Softer metals, such as brass and bronze, allow the use of the coarser grades.

Cleaning File. The particles of metal removed by a file frequently remain in the teeth and diminish their cutting qualities. In the case of hard metals, these particles, or "pins", often scratch the work. It is necessary, therefore, that files be frequently cleaned. This may be done in a measure by striking the edge of the file lightly against the bench or vise, but it is more effectually performed by using a stiff brush or a piece of card clothing, Fig. 56. In the finest grades of files, a thin piece of wood or sheet brass may be drawn across the surface of the file as shown in Fig. 55, and the filings are removed by the points extending into the file teeth.

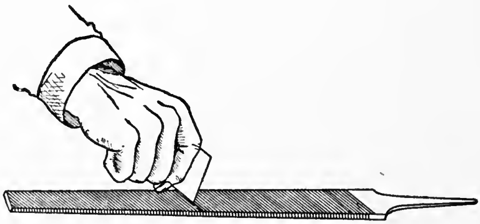


Fig. 55. Removing Pins from a File

When filing cast iron, neither the file nor the work should be allowed to become greasy, as this tends to make the file slide without cutting. In filing steel, however, if the file be oiled or filled with chalk, the pinning of the file is prevented in a large degree, and frequent use of the card or brush is not necessary.

Draw Filing. What is known as draw filing is done by grasping the file at each end and moving it sidewise across the work, Fig. 57. The amount of stock removed by this process is usually very small, the object being to lay the file marks parallel to the length of the work. For draw filing, single-cut files are better than double-cut as they are less likely to scratch the work. The remarks concerning cleaning, oiling, and chalking apply both to cross filing and draw filing.

Polishing. No matter how carefully filing is done, it does not leave a surface that is pleasing to the eye; the file marks are more or

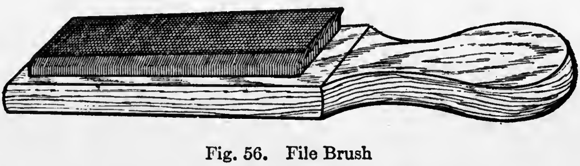


Fig. 56. File Brush

less irregular and the whole surface is dull. Exposed parts of machines which are not painted are usually polished. Polishing does not necessarily improve the surface, but simply brightens it and renders it more attractive. As a rule, a polished surface is not a true surface, no care being taken to maintain its trueness. In ordinary machine work, polishing is usually done by abrasives, such as emery, corundum, and carborundum; while rouge, crocus, rottenstone, and tripoli are used on fine work, especially on brass and composition. Emery, for example, is crushed and sorted into grades varying from No. 8 to flour, the number of the grade indicating the number of meshes per linear inch in the sieve used in sorting. These grades sometimes bear arbitrary designations, No. 1 indicating a coarse grade and Nos. 0, 00, 000, 0000 showing the finer grades.

Methods of Using Powders and Cloths. Emery powders are sometimes mixed with oil and applied directly to the work by

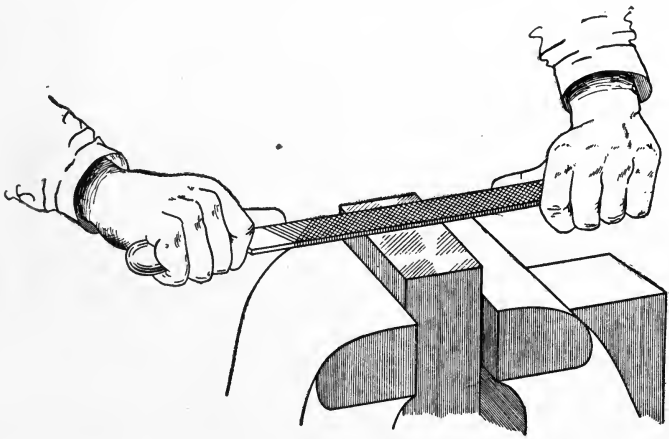


Fig. 57. Draw Filing

wooden blocks or clamps; but the more common method is to use what is known as emery cloth, the grains being glued to a strong cloth backing. The finer grades are used on paper in the same manner.

Emery cloth is used in many ways—it may be wrapped around a file; folded or tacked to a block of wood; glued to wooden sticks about 15 in. $\times$ $1\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in., fastened around rollers for internal curves, or glued to wooden or steel discs and rotated in a lathe or special machine. In all cases the object is to grind down the surface, using a sufficient number of grades of cloth to produce the degree of polish desired. The marks are laid parallel to each other, making what is known as a "grain". When the process is to be carried to such an extent that no grain is to be visible, the finer polishing agents are used, usually applied with a cloth wheel or "lap". Old cloth does finer work than new, and oil on the cloth will make a finer cut.

Hand Scraping. When two flat or curved surfaces are to be worked together, and close contact over the surfaces of both is desired, they are hand scraped. Scraping removes less metal than filing and also enables the workman to confine the removal to limited areas. The scraper, which should be made from a very close-grained tool steel, is nearly 2 feet long exclusive of the handle. The general shape is shown in the upper view of Fig. 58. The cutting edge is about $\frac{3}{32}$ of an inch thick and $1\frac{1}{2}$ inches wide. It is ground on an emery wheel or grindstone and carefully oilstoned, leaving the cutting edge as straight as possible. Scrapers are sometimes made from old files, the teeth being ground off and the end drawn out

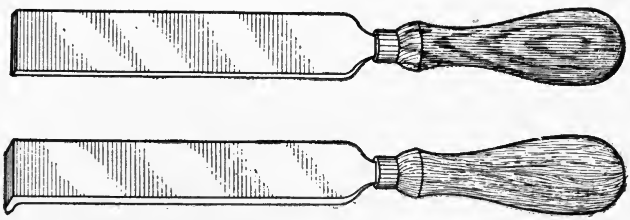


Fig. 58. Straight and Bent Hand Scrapers

wide and thin. Sometimes the end is bent at right angles to the shank, as shown in the lower view of Fig. 58. The cutting done by scrapers should be perfectly smooth and free from scratches.

Testing Plane Surfaces. In using the surface plate as a test for the trueness of a plane, such as a valve or its seat, the plate is covered with a very thin coating of red lead and then rubbed over the valve or seat. The latter should have previously been finished as smoothly as possible. The spots where the red lead shows contact are scraped off and the process continued until contact over the entire surface is obtained. During the last part of the operation, alcohol should be used instead of red lead, as it leaves clean bright spots to indicate where the scraper must be applied. Small pieces of work are rubbed over the surface plate, and in any case care should be taken to distribute the wear uniformly over the plate in order to prolong the trueness of the plane. The scraper for concave surfaces, such as bearings, is of the general shape of a half-round file without teeth. In such cases, the spindle itself takes the place of a surface plate. The method of holding and using such a scraper is shown in Fig. 59.

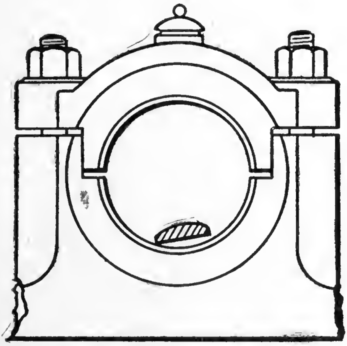


Fig. 59. Scraping Spindle Bearing

Scraping for Finish Only. Scraping is sometimes done as a matter of finish, and not for the purpose of getting an accurate surface. It is then termed "spotting". A spotted surface, therefore, does not always indicate accuracy. Many machine parts can be more cheaply finished by scraping than by polishing.

HAND PUNCHES

Prickpunch. The prickpunch, Fig. 60, is made of tool steel with a hardened conical point of about 60 degrees. It is about $3\frac{1}{2}$ inches long and $\frac{1}{4}$ inch in diameter. It is used for making very small indentations at intervals on a line, or at intersections of lines.

Center Punch. The center punch, also shown in Fig. 60, is made of the same general appearance as the prickpunch, but is

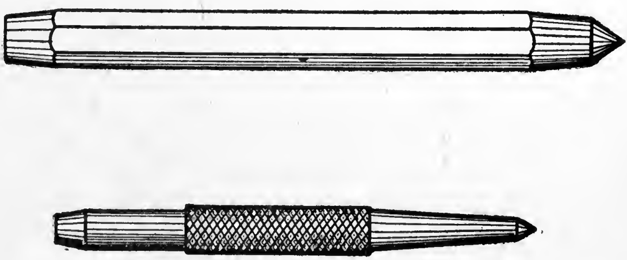


Fig. 60. Hand Punches. Forged Center Punch Above; Prickpunch Below

about 5 inches long, $\frac{1}{2}$ inch in diameter, and has a point angle of about 90 degrees. The principal use of this punch is to make center holes, marking the centers on the ends of pieces to be turned.

Ordinary forged center punches are usually made of hexagonal steel; but if round stock is used, the grip should be fluted or knurled to prevent slipping in the fingers.

Scratch Awl. The scriber or scratch awl, Fig. 61, is made in many forms, but consists essentially of a cast-steel rod about 8 inches long and $\frac{3}{16}$ inch in diameter, with a long, slender, hardened

Fig. 61. Forms of Scribers
Courtesy of L. S. Starrett Company, Athol, Massachusetts

point at each end. Frequently one point is bent at right angles to the shank. As the name indicates, this tool is used for marking lines on the surface of metal.

TEMPLETS

Where the same lay-out is to be many times repeated, templets are used. This method avoids the necessity of making measurements in the laying out of the work.

Marking Templet. The marking templet consists of a piece of the same shape as the finished article. It is usually laid on a flat

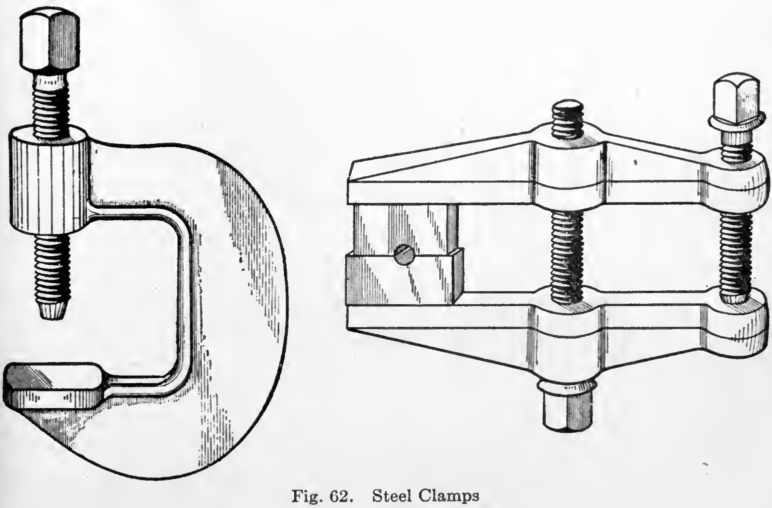


Fig. 62. Steel Clamps

surface and held fast by iron clamps as shown in Fig. 62. The outline is then marked on the surface with a scriber and sometimes emphasized by prickpunch marks.

Filing Templet. The filing templet is of the same character as the marking templet except it is hardened. It is clamped in the vise with the piece to be shaped, and the surface filed down to coincide with the form of the templet.

Jigs. Where holes are to be drilled in duplicate, a templet known as a plate jig is used. These are made so that they fit over the piece to be drilled and, when clamped in position, indicate the location of the holes by means of hardened steel bushings set in the templet.

The making of templets and jigs is one of the finest branches of the machinist's work and is generally classed under the head of "Tool-Making". The rapid and economical production of machine parts in quantity depends largely on the tool-maker, who must, therefore, be considered the highest type of machinist.

DRILLING

Drilling. Drilling is the term used by shop men to denote hole production by means of a rotating tool which is provided with cutting edges located at its point. The drill, therefore, is an end cutting tool as distinguished from the ordinary reamer which usually cuts on its sides.

Types of Drills

Flat Drills. Drills are of two general classes, the flat and the twist. A flat drill of a common type is shown in Fig. 63. The angle between the two cutting edges should be about 110 degrees. These drills are usually made from round tool steel drawn out wide and thin, as shown, the undressed end being used for holding. The flat drill is usually made in the shop where it is to be used. Its low first cost is the principal reason for its existence.

Flat Chucking Drill. Flat drills made from thin flat stock are used in connection with a slotted rest to start and enlarge previously cored holes in lathe chuck work. They are called chucking drills. The end of the shank of the drill is provided with a center hole to receive the dead center of the machine. The drill and rest are shown in Fig. 64.

Twist Drills. The simplest form of twist drill is cylindrical throughout its entire length, as shown in Fig. 65, and has two spiral flutes which at the end serve to form the cutting lips, and which also serve to carry the chips from the hole. The included angle of the lips is 118 degrees. The twist drill will work more accurately than the flat drill, as the cylindrical portion serves as a guide to keep the cutting lips in their proper position. The edges, being somewhat

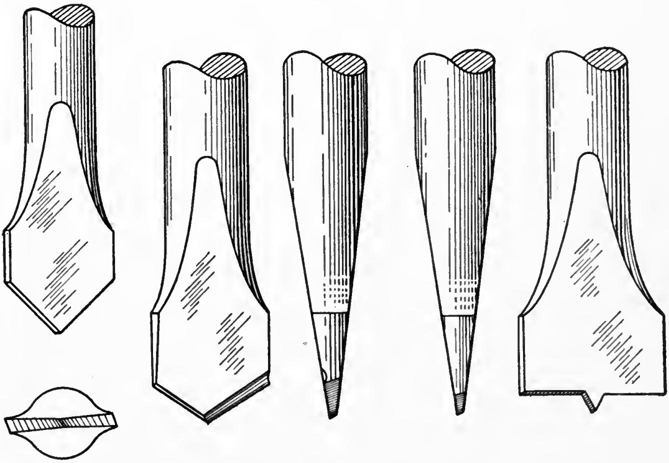


Fig. 63. Blacksmith's Drills

hooking, removes the metal by a cutting instead of a scraping action as in the flat drill. This form of drill not only can be fed faster but can be forced into the work with less power, as it has a tendency, especially noticeable in soft metals, to feed itself into the work. Straight shank twist drills are made from .0135 inch to $2\frac{1}{2}$ inches in diameter; the smaller sizes are sold in sets designated by the numbers 1 to 80; by the letters A to Z; or by the fractional sizes $\frac{1}{2}$ inch to $\frac{1}{16}$ inch.

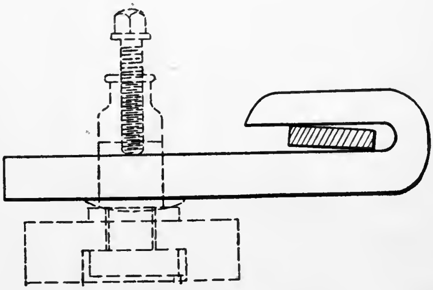


Fig. 64. Chucking Drill Rest

Tapered Shanks. The taper-shank twist drill is shown in Fig. 66. It consists of a body *A*, which is fluted and does the actual work, and a taper shank *B*, by which it is held. This taper fits accurately into the spindle or chuck of the drill press. At the end there is a tongue *C*, which slips into the keyway in the spindle or chuck. As this surface is flat, it serves as a bearing by which the drill is driven. This relieves the tapered portion from the stress of driving by frictional resistance alone. For small drills this frictional resistance is sufficient, but for larger sizes it will not do at all. If for any reason the tongue should become broken, no dependence should be placed upon the frictional resistance of the taper shank to drive the drill.

Fig. 65. Typical Twist Drill
Courtesy of Union Twist Drill Company, Athol, Massachusetts

The drill will slip and wear the socket, which will become enlarged and make a misfit for other drills.

The *standard taper* for drill shanks, known as the Morse, is $\frac{5}{8}$ inch to the foot. There is another standard taper, known as the Jarno, which has a taper of $\frac{6}{10}$ inch to the foot. No attempt should be made to run the drills of one taper in the sockets of the other.

Fig. 66. Taper Shank Twist Drill
Courtesy of Morse Twist Drill Company, New Bedford, Massachusetts

A flat taper key, or drift, introduced into the keyway, engages the end of the tongue and serves to remove the drill from the spindle.

Farmer Drills. Drills of cylindrical form are also made with straight flutes as shown in Fig. 67. They are used for drilling soft metals, such as brass, especially when the drill passes entirely through

Fig. 67. Straightway or Straight Fluted Drill
Courtesy of Union Twist Drill Company, Athol, Massachusetts

the piece. As it breaks through the metal, a drill with spiral flutes tends to draw itself through rapidly, as if it were a screw working in a nut. This may break the drill or move the work from position. Straight flutes give the same cutting action as a flat drill and avoid the tendency to draw.

Care of Drills

Lubrication of Drills. When drilling tougn metals, such as steel and wrought and malleable iron, heat is generated by the bending or changing of the form of the metal being removed and by friction caused by the chips moving over the lips of the drill. The heating is similar to the heating of a piece of wire bent quickly back and forth. As there is danger of heating the drill to a temperature that will draw the temper and soften the drill, plenty of lard oil, or a mixture of potash and water, should be used. This is not so much for lubrication as to conduct away the heat.

Copper is the most difficult to drill of all the common metals on account of its extreme toughness; then, too, copper heats to a higher temperature on account of its low specific heat. Brass does not require the use of oil, and cast iron is usually drilled dry.

Fig. 68. Oil Tube Drill
Courtesy of Cleveland Twist Drill Company, Cleveland, Ohio

As the heat is produced at the point of the drill, it is desirable, particularly in the case of deep holes, that the oil be applied directly at the drill point. For this purpose, oil-tube drills, such as shown in Fig. 68, are used. The oil is supplied under pressure, and not only removes the heat but also carries away the chips.

Speed of Drills. The speed at which drills should be rotated depends both on the diameter of the drill and on the material operated upon. No absolute rule can be given for any one metal or diameter of drill because of the variation in hardness and tenacity of the material and the condition of the cutting edges of the drill. The operator must exercise his own judgment.

Table I, giving the speed of drills in revolutions per minute, is based on a peripheral speed of 30 feet a minute for mild steel, 35 feet per minute for cast iron, and 60 feet per minute for brass, using carbon tool steel drills.

The rate of feed also depends on the drill diameter and on the material. The Cleveland Twist Drill Company gives, as a maximum, one inch of feed for 95 to 125 revolutions.

TABLE I*

Speed of Drills

Diameter of Drill	Soft Steel or Wrought Iron (r. p. m.)	Cast Iron (r. p. m.)	Brass (r. p. m.)
1/16	1824	2128	3648
1/8	912	1064	1824
3/16	608	710	1216
1/4	456	532	912
5/16	365	425	730
3/8	304	355	608
7/16	260	304	520
1/2	228	226	456
9/16	203	236	405
5/8	182	213	365
11/16	166	194	332
3/4	152	177	304
13/16	140	164	280
7/8	130	152	260
15/16	122	142	243
1	114	133	228
1 1/16	108	125	215
1 1/8	102	118	203
1 3/16	96	112	192
1 1/4	91	106	182
1 5/16	87	101	174
1 3/8	83	97	165
1 7/16	80	93	159
1 1/2	76	89	152
1 9/16	73	85	145
1 5/8	70	82	140
1 11/16	68	79	135
1 3/4	65	76	130
1 13/16	63	73	125
1 7/8	60	71	122
1 15/16	59	69	118
2	57	67	114

Resharpening Drills. Great care should be exercised in the resharpening of drills. The cone point of a drill should be symmetrical, that is, the lips should be of the same length and form the same angle with the axis. If the lips are of unequal length, the hole will be larger than the drill, as is shown in Fig. 69. The point is not in the axis, and the hole will not only be large but also will not be parallel to the drill spindle. If the lips do not form equal angles with the axis, all the cutting will devolve upon the one making the greater angle, as shown in Fig. 70. Such a drill will not cut as fast as, and will become dull sooner than, one which is properly ground.

*Courtesy of Cleveland Twist Drill Company.

Hand-grinding, especially of twist drills, is neither accurate nor satisfactory; it is much better to do such work on a regular drill grinder built especially for the purpose.

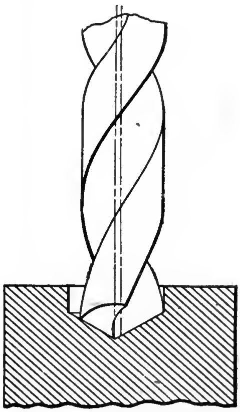


Fig. 69. Drill with Lips of Unequal Length

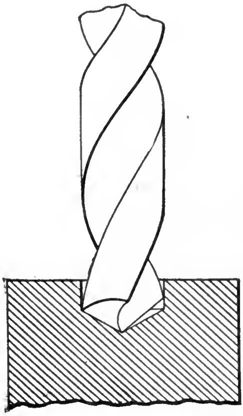


Fig. 70. Drill with Lips of Unequal Angles

When resharpening carbon tool steel drills, care must always be exercised that the cutting edges are not overheated on the stone or emery wheel. If overheated, the temper will be drawn and the drill become too soft to properly do its work. The clearance angle is also of extreme importance. This should be 12 degrees, as shown in Fig. 71. If the drill lips are not properly cleared or backed off, the drill must crush.

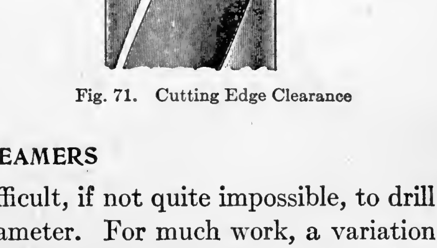


Fig. 71. Cutting Edge Clearance

REAMERS

Use of Reamers. It is difficult, if not quite impossible, to drill a hole to an exact standard diameter. For much work, a variation of a few thousandths of an inch from the nominal diameter is of no account. Where greater accuracy than this is required, the holes are reamed, that is, the hole is first drilled somewhat smaller than it is desired and is then reamed out to the proper size with a reamer.

Holes drilled with common chucking drills are usually $\frac{1}{16}$ inch under the finish size. A chucking reamer, Fig. 72, is used to enlarge the hole to within about .005 inch of the true size. This reamer is centered on both ends and turned to size. The entering

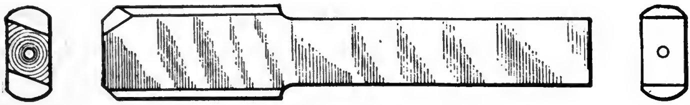


Fig. 72. Flat Chucking Reamer

end, which does the cutting, is given a short, sharp taper, while the straight portion serves as a guide to keep the tool in position. By this means, the drilled hole is straightened and brought close to size.

Hand Reaming. To give the hole a smooth surface and a correct diameter, a fluted hand reamer, of which there are various forms, is used. This tool is not intended to remove large amounts of metal, but serves only to increase the size of a hole by a small fraction of an inch up to the diameter required. The hole should not be more than 0.007 inch smaller than the hand reamer. It is evident that if the reamer were to be made of the same diameter throughout its whole length, it would be very difficult to make it enter the hole. In order to facilitate this, it is usually made slightly tapering for a distance from the entering end equal to about one diameter.

One form of reamer has a shallow screw thread cut at the entering end. This thread takes hold of the metal and draws down into the work. When using a reamer, it is always well to pass the entire

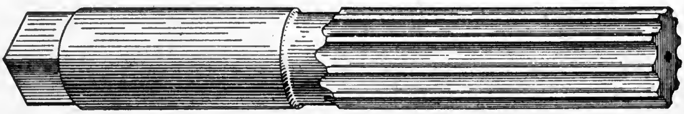


Fig. 73. Solid Hand Reamer

tool through the hole. The leading end is subjected to the greatest amount of wear because it does the greatest amount of work. If, therefore, only the leading end is put through, the hole will not be of a uniform diameter throughout. Oil should always be used on reamers when they are working in wrought iron or steel.

The hand reamer, Fig. 73, is the typical form, and one which can be used in many cases in place of special forms. Fig. 74 is better adapted for use in the lathe than the hand reamer. This may follow the chucking reamer to finally finish a hole.

In reaming cored holes, the cylindrical chucking reamer, sometimes called a roughing reamer, is often used. It is made either

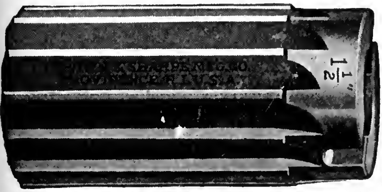


Fig. 74. Plain Shell Reamer
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Fig. 75. Rose Shell Reamer
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

rose, Fig. 75, fluted, or with three spiral flutes, Fig. 76, and generally has solid shanks. The last-named style will finish very smooth and close to size when started true by preliminary boring.

Fig. 76. Spiral Chucking Reamer Drill

A solid reamer cannot be sharpened without reducing its diameter; therefore, it must be used carefully in order to prolong its life. Reamers with adjustable blades meet this objection, but cost much

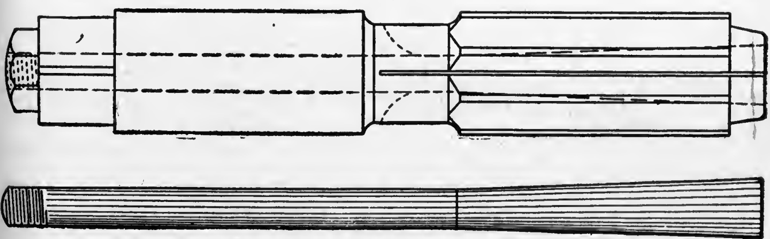


Fig. 77. Expanding Reamer and Arbor

more than the solid form. An expanding reamer, Fig. 77, can be slightly enlarged to compensate for grinding and is then used as a solid reamer. Fig. 78 shows an adjustable reamer with inserted blades.

Taper Reamers. Reamers are made for tapered as well as for straight holes. The angle varies with the intended use of the taper. For example, the *locomotive taper* of $\frac{1}{16}$ inch per foot is intended for bolt holes where plates are to be drawn solidly together and the

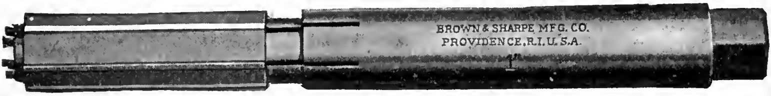


Fig. 78. Reamer with Inserted Blades
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

holes completely filled. It is very difficult to remove a bolt from a hole with such a slight taper. When pieces are pinned together, such as a hub to a shaft, it is intended that they can be separated when desired, so the taper is made steeper, generally $\frac{1}{4}$ inch per foot.

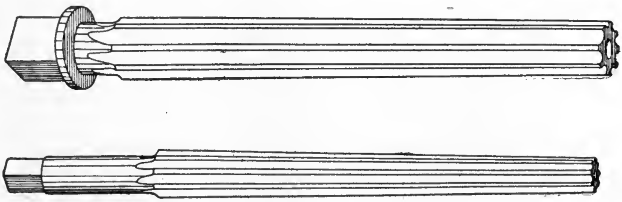


Fig. 79. Types of Taper Reamers

This has come to be known as the *pin taper*. Taper holes for holding lathe centers and taper shank twist drills are generally made $\frac{5}{8}$ inch per foot—*the Morse taper*. This angle holds the tool firmly, and still it can be easily removed. The three tapers mentioned are recognized as standard, and reamers for them are carried in stock. Of course many other tapers are used by different manufacturers, but they are regarded as special. Fig. 79 shows taper reamers.

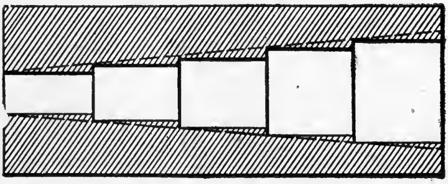


Fig. 80. Method of Stepping Holes before Using Taper Reamer

Taper reamers differ from hand reamers only in the angle and by not requiring the tapered entering end.

Holes to be reamed by taper reamers must be slightly larger than the small end of the reamer; and, if the hole is deep, it is usual to make a stepped hole, shown exaggerated in Fig. 80, by using drills of different diameters.

When not carefully sharpened, all forms of reamers have a tendency to chatter and produce rough surfaces. To avoid this, the flutes are frequently irregularly spaced; another method is to use spiral flutes, usually left hand.

HAND THREADING TOOLS

Taps

Types of Taps. When internal thread cutting is done by hand, the tool used is called a tap. There are many styles of taps, the

Fig. 81. Types of Hand Taps: Left—Taper Tap; Center—Plug Tap; Right—Bottoming Tap
Courtesy of Wiley and Russell Manufacturing Company, Greenfield, Massachusetts

names in some cases being suggested from the shape, but more often from the use. In most machine shops are found the following forms: hand, machine screw, pipe, pulley, stay-bolt, boiler, and tapper; of these the hand and machine screw are the most common. The object of all is to make helical grooves, called threads, in holes, so that they may receive and hold screws, bolts, studs, etc.

Size of Drill for Tapped Hole. As the size of a tap is the outside diameter of its threads, it is evident that the hole drilled for

TABLE II

Taps and Corresponding Drills

Tap Diameter (in.)	No. Threads (per in.)	U. S. Standard Drill Diameter (in.)	V-Thread Drill Diameter (in.)	Tap Diameter (in.)	No. Threads (per in)	U. S. Standard Drill Diameter (in.)	V-Thread Drill Diameter (in.)
1/4	20	3/16	11/64	1 7/8	5	1 5/8	1 17/32
5/16	18	1/4	15/64	2	4 1/2	1 23/32	1 21/32
3/8	16	9/32	9/32	2 1/4	4 1/2	1 31/32	1 7/8
7/16	14	11/32	21/64	2 1/2	4	2 3/16	2 3/32
1/2	13	13/32	25/64	2 3/4	4	2 7/16	2 11/32
9/16	12	7/16	7/16	3	3 1/2	2 5/8	2 1/2
5/8	11	1/2	1/2	3 1/4	3 1/2	2 7/8	2 3/4
11/16	11	9/16	9/16	3 1/2	3 1/4	3 1/8	2 15/16
3/4	10	5/8	19/32	3 3/4	3	3 5/16	3 3/16
13/16	10	21/32	21/32	4	3	3 9/16	3 7/16
7/8	9	23/32	45/64	4 1/4	2 7/8	3 13/16	3 11/16
15/16	9	3/4	49/64	4 1/2	2 3/4	4	3 7/8
1	8	27/32	13/16	4 3/4	2 5/8	4 1/4	4 1/16
1 1/8	7	15/16	29/32	5	2 1/2	4 1/2	4 1/4
1 1/4	7	1 1/16	1 1/32	5 1/4	2 1/2	4 3/4	4 1/2
1 3/8	6	1 5/32	1 1/8	5 1/2	2 3/8	5	4 3/4
1 1/2	6	1 9/32	1 15/64	5 3/4	2 3/8	5 1/4	5
1 5/8	5 1/2	1 3/8	1 5/16	6	2 1/4	5 1/2	5 1/4
1 3/4	5	1 1/2	1 13/32				

tapping must be smaller than the tap by nearly, if not quite, twice the depth of the thread. The shape of the thread partly determines the amount to be subtracted from a tap diameter. There are now recognized as standard, five different threads—sharp or V; Franklin Institute or United States standard; Whitworth; International or metric; and the 29 degrees or Acme. These shapes will be described and compared under "Screw Cutting". Table II shows the diameters of the holes that are to be drilled for cutting the various sizes of the threads according to the United States standard and the ordinary V-thread.

Hand taps are most commonly used in shop practice, and a description of their operation will answer for all styles. They are usually sold in sets of three—taper, plug, and bottoming—Fig. 81.

Hand Tapping. The cutting of a thread with a tap is not a difficult operation but requires care in the manipulation. The tap does not need to be forced into the work, since the thread will draw it forward. The tapering of the tap has a two-fold effect. No one thread does all of the work in the removal of the metal; each succeeding thread removes a small amount until the full thread has entered the hole. The second effect is that, as in the case of a reamer, the tap is easily entered and started. Care must always be exercised at this point of the work. The taper of the tap allows it to easily enter the hole and also makes it possible for it to enter at an angle. If it is started in the latter condition, the thread will not be at right angles to the hole. The degree of care needed in the starting of the tap depends upon the job that is to be done. In the case of tapping a nut, it will usually be quite sufficient to set the tap by the eye. In finer classes of work, however, the tap should be set with a square. Start the tap into the hole and place a square on the surface beside it in two positions at right angles to each other and see that the tap stands parallel to the vertical blade.

Starting the Tap. When holes have been drilled that are to be tapped, a good way of setting the tap is to put a center in the drill spindle. Put the tap into the hole and bring this center down into the center hole in the head of the tap; this will steady the latter while it is being started.

In using the tap, it is well to work it back and forth. This allows the chips to work clear of the cutting edges, and the oil to cover them. In case of heavy work, it is possible to drive the tap with the drill spindle, but when thus driving a tap in a machine, the backing up is impossible.

Use of Bottoming Tap. Sometimes a thread is to be cut down to the bottom of a hole that does not pass entirely through the metal. In this case the bottoming tap is used. This is a tap that is not tapered at the entering end. The method of working is to first cut the thread as far as possible with the plug tap and then use the bottoming tap, which will enter easily and can be driven to the bottom.

Machine Tapping. Machine tapping is best done by using a frictional tapholder, that is, one in which the friction is enough to cut the threads, but which will slip when the tap strikes the bottom of the hole. This will insure the hole being tapped to the bottom and avoid all danger of breaking the tap. To withdraw the tap, the machine is reversed, usually at a higher speed than used in tapping.

Lubrication. When tapping wrought iron and steel, a plentiful supply of lard oil should be used. On brass the use of oil is unnecessary.

Threading Dies

Dies are used for cutting threads on bolts and other similar parts to be placed in holes which have been threaded by taps. The general rules given for the use of taps apply to dies. As the number of threads in a die is much less than on a tap, and because the chips have a much freer exit, it is not as necessary to back up a die as it is a tap.

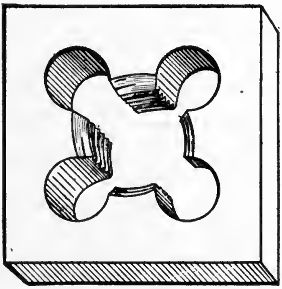


Fig. 82. Threading Die

Solid Dies. Dies for small work are usually made solid, as shown in Fig. 82, and often have a slight adjustment for altering the size. They cannot be sharpened, but have an advantage in readily centering on the work. As the full thread is cut at one passage of the die, it takes considerable power to operate solid dies of large size. For this reason, hand-operated solid dies are seldom used above one-half inch. The holder or die stock shown in Fig. 83 has

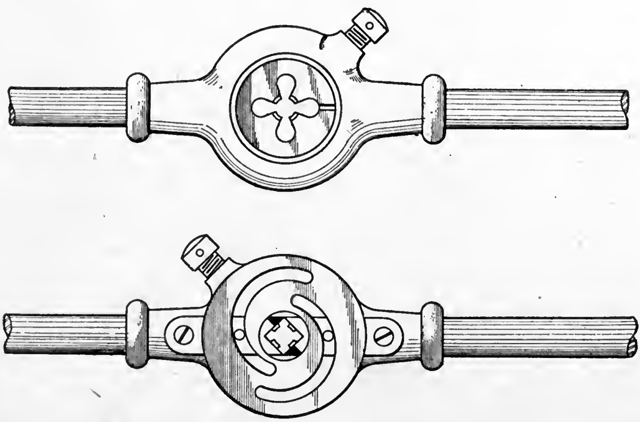


Fig. 83. Self-Centering Die

a guide to hold the work at right angles to the die, but die stocks are often made without this convenience.

Split Dies. The split form of die, generally known as the jamb-die, Fig. 84, can be easily resharpened, has unlimited adjustment for size, and cuts the thread by easy stages, as it were. It is made in sizes up to 2 inches and is for hand operation only. The holder for this form of die is called a screw plate, Fig. 85. These are not furnished with guides for the work.

Cutting Pipe Threads. Another common form of thread cutting is that on wrought-iron pipe. The pipe thread is rounded slightly at top and bottom and is made tapering at the rate of three-quarters of an inch per foot. The dies are usually solid, square in form, and the die stocks are provided with a ring which fits over the pipe and serves to hold it square with the die. This avoids the danger of cutting the thread at an angle with the pipe axis.

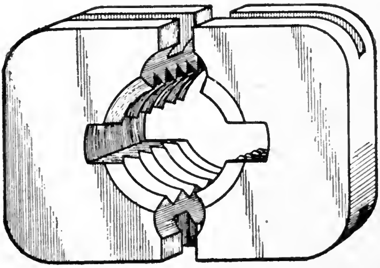


Fig. 84. Split Die

Cutting Bolt Threads. Bolt cutting is seldom done by hand, such work being usually performed on bolt-cutters. This is ordinarily the roughest and cheapest class of work, and the running of

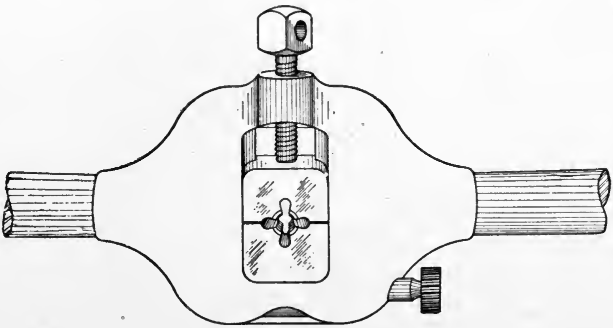


Fig. 85. Threading Die Holder

the bolt-cutter is often the first work to which the apprentice is assigned.

An ordinary bolt-cutter is shown in Fig. 86; its operation is as follows: The dies are held in the head *A*. Instead of being solid, as in Fig. 82, they are made in sections and can be opened or closed by the movement of the lever *B*. A chuck *C* is placed on a traveling head, and this can be moved back and forth by the hand-wheel *D*. The method of working is very simple. The dies in the head are closed in order to be in the working position. The bolt to be cut is gripped in the chuck by turning the handle *E* and forced against the dies by the handle *D*. As soon as the dies have taken

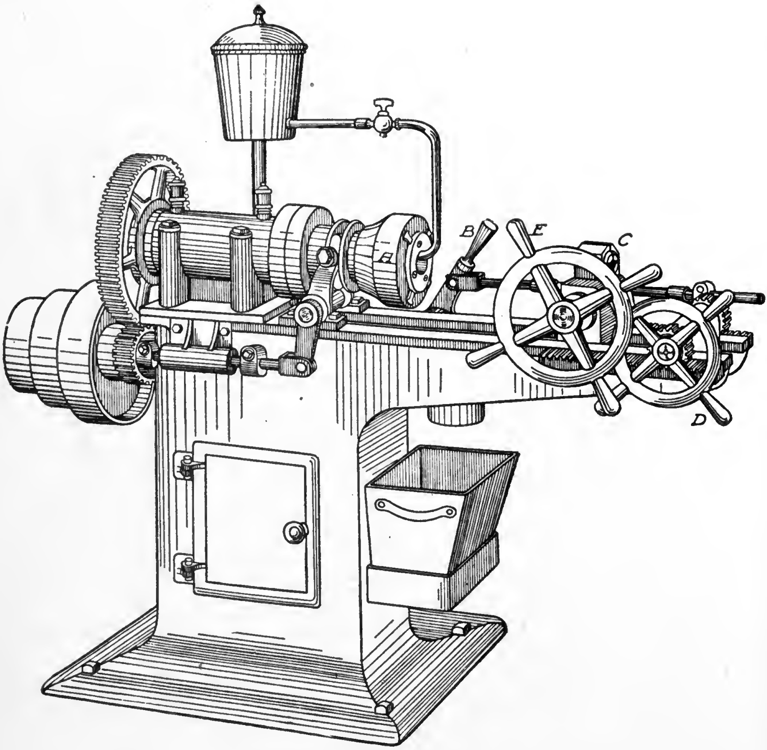
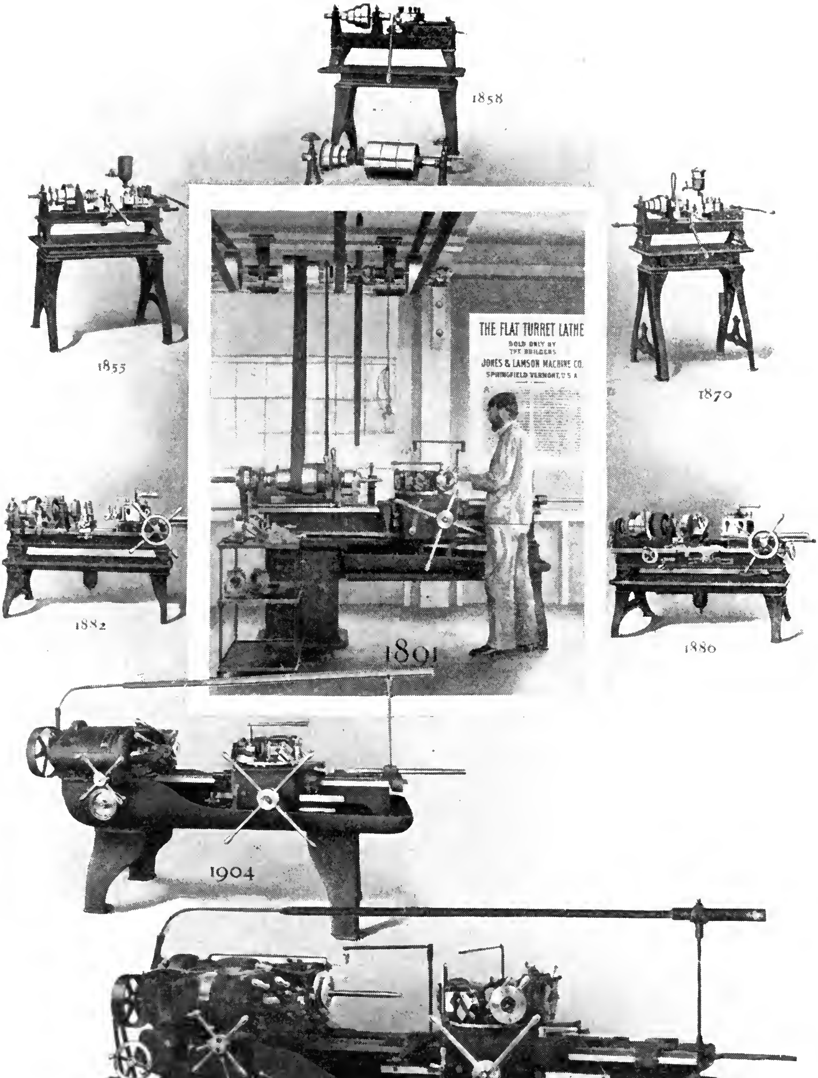


Fig. 86. Bolt Cutter

hold, they draw the bolt ahead. When a sufficient length of thread has been cut, the dies are opened and the bolt withdrawn. This avoids the necessity of backing out, as would be required if the dies were solid. While the thread is being cut, the dies are kept flooded with oil.



HISTORICAL DEVELOPMENT OF HARTNESS FLAT TURRET LATHE
Courtesy of Jones and Lamson Machine Company, Springfield, Vermont

MACHINE SHOP WORK

PART II

POWER-DRIVEN TOOLS

LATHES

Origin. The lathe is undoubtedly the oldest form of machine tool. Its prototype is the drilling machine. Each of these machine

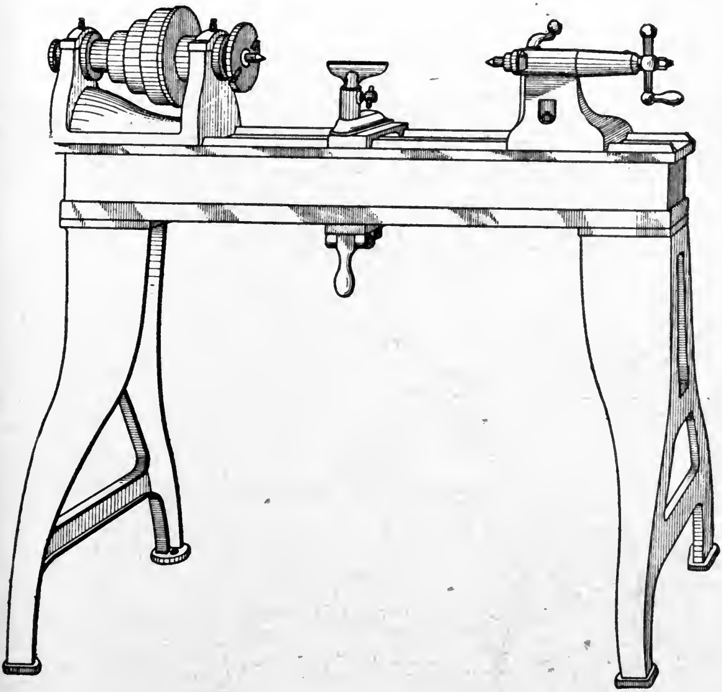


Fig. 87. Typical Speed Lathe for Hand Turning

tools probably developed from that earliest example of mechanical rotary motion of which we have a record, the "potters' wheel".

Speed Lathes. This term includes that line of lathes illustrated in Fig. 87, which shows a typical design. These machines are sold in the open market in a variety of sizes from the smaller jewelers' lathe to those having a swing of 12 inches. All types and all sizes are designed to be used with hand-controlled cutting tools, and are often designated as hand lathes. If desired, they can be driven by foot power and are then often termed foot lathes.

Tools for Hand Turning. In turning brass and composition the tools cut by a scraping action, and are almost always held at

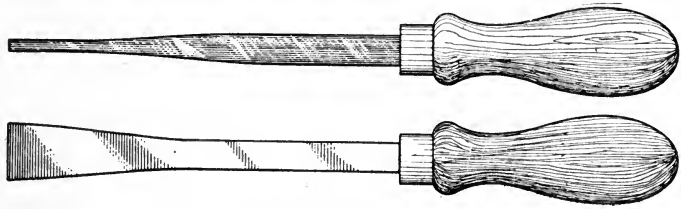


Fig. 88A. Planisher

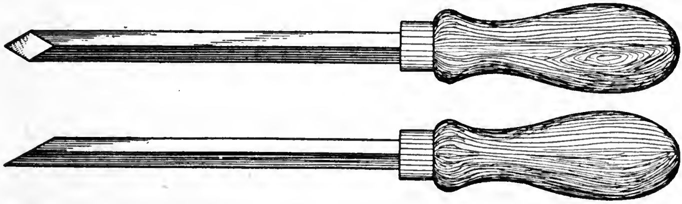


Fig. 88B. Graver

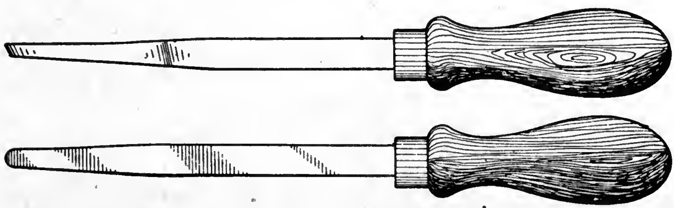


Fig. 88C. Round Nose

Fig. 88. Cutting Tools for Hand Turning

or below the center. The three tools shown in Fig. 88, called the planisher, graver, and round nose, are typical of all the tools necessary for turning brass, etc. The manner of holding these tools in connection with the T-rest is illustrated by the planisher in Fig. 89. Fig. 90 shows another view of the T-rest. Typical hand tools for cutting iron and steel are the diamond point or graver and the round nose, shown in Fig. 91. They are used differently from hand tools for brass, in that the cutting edge is carried above the center, and the metal is removed by cutting instead of scraping.

Graver. The graver frequently takes the place of the planisher, for it can be used as shown in Fig. 92, either on the outside or on the

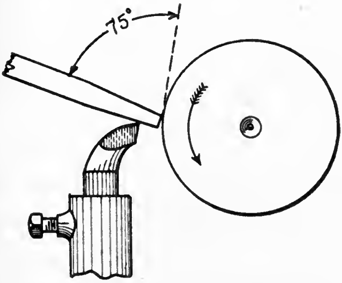


Fig. 89. Hand Tool Rest with Tool in Position

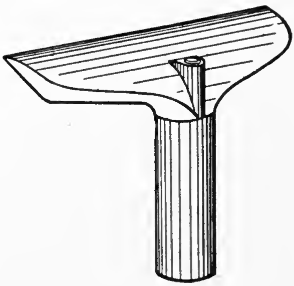


Fig. 90. Simple Hand Tool Rest

end of a piece of work. The graver can be used on brass for a great variety of operations; but its use, except in the hands of an expert workman, is attended by the danger of catching in the soft metal and thus breaking the tool or spoiling the work.

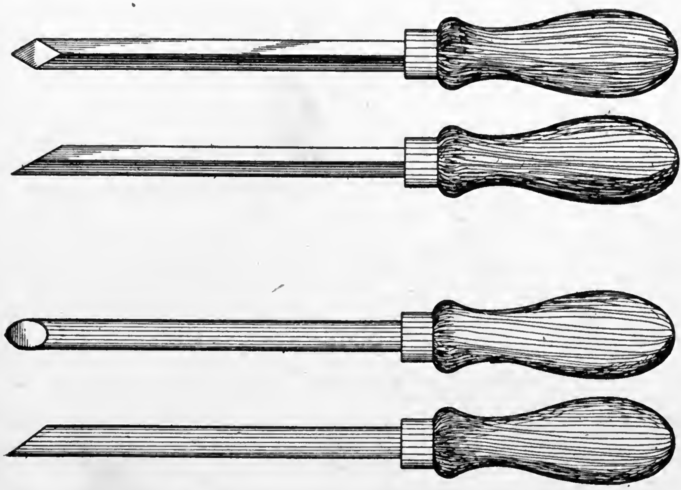


Fig. 91. Typical Hand Tools for Steel Turning

Round Nose. The round nose is used solely for turning concave surfaces, being held as high on the work as proper cutting will allow, as shown in Fig. 93.

Slide Rest. To make the hand lathe more rapid and more certain in operation, it is frequently provided with a tool holder called the slide rest, as shown in Fig. 94. This holds the tool rigidly and guides it mechanically, so that the work is done more rapidly than with the hand tools. Slide rest tools are miniatures of those

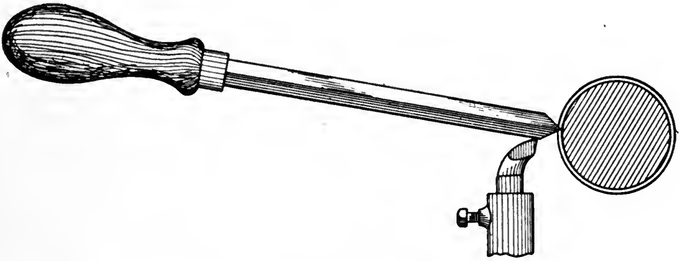


Fig. 92. Position of Tool for Turning Steel

used on larger lathes, hence a description will not be given at this point.

Engine Lathes. This type of machine tool is well illustrated by Fig. 95, which shows the common cone belt-driven screw-cutting engine lathe of ordinary dimensions. It is commonly sold in sizes from 10-inch swing to 30-inch swing. Larger sizes are usually built to order. When an engine lathe is used for turning, the tool is rigidly held in a "tool post" clamped to the cross-slide, and is not directly hand controlled. The modern engine lathe is designed usually so that by combining a direct belt-driven cone and suitable back gears a range of at least eight rotative spindle speeds are obtained.

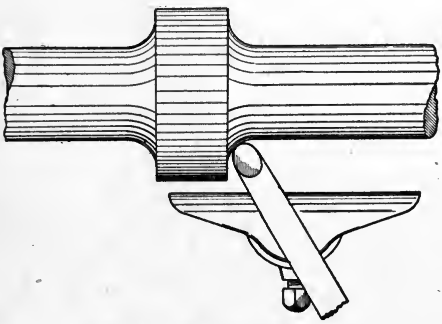


Fig. 93. Hand-Turning a Fillet

The engine lathe illustrated in Fig. 95 has a strong cast-iron bed *A* carried on four well braced legs that may be bolted to the floor, though the weight of the machine may be sufficient to hold it in position. On the left-hand end of the bed there is fastened the headstock *B*, which carries the main running gear of the machine.

At each end of the headstock there is a bearing for the spindle. Running loosely on the spindle and between the bearings is the cone pulley *C* to which the pinion *D* is attached.

Gear Drive. The back gearing is designed to reduce the speed of the spindle without changing the belt speed. The mechanism of the back gearing is clearly shown in Fig. 96. The large gear *E* alone shows in Fig. 95. It is driven by the pinion *D* which is attached to the cone. Referring interchangeably to Figs. 95 and 96, a pinion on the same sleeve as the gear *E* drives the gear at the right of the cone *c*, which gear is keyed to the work spindle. When

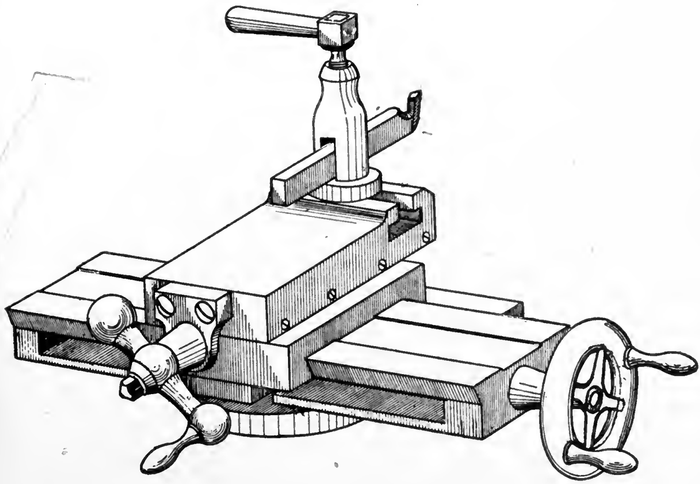


Fig. 94. Hand Lathe Slide Rest

the back gearing is not in use, it is thrown out of mesh with the gears on the pulley and spindle by means of a shaft having eccentric bearings upon which it turns; at the same time the cone pulley locks fast to the gear at its right; the work spindle then turns with the cone pulley. With the back gearing in use the spindle runs more slowly, with the belt on the same step of the cone, than it does when driven direct.

Work Spindle Arrangement. The work spindle projects through the bearings at each end. At the right it is usually threaded to receive a faceplate *F*, and is also bored out and tapered for a work center *G*. This center is called the live center because it turns with the spindle. The dead center *H* is in the tailstock, and does not turn. At the left the work spindle projects beyond

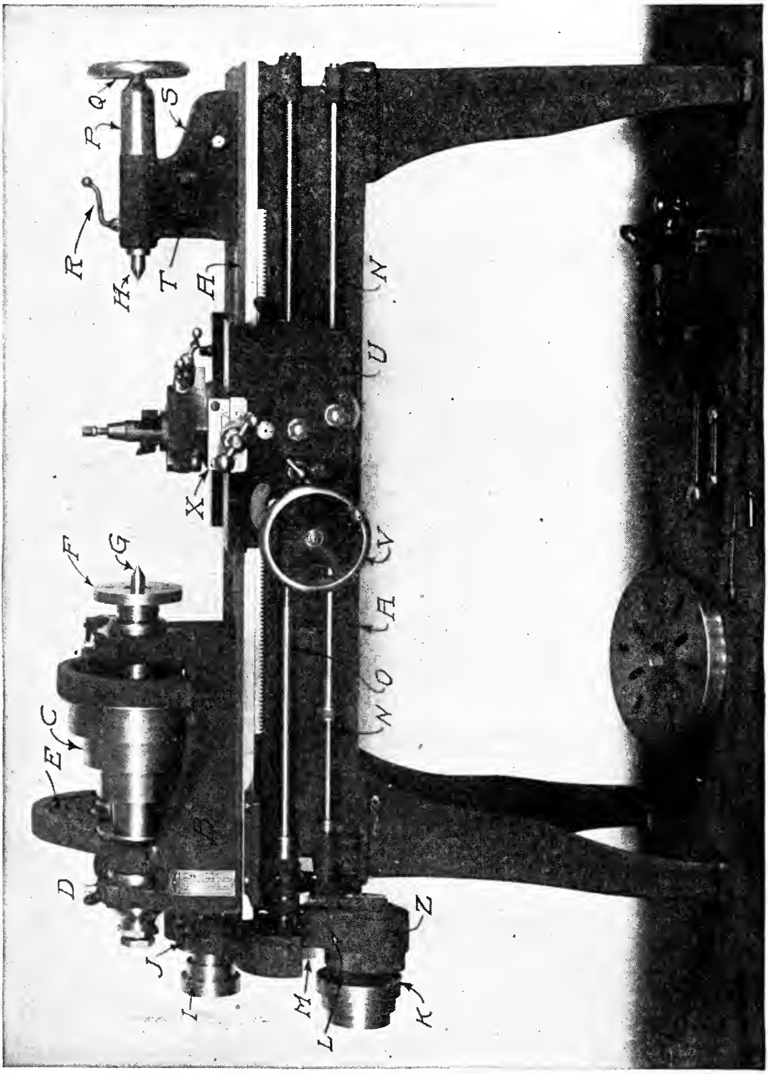


Fig. 95. Typical Engine Lathe

the bearings and presses axially against a thrust step. The cone pulley *I* serves as the driving pulley for a narrow belt running to the corresponding pulley *K* on the feed rod *N*. The pinion *J* drives the lead-screw *O* through the intermediate gear *M* and the direct gear *L*.

Handling the Work. The work is held on the centers *G* and *H*, the distance between which is adjusted by moving the tailstock *S* (sometimes called the tailblock). The latter is held to the bed by a clamp and bolts tightened by the nuts *T*. To move the tailstock, these nuts are slackened and the stock moved to the proper position. The final adjustment is made by turning the hand wheel *Q*, which rotates a screw in the sleeve *P*. Sleeve *P* works in a nut in the spindle of the dead center *H*, which is thus moved in and out. When the centers have been properly adjusted and the work is in position, the dead center is clamped by the handle *R*.

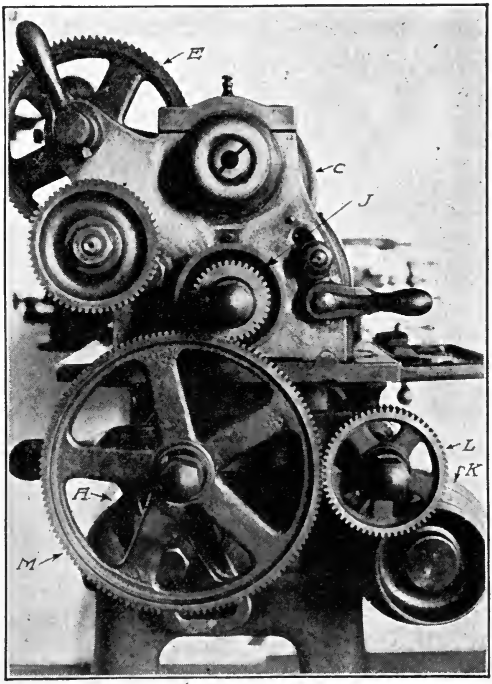


Fig. 96. Typical Set-Up of Gears on Lathe Using Back Gear

When work is to be turned, the tool is properly adjusted, and the carriage *U* moved along the bed. This movement is accomplished by means of gearing, which is placed behind the apron of the carriage, and driven by the shaft *N* by the cone pulley *K*, which is keyed to shaft *N*. The driving gearing meshes with a rack beneath the upper ledge of the bed. Connection between the gearing and shaft *N* is made by a friction clutch. The carriage may also be moved by hand, by turning the hand wheel *V*, to which is keyed a pinion indirectly meshing into the rack.

Tool-Feeding Mechanism. The tool is fed to the work and withdrawn from it by turning the cross-feed handle *W*. By means of the screw and nut, this moves the cross-slide *X*. These arrangements permit any desired transverse or longitudinal position of the tool. The motion of the carriage is usually from right to left when at work. When screws are to be cut, a different feed is used. In ordinary turning, there will be a variation in the relations between the rotation of the work and the longitudinal motion of the tool, due to the slipping of the belt connecting the cone pulleys *I* and *K*, or to the slipping of the friction clutch which connects the shaft *N* to the driving gear. To cut a screw-thread, it is necessary that there shall be no relative change in the rotation of the work and the longitudinal motion of the tool. In other words, the tool must travel a given distance for every revolution of the work. To accomplish this, the carriage is driven by the lead-screw *O* working in a nut set in the carriage. The screw is, in turn, driven by the train of gears *J*, *M*, and *L*. The gear *J* is keyed to the stud. The intermediate gear *M* runs loose on a sleeve. The gear *L* is keyed to the lead-screw *O*. By changing the sizes of the gears used on the stud and the screw, any desired thread may be cut. The size of the intermediate gear *M* has no effect on the thread being cut. This gear *M* is used to connect the other two gears *L* and *J* and can be adjusted to any desired position for that purpose.

LATHE EQUIPMENT

Setting Up Change-Gears for Thread-Cutting. The descriptions in the preceding pages apply particularly to the usual form of engine lathe, and a clear understanding of its construction and the details of its essential parts is desirable. Instead of being placed directly on the main spindle, the first gear *J* of the train of "change-gears" used for driving the lead-screw *O* for thread-cutting, is fixed to the stud shaft *H*, shown at *B* in the diagram, Fig. 97, upon the inner end of which is fixed the stud shaft gear *G*, which engages a gear *F* of the same diameter fixed to the main spindle at the left of the cone pinion *D*. By this means the stud shaft *H* rotates at exactly the same speed as the main spindle. The small feed-cone *I* is fixed to the stud shaft *H*, and the large feed-cone *K* to the feed-rod *N*, by which ordinary turning feeds are produced.

Referring to the end elevation *A* in Fig. 97, the change-gears *J* and *L* being of equal diameters and equal numbers of teeth, it follows that the lead-screw *O* will revolve at the same rate as the main spindle. Therefore, if the lead-screw is cut with four threads per inch, the lathe carriage will move a quarter of an inch at each revolution, and the lathe will cut four threads per inch.

The intermediate gear *M* does not change the rate of speed, although it reverses the direction of revolution.

If the change-gear *J* is only one-half the diameter of the change-gear *L*, the lead-screw *O* will revolve only one-half as fast as the main spindle, and therefore the lathe will cut eight threads per inch; but if the case is reversed and the change-gear *L* is only half the diam-

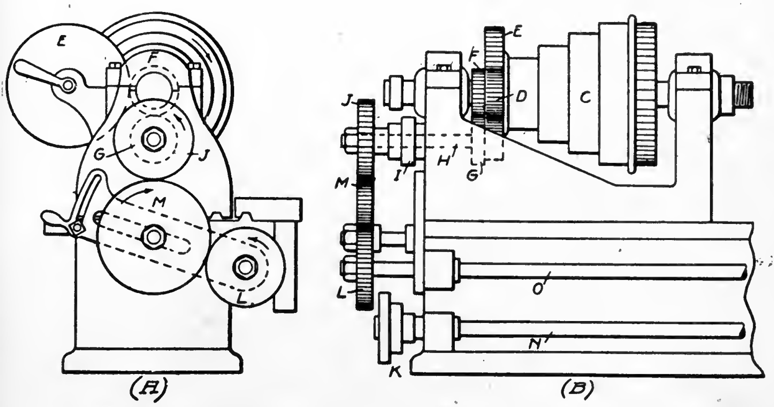


Fig. 97. End and Front Elevation of Engine Lathe for Thread Cutting

eter of the change-gear *J*, the carriage will move twice as fast as in the first instance, and the lathe will cut two threads per inch. From this condition we deduce the rule:

The thread to be cut will bear the same ratio to that of the lead-screw, as the two change-gears bear to each other.

The ratio will be the same whichever change-gear is the larger. It must be remembered, however, that if the change-gear on the stud shaft is the larger, the resultant thread will be coarser than the lead-screw, and *vice versa*.

To cut any desired number of threads per inch, we first find the ratio which the desired number of threads bears to the number of threads on the lead-screw, and then select such change-gears as bear this ratio to each other.

The gears will revolve in the directions shown by the arrows; therefore the lead-screw revolves in the direction opposite to the main spindle, so that with a right-hand thread on the lead-screw *O* (the usual arrangement), the lathe, geared as here shown, will cut left-hand threads. If right-hand threads are desired, the intermediate gear *M* is moved to the left, and another gear introduced between it and the gear *L*. The usual type of engine lathe is therefore provided with an auxiliary set of gearing for the purpose of reversing the rotation of the stud shaft *H*. These auxiliary gears are known as tumbler gears.

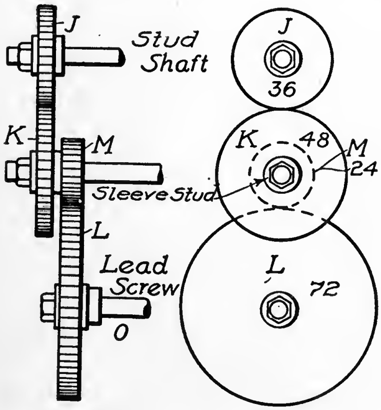


Fig. 98. Compounding Gears

Compounding. When the proper ratio cannot be obtained by the use of the change-gears at hand, or when the gears of the desired numbers of teeth would be too small to connect properly, or too large to put in place, the method called compounding is used. Assume that the ratio of 4 to 1 is required Referring to Fig. 98, a 36-toothed gear *J* is placed on the stud shaft, and a 72-toothed gear *L* on the lead-screw. On the sleeve stud are two gears, a 48- and a 24-toothed, fixed to each other by placing them on a splined compounding sleeve which runs loosely on the stud. The 36-gear is engaged with the 48-, and the 24- with the 72-toothed gear, as shown. Front and edge views of these gears are given to show clearly their relative positions.

The results of this combination are: If the 36-gear engaged the 72-gear, the ratio would be 2; and if the 24-gear engaged the 48-gear, the ratio would also be 2. These ratios multiplied would be 4, as required. As shown, the ratios are: 36 to 48, ratio $1\frac{1}{3}$; and 24 to 72, ratio 3—which ratios multiplied together produce 4.

The effect, then, of introducing the 24- and 48-gears instead of a single intermediate (usually called an idler gear, as it does not affect ratios), is to double the ratio existing between the gear on the stud shaft and the gear on the lead-screw. The combination just described will cut a 16-pitch thread on a lathe having a 4-pitch lead-screw. (Usually a lathe will cut this thread without compounding. The gears shown and described are given merely as a simple example.)

Should the above order of arranging the gears be reversed, the effect will be to *divide* the thread ratio instead of *multiplying* it; and instead of cutting 16 threads per inch, the lead-screw threads of 4 to an inch will be divided by 4, producing 1, and the lathe will cut 1 thread per inch.

Lathes are usually provided with compounding gears of the ratios of 2 to 1—as 24 to 48, 36 to 72, and so on. But it is very convenient to have those of 3 to 1—as 24 to 72, 36 to 108, etc.

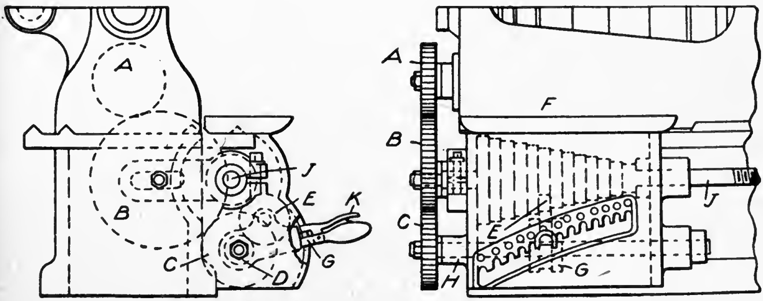


Fig. 99. End and Front Elevation of Rapid Change-Gear Device

It is always advisable to use as large change-gears as possible, as the revolutions of the lead-screw will be more regular and steady, the strain on the gear teeth will be less, and smoother and more accurate work will result.

Rapid Change-Gear Devices. The more recent development of the thread-cutting mechanism of engine lathes aims to arrange the change-gears so that any desired thread may be cut without removing or replacing any of the gears. To accomplish this, all the necessary change-gears are permanently located on the lathe, and any one of them may be brought into use as required, by shifting one or more levers or equivalent devices.

One of the most prominent of these devices is shown in Fig. 99, which illustrates at the left, an end and, at the right, a front elevation of the device applied to an engine lathe. Motion is communicated from the work spindle by means of the gear *A* on the head shaft, and through the gears *B* and *C*, to the supplemental shaft *H*, upon which is fitted a forked sliding arm *G*. This sliding arm *G* carries a pinion *D* splined to the shaft *H*, and also a connecting pinion *E* journaled in it and capable of engaging either one of the sets of change-gears *F*, which are fixed upon the lead-screw *J*, by sliding the lever to the right or left, raising it until the gears engage properly, and permitting the pin on the thumb-lever *K* to enter one of the series of holes shown in the gear casing and thus secure the lever *G* and connecting pinion *E* in proper position to transmit motion for the supplementary shaft *H* to the lead-screw *J*. An index on the outside of the gear casing gives the necessary information as to the position of the lever *G* for any desired thread. No calculations are necessary.

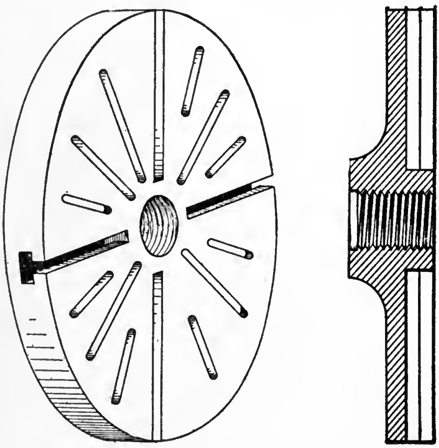


Fig. 100. Heavy Faceplate

Size of Lathe. In this country, the size of a lathe is designated by the greatest diameter it will swing over the guides, and by the length of the bed. The one illustrated is known as a 14-inch by 8-foot lathe. In England, the distance from the guides to the center is the unit of size, and, in a few cases, the greatest distance between centers is considered to be the length of the lathe. Thus a 15-inch lathe in England would be a 30-inch lathe in the United States.

Attachments. The attachments usually furnished without extra charge are a large faceplate of the full swing of the lathe, a center rest, and a follower rest. The small faceplate is used only for driving the work indirectly through suitable attachments.

Faceplate. The large faceplate shown in Figs. 95 and 100 is often used as a direct support for the work, the T-slots and other openings being used for bolting and clamping the work firmly to the faceplate.

Center Rest. When work is being done on the end of a shaft so that the tailstock cannot be used, it is necessary to support the shaft in some other way. This is done by means of the center rest, shown in Fig. 101. This consists of a frame hinged at *A*, and fitted with three movable jaws *BBB*. The rest is clamped to the lathe-bed in the proper place. The jaws *BBB* are then adjusted to form

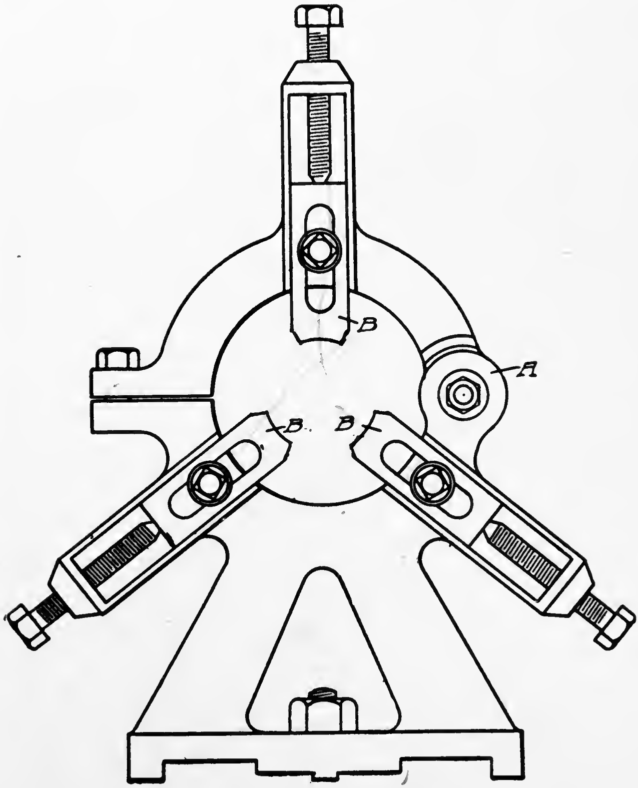


Fig. 101. Typical Center Rest

a bearing for the work, care being taken that the axis of the work coincides with the axis of the lathe. Unless it coincides, the work will not be turned true; that is, the end will not be square, but will be hollowed or conical, as shown somewhat exaggerated in Fig. 102. The center rest is also used to support or steady long shafts that are being turned.

After adjusting the center rest to size, it can be moved along the bed of the lathe without changing its relation to the lathe axis;

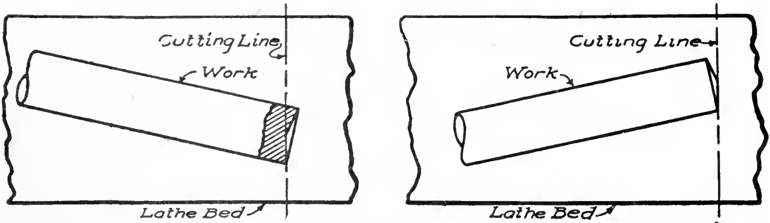


Fig. 102. Diagrams Showing Effects When Work is Not Held True in Cutting

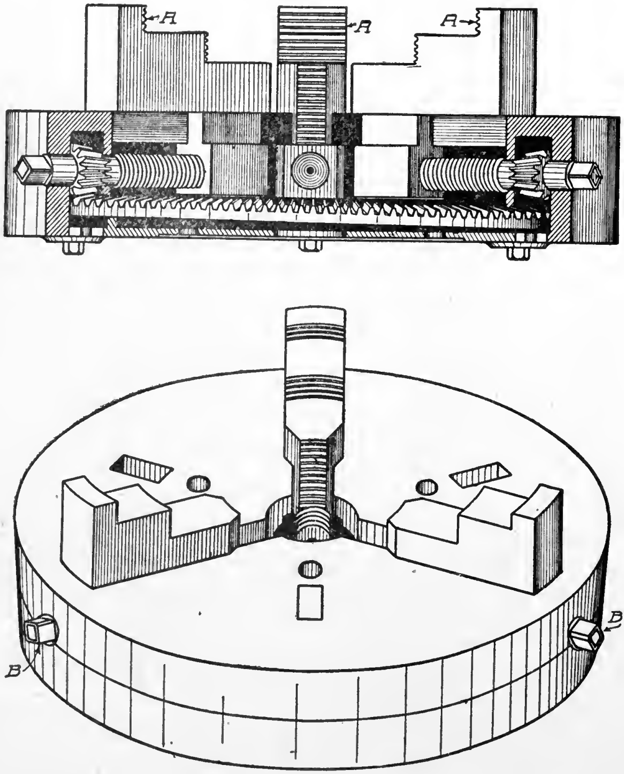


Fig. 103. Combination Chuck

but care must be taken not to reverse the center rest in the lathe, as, in most cases, such action would necessitate a readjustment.

The names back rest and steady rest are synonymous with center rest, the use of the device often determining the name.

Follower Rest. The follower rest serves some of the purposes of the center rest, but is fastened to the carriage, and moves with it at the point of greatest stress. It may consist of adjustable jaws or a solid ring to slip over the piece being turned. It is especially valuable in turning shafting and other work where the ratio of length to diameter is very great.

Chucks. The lathe chuck, Fig. 103, consists of a body which is fastened to a special faceplate in such a way that it is concentric with the spindle. The three jaws *AAA* can be moved in and out toward or from the center, by turning the screw-heads *B*. These chucks are used either universal or independent. If used universal, all the jaws are operated simultaneously. That is, when one of the screw-heads *B* is turned, all of the jaws are moved an equal distance toward or away from the center. This makes it possible to put the work in position quickly if it is approximately round in its unfinished condition. With the independent chuck, Fig. 104, each jaw is operated separately. Such a chuck is used for holding pieces of irregular shape and those which must be held eccentrically. In Fig. 103 the universal and independent features are combined in one tool, means being provided for working the jaws separately or together as desired.

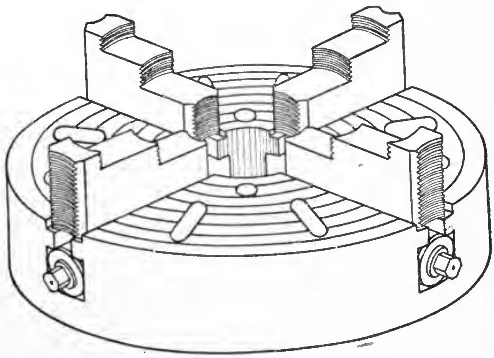


Fig. 104. Lathe Work Chuck

In using a universal chuck, each screw should be tightened. The method of procedure is to place the work in the chuck, and turn one screw-head until all of the jaws are in contact with the piece to be worked on. Then turn the chuck, and tighten each screw-head successively until each one is tight enough. Owing to wear and lost motion, it is sometimes necessary to apply the wrench to each one three or four times before the final adjustment is effected.

Universal chucks generally have three jaws, while independent chucks have four. It follows that a combination chuck is not wholly satisfactory, because, with three independent jaws, it is very difficult to adjust work accurately, and with four universal jaws it is equally difficult to get every jaw to bear on the work. For certain classes of work—especially valves and pipe fittings—chucks with two jaws are often used.

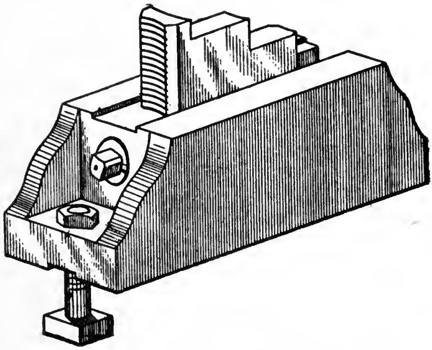


Fig. 105. Faceplate Chuck Jaw

The large faceplate of a lathe can be made into an independent chuck by attaching what are known as faceplate jaws, Fig. 105. In this case, there may be six, eight, or more jaws.

As work chucks are expensive, it sometimes happens that a piece is to be held for which no provision is made. A chuck can then be made of wood, as shown in Fig. 106. Two pieces of wood *A* and *B* are bolted together by the bolts *EE*, while separated by the filling pieces *CC*. The piece is firmly bolted to the faceplate by the bolts *DD*. The lathe is then run at high speed, and the interior bored out exactly the size of the piece that is to be held. The nuts of the bolts *EE* are slackened, and the filling pieces *CC* removed. The piece to be worked on is then inserted, and by tightening the nuts *EE*, it is securely clamped between the pieces *A* and *B*.

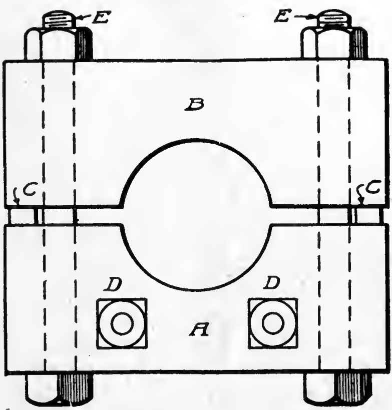


Fig. 106. Emergency Chuck

Lathe Dogs. As the frictional contact of the work on the live center is not sufficient to drive it, some device must be used to make the work rotate with the center. To accomplish this, a lathe dog is used. For round work, such as shafting, a dog like that shown in Fig. 107 is often used. The shaft or piece to be turned is placed in the hole *A*, and held firmly in place by the set screw *B*. The tail-piece *C* is put through a hole in the faceplate, and the work rotates with the live center.

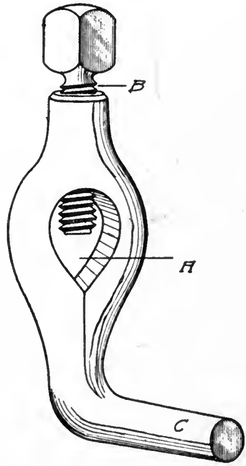


Fig. 107. Lathe Dog for Round Work

While this type of dog is satisfactory in most cases, the contact between the dog and the faceplate being beyond the end of the piece, introduces a bending strain which is appreciable in slender work. To avoid this, dogs are made with a straight tail, and driven by a stud projecting from the faceplate.

For work other than round, a dog such as that shown in Fig. 108 may be used. The piece to be worked on is placed between the jaws, and held in position by the bolts. The holes in the upper jaw are made larger than the screws, in order that the angle between the jaws may be varied. The connection between the faceplate and dog is made as with Fig. 107.

Mandrels. Another method of holding work is by the use of a mandrel. This is a piece of steel with a slight taper; the ends are flattened for the lathe dog, as shown in Fig. 109. It frequently happens that a piece with a hole in it is to be turned or finished over its outer surface. In this case a dog cannot be used, and it is troublesome to hold it in a chuck. Such a piece is shown in Fig. 110. This is a stuffing-box gland. If it were to be held by the jaws of a chuck, the face could not be reached at all, and only a portion of the edge *B*, whereas a dog clamped to it would offer even greater obstruction. The method of using the mandrel is to ream the gland out, so that it can be driven upon the mandrel. When this is done, the frictional resistance

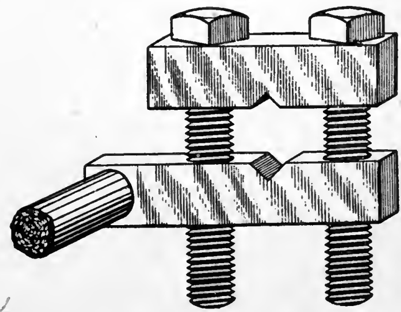


Fig. 108. Clamp Dog

between the two will be sufficient to drive the piece. So held in place, it can be finished over its outer surface with but one setting

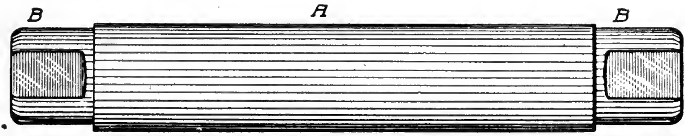


Fig. 109. Work Mandrel

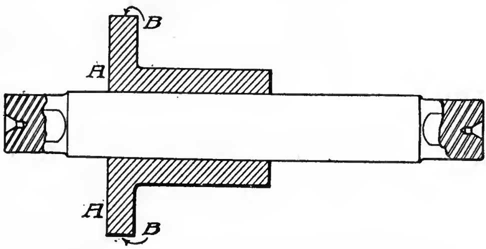


Fig. 110. Stuffing-Box Gland Held on Mandrel

in the lathe. All finishing possible may be done while it is in the chuck, leaving, in this case, only the face *A* and edge *B* to be finished while on the mandrel.

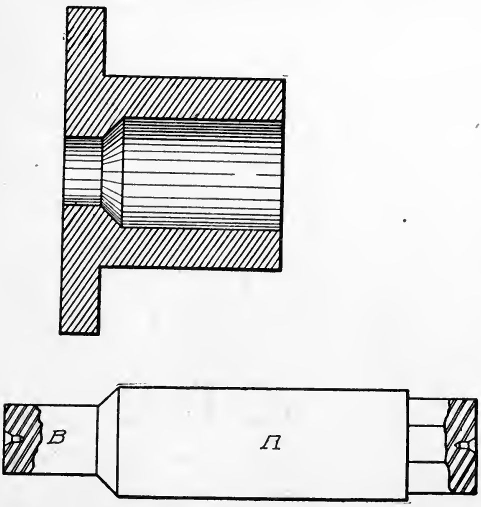


Fig. 111. Stuffing-Box Gland Requiring Special Mandrel

Should the gland be shaped, as shown in Fig. 111, it would be necessary to make a special mandrel to fit the bore. The cylindrical part *A* of the mandrel should be a driving fit, and the part *B* a loose fit.

Expanding Mandrels. Where a mandrel like that shown in Fig. 109 is frequently used, the constant driving of the work on and off will wear the mandrel to a smaller diameter, causing it to become useless. Again, solid mandrels are usually made of standard diameters, varying by sixteenths of an inch. It sometimes happens that a piece to be turned has a hole which will not fit any standard solid mandrel.

To overcome these difficulties, an expanding mandrel shown in Fig. 112 is much used. This is really a chuck, so arranged that

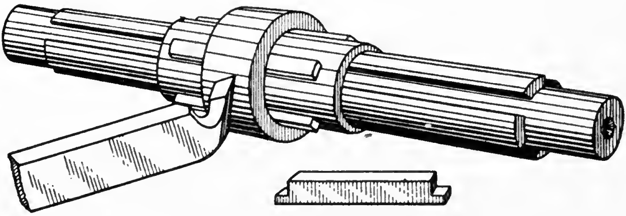


Fig. 112. Diagram Showing Use of Expanding Mandrel

the grips can be forced out against the interior of the hole. When the work has been finished, the grips are again drawn in and the piece removed. Another form of expanding mandrel is shown in Fig. 113.

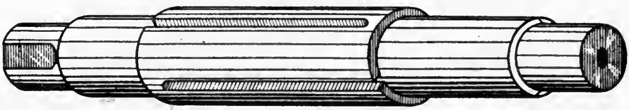


Fig. 113. Another Form of Expanding Mandrel

Cutting Tools. *General Characteristics.* The cutting tools used in lathes are of a great variety of shapes. These shapes are adapted to the work that is to be done, and to the kind of finish that is to be left upon the metal. There are two fundamental requirements for all cutting tools: the cutting edge alone must touch the metal; the edge must be keen. A typical form of tool is shown in Fig. 114. The cutting edge of the tool at *A* is in contact with the work. The bottom line *AB* runs back from the metal and does not touch it. The top face *AC* slopes down and back. The line *AD* is a tangent at the cutting point, and the line *AE* is radial at the same point. Therefore, the angle *DAE*

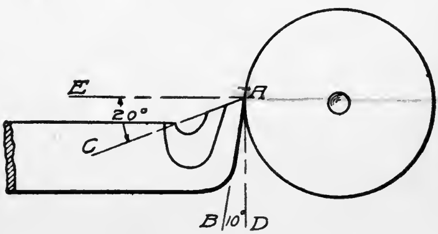


Fig. 114. Cutting Tool Angles

is always a right angle. The angle *DAB* is called the angle of clearance, and should be small—in lathe tools, not over 10 degrees. The angle *CAE* is called the angle of rake, and should be as great as circumstances will permit—about 20 degrees on lathe tools for wrought iron and steel, leaving 60 degrees for the solid or cutting angle, which is the same angle as that used in the case of the ordinary cold chisel.

Material. The physical qualities of the material to be turned will to a great extent determine the cutting angles of the tool—first, as to whether it is hard or soft; and second, whether it is crystalline or fibrous. The degree of hardness of a material determines how much can be removed in a given time, or—what amounts to the same thing—whether the speed of the cutting shall be fast or slow, and whether the feed shall be coarse or fine. A crystalline or fibrous nature will make considerable difference in the top angles of the tools, and this will be readily seen in the tendency of a crystalline metal (as cast iron) to break up into small chips, while the fibrous turnings (as wrought iron) will curl off into spiral or helical shavings. Therefore the fibrous material will require tools of sharper angles than those for a crystalline metal.

For cutting soft brass and other similar metals, the top surface *AC* of the tool will be practically level, while the face angle *BAD* will be 3 degrees or frequently less.

Clearance. Clearance prevents the tool from rubbing on the work, while rake adds to the keenness of the cutting edge, and gives freedom to the removal of the chips. A tool should have sufficient strength at the cutting point to do the work required.

Setting the Tool. The tool should be set so that the cutting edge will coincide very nearly with a horizontal line passing through the axis of the work. Most machinists set the cutting edge a little above this horizontal line. When so set, the stress tends to force the tool down along the line of its greatest strength. The tool may, however, be set too high. If this is done, as in Fig. 115, the angle of clearance will disappear, and the curve of the work will rub against the bottom of the tool. This will tend to force the tool out; heating the tool and producing a rough surface on the metal being turned. If, on the other hand, the tool is set too low, as in Fig. 116, the cutting edge does not stand in line with the motion of the work at the point of contact. The result will be that the metal will be scraped rather than cut, as there is no rake; and the pressure upon the tool will be in the line of its least resistance, as indicated by the arrow. Such a position might cause the point of the tool to break off. It will also cause the tool to tremble or

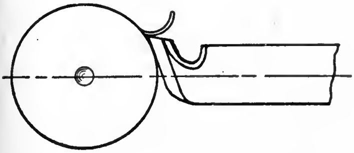


Fig. 115. Tool Set too High

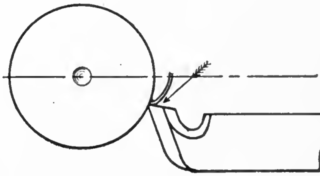


Fig. 116. Tool Set too Low

chatter as it removes the chips, leaving a rough and wavy surface on the metal.

As stated above, most machinists prefer to set the cutting edge a little above the center. The amount the tool is set above the center is slight, and of course depends upon the character of the work, and upon the shape of the cutting tool. The angle *ACB*, Fig. 117, should be only about 5 or 6 degrees.

Tool-Posts. The tool is usually held to the carriage by means of a tool-post, shown in Fig. 118. The post consists of a piece with a slotted hole through the center for the tool *B*. A ring *C* slips over the post and rests upon the body of the carriage. This ring may be beveled as shown, to provide vertical adjustment for the point of the tool. The post has a collar *D* at its lower end, that goes loosely into a slot in the carriage. At the top there is a set screw *E*. When the tool has been properly adjusted by turning the ring *C* to give it the correct elevation, the set screw is tightened down upon the top of the tool. This raises the tool-post to a bearing on the under side of the slot, and clamps the whole firmly in position.

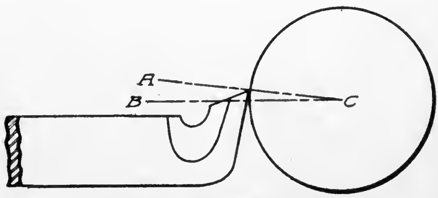


Fig. 117. Standard Setting with Cutting Edge of Tool a Little Above Center

In setting the tool, it should be done with the cutting edge as far back toward the supporting ring as possible. If it has too much overhang, as shown by the dotted lines of Fig. 118, it will spring under the pressure of the work and will tend to chatter.

While this form of tool-post is used more than any other, there are certain objections to it. In the first place, changing the height

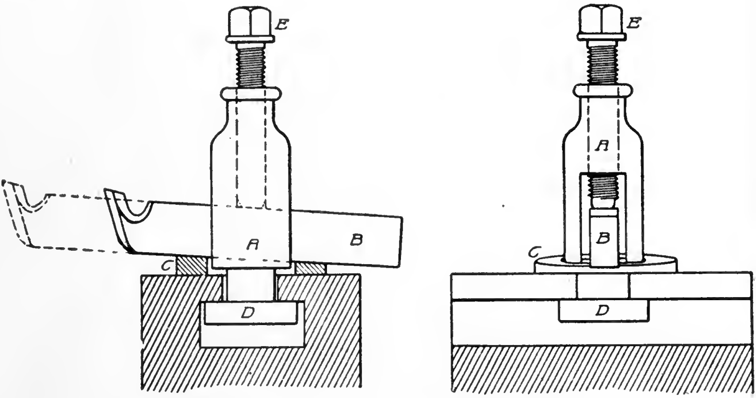


Fig. 118. Tool-Post Holding Tool to Carriage

of the tool-point also changes the angles of rake and clearance. These are supposed to be correct when the base of the tool is horizontal. Any change from this position will alter these angles materially. Again, this post is not rigid enough for heavy work. On lathes of over 30-inch swing, the style of tool-holder shown in Fig. 119 is often employed. English manufacturers use it almost exclusively on all sizes. There is no provision for raising and lowering the point of the tool; and while this is not of serious importance on large lathes (30-inch and over), it becomes a matter of moment when turning the kind of work which as is usually handled in lathes of 14-inch and 16-inch swing.

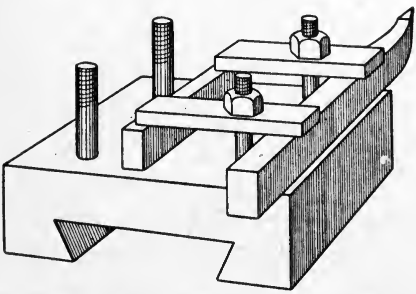


Fig. 119. Tool Holder for Heavy Turning

The type of tool-post shown in Fig. 120 has two beveled rings to adjust the height of the tool.

The Lipe tool-post shown in Fig. 121, combines the good points of all the other types; the tool can be held by one or two screws as the character of the work may require, and the tool may be adjusted vertically and horizontally after being clamped down. The construction and operation of this tool-post are so evident from the illustration, that further description will not be given.

An entirely different method of adjusting the tool point is by means of what is called the elevating or rise-and-fall rest, shown in Fig. 122. In this type, there is a T-shaped casting carried on the upper part of the carriage, supported by trunnion screws at the front, and by an adjust-

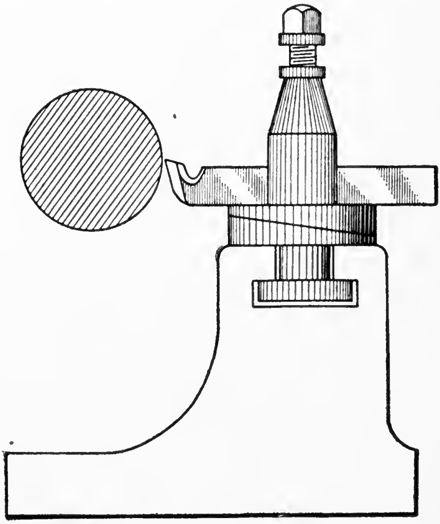


Fig. 120. Bevel Ring Tool-Post

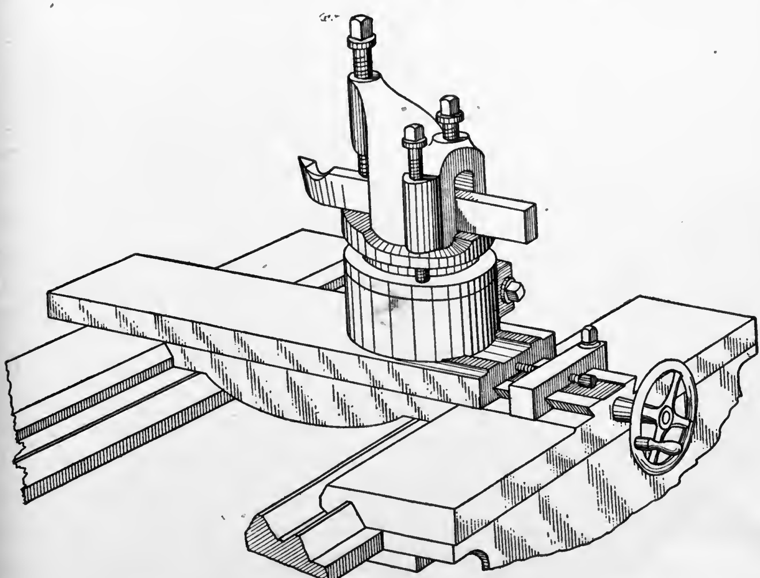


Fig. 121. Lipe Tool-Post

ing screw at the rear. With this is used a tool-post as shown in Fig. 118, with a plain ring. The elevating rest is used quite extensively on small lathes, but the convenience of adjustment is gained by a loss in rigidity. The cross-rail is slender; and the

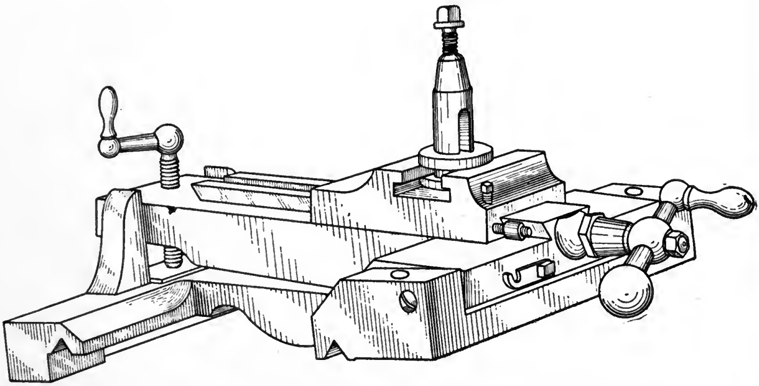


Fig. 122. Tool-Post with Rise-and-Fall Rest

elevating portion, being supported at three widely separated points, lacks stiffness. As the effective swing over the carriage is limited by the height of the cross-rail and by the parts carried above it, they are made slender—in fact, too slender in many cases.

Turning Tools. *Side or Facing Tool.* A very common form of lathe tool is shown in Fig. 123. It is used for squaring up the ends of shafts, facing shoulders, and similar work. While the ordinary forms will not remove a large amount of metal, they can, when made thick and heavy, be used for making roughing cuts on the surface of cylindrical work. The common form is made

Fig. 123. Side or Facing Tool

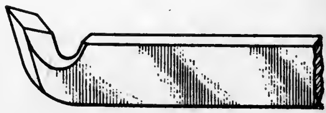


Fig. 124. Diamond Point

slender in order to work between the dead center and the piece in squaring up ends.

Diamond Point. A common form of tool for turning wrought iron and steel is the diamond point, shown in Fig. 124. The name is derived from the shape of the top face. This tool has both front and side rake, which form a keen edge without reducing the strength. It is used for finishing only when the point is ground slightly rounding. In finishing, but little metal should be removed and a fine feed used.

The feed of a tool is the amount of longitudinal advance at each revolution of the work.

For roughing out cast iron, a strong and rapid working tool is a round nose with considerable side rake. For finishing wrought

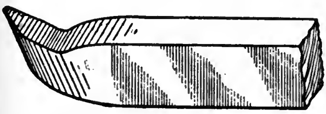


Fig. 125. Tool for Finishing Wrought Iron and Steel

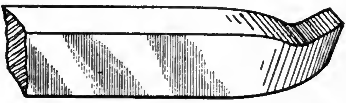


Fig. 126. Tool for Finishing Cast Iron

iron and steel, a modification of the diamond point, as shown in Fig. 125, is often used. For cast iron, a square-nosed tool, Fig. 126, may be used. The square-nosed tool must be carefully ground and accurately set; otherwise it is very likely to gouge into the softer parts of the metal. When finishing wrought iron and steel, the tool should be liberally supplied with oil or soda water. Cast iron, on the other hand, is usually worked dry, both in roughing out and in finishing.

Cutting-Off or Parting Tool. This tool is illustrated in Fig. 127. The blade is quite narrow—as narrow, in fact, as the character of the work will allow. As the blade needs to be narrower at the shank and at the bottom than it is at the cutting edge, it follows that the tool will be weak. It must be set horizontally, so that, as the tool is fed to the work, only the cutting edge will touch the metal. It must also be set so that the cutting edge will pass through the axis of the work as it is fed to the center. If set too high, it will cease to cut before the center of the work is reached; while if too low, the tool has a poor scraping action, and will leave a portion of the work uncut. On work held between centers, one should not attempt

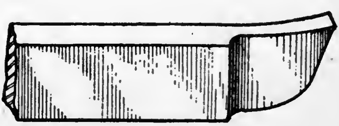


Fig. 127. Cutting-Off or Parting Tool

to cut to the center of the piece, as the work will surely ride up onto the tool.

Boring Tools. The term boring as used in machine practice usually means methods of machining internal surfaces, other than those of common drilling and reaming. Also methods for holding the work other than those common to ordinary drilling and chucking operations are often used. When boring machine parts, use may be made of the common inside turning tools or of special appliances termed *boring bars.*

Fig. 128. General Form of Boring Tool

When a hole is to be bored in lathe work, tools of a shape different from those used in turning should be used. The general form of the tool is shown in Fig. 128. The length of the shank depends on the depth of the hole to be bored, for it must be long enough to reach from the tool-post to the bottom of the hole. This overhang makes the tool more likely to spring, and necessitates a much lighter cut being taken than when removing the same amount of metal by outside turning tools. The result of this lighter cut is seen in the increase of time required to remove a given amount of stock. The shape of the cutting edge is practically the same as that of the tools for turning, except that the boring tool must have more clearance to avoid striking the work. Therefore, with the same solid angle, the tool will have less rake. The reason for this will be seen by comparing Figs. 114 and 129. In Fig. 114, it will be seen that the surface of the work is outside a tangent at the cutting point and can never interfere with the bottom of the tool. In Fig. 129, the surface of the work is inside the tangent, and, unless the tool has a large amount of clearance, it will cause trouble by striking the concave surface.

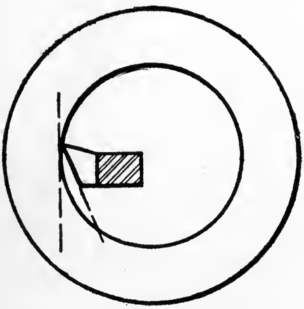


Fig. 129. Boring Tool Set for Clearance

Fig. 130. Tool for Turning in Brass

Tools for brass differ from those used on steel and iron in that they have no rake. A tool suited for working brass is shown in Fig. 130. Brass does not readily split, and the chips break off as soon as started from the main body. When turning wrought iron and steel, on the other hand, the metal does not break, but forms long spiral chips if the tool is in condition. If a tool with top rake is used in turning brass, the work will not only be rough in appear-

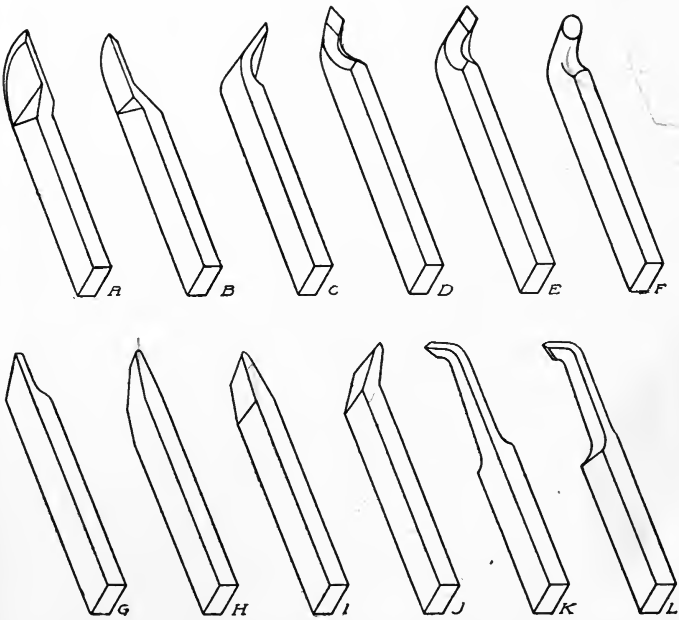


Fig. 131. Common Forms of Slide-Rest Tools. *A*—Left-Hand Side; *B*—Right-Hand Side; *C*—Right-Hand Bent; *D*—Right-Hand Diamond Point; *E*—Left-Hand Diamond Point; *F*—Round Nose; *G*—Cutting-Off; *H*—Roughing; *I*—Threading; *J*—Bent Threading; *K*—Boring; *L*—Inside Threading

ance, but there is great danger of the tool gouging into the stock and spoiling the work or tool, possibly both. The finishing tools for brass may be square or round-nosed, without rake; in fact, a small amount of negative rake will produce a much better surface. When the brass contains a large percentage of copper, some rake to the tool may be required, owing to the ductility and toughness of the metal.

Fig. 131 shows common lathe tools for cast iron and steel.

The shape of the tool has a very important influence on the amount of work it can be made to do. As has already been explained, these shapes vary with the different metals that are being worked, and also with the class of work performed. It is highly important that the cutting angles be correctly formed. While hand-grinding on the emery wheel and grindstone is fairly satisfactory, the best results can be obtained only by the use of a regular tool-grinding

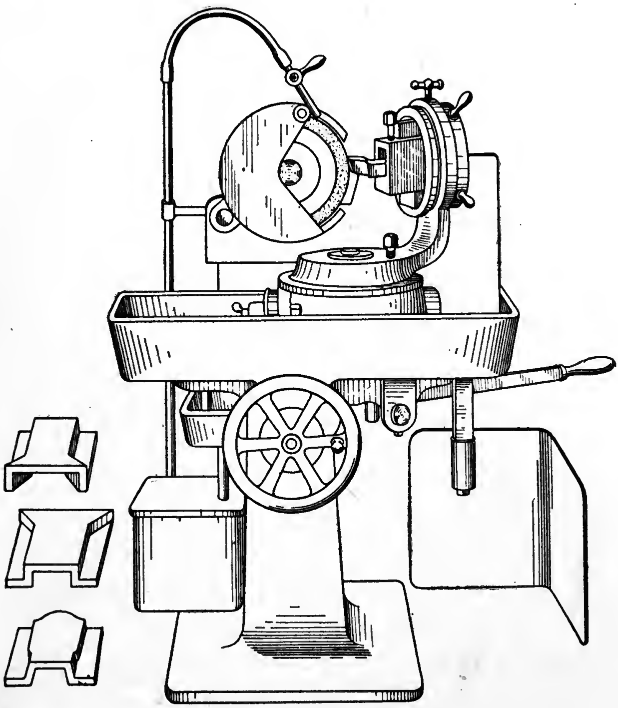


Fig. 132. Tool-Grinding Machine

machine, such as that shown in Fig. 132. In addition to the grinding, tools for fine finishing should be carefully whetted on a fine oil-stone.

Cutting Speed. *Importance of Speed Element.* The speed at which cutting is done is an important matter. This varies with the shape of the tool, the quality of the metal being worked, and the strength of the lathe. The amount of metal removed in a given time is, therefore, equally variable. It is impossible to make a correct estimate of the time that a given piece of work will require, unless all of the above elements are known. For approximate estimates, the cutting speed for carbon tool steel cutting tools may be taken to range about as follows:

In cast iron	from 30 to 40 feet per minute
In wrought iron	from 25 to 30 feet per minute
In steel	from 15 to 40 feet per minute
In brass	from 60 to 100 feet per minute

Suppose a wrought-iron shaft 6 feet long and 4 inches in diameter is to be turned. Let the lathe be capable of carrying a feed of $\frac{1}{32}$ inch per revolution. The shaft has a circumference of $4\times3.1416=12.5664$ inches. To give the tool a cutting speed of 25 feet per minute the shaft must make $\frac{25\times12}{12.5664}=24$ revolutions per minute (approximately), giving a feed of $\frac{1}{32}\times24=\frac{3}{4}$ inch in that interval of time. With a travel of $\frac{3}{4}$ inch per minute, it will take the cutting tool on the lathe carriage $(6\times12)\div\frac{3}{4}=96$ minutes to take a cut the whole length of the shaft.

The amount of feed is really the governing element. This may be as much as $\frac{3}{16}$ inch per revolution, and, for finishing cuts, may not be more than $\frac{1}{100}$ inch. The depth of the tool cut also influences the time required to finish a given piece of work, and this may vary from $\frac{1}{100}$ to $\frac{1}{2}$ inch, depending entirely upon the shape of the tool and the strength of the lathe.

Speeds for High-Speed Steel. The cutting speeds given above are what may be used with the best grades of tool steel, such as Jessop's; but by using air-hardening or tungsten steels, the speed of cutting may be very much increased over the values given above. These high-speed steels are rapidly coming into favor, more especially for heavy roughing cuts.

With the aid of these steels, the cutting speeds have been increased, and the chip is made heavier in both depth and feed, up to the point where the lathe refuses to carry the load. The ability of this quality of steel to stand without injury, the high temperatures resulting from the fast feeding, is the feature which enables it to perform the work at this rate.

For what are now known as the high-speed steel tools, the speeds for the different metals mentioned will be as follows:

Soft cast iron	50 to 80 feet
Hard cast iron	20 to 40 feet
Hard cast steel	30 to 40 feet
Soft machine steel	60 to 120 feet
Hard machine steel	20 to 45 feet
Wrought iron	35 to 45 feet
Tool steel, annealed	40 to 80 feet
Tool steel, not annealed	15 to 20 feet
Soft brass	110 to 130 feet
Hard brass	90 to 110 feet
Bronze	60 to 80 feet
Bronze, "gun metal"	40 to 60 feet
Gray or red fiber	40 to 60 feet

Usually an increase in speed must be accompanied by a reduction in the feed—that is, in the number of revolutions of the work per inch of movement of the tool. The following directions will be proper in this respect:

Roughing cuts on soft cast iron may be made with a feed as coarse as 4 to 5 per inch, with a strong round-nosed tool.

Roughing cuts on soft machine steel forgings, 5 to 8 per inch.

Sizing cuts on soft cast iron, 12 to 16 per inch.

Sizing cuts on soft machine steel, 16 to 20 per inch.

Finishing cuts on soft cast iron, with a narrow-point tool, 15 to 25 per inch.

Finishing cuts on soft machine steel, with a narrow-point tool, 20 to 40 per inch.

Finishing cuts on soft cast iron, with a wide point, practically a straight-faced tool with the corners slightly rounded, 1 to 4 per inch.

Under the same circumstances, for a soft machine steel, 4 to 8 per inch.

Brass will be turned with feeds of from 10 to 40 per inch, according to the kind of cut and shape of the tool.

Fiber will stand a heavy feed in proportion to the speed.

Cooling the Tools. For cooling the tool while performing heavy duty, a solution of sal soda is preferable to water, as it prevents rusting of the work and machinery. Its office is simply to keep the tool cool. If a tool becomes overheated, the edge begins to turn over and it becomes dull.

Referring to Fig. 116, it will be seen that the chip, as it is being removed, presses down on the top face of the tool. This pressure increases with the depth of cut and the feed. The resulting friction would soon cause a high temperature in the tool if it were not reduced by the lubricant. The lubricant cools the tool by absorbing a portion of the heat, and lessens the amount of heat developed by reducing the friction between the tool and the chip. Clean, pure water is the only lubricant which can be used on cast iron; but the rapid rusting which follows its use makes it undesirable, and as a result cast iron is usually turned dry. Brass is also usually turned dry. Prime quality lard oil is sometimes used for cooling the tool; but the greater cost prevents its extended use, unless some means are provided for collecting, separating, and filtering it.

LATHE OPERATIONS

Mounting Work on Lathe. *Centering Method.* A piece to be turned is supported on the two centers of the lathe. In order that this may be done, it is prepared by drilling and countersinking

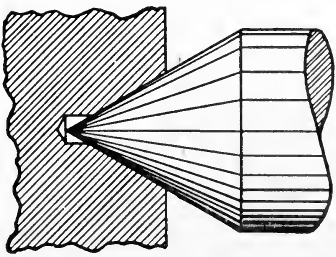


Fig. 133. Hole and Center of Correct Angle for Centering Work

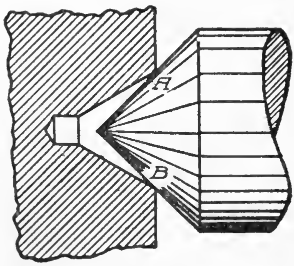


Fig. 134. Effect of Using Different Angled Hole and Center

a hole in each end. This is called centering the work. The countersunk hole should have the same angle as the lathe center upon which it is to run. The hole should be drilled deep enough so that the point of the lathe center may not strike. The shape of the hole is shown in Fig. 133. The generally accepted standard angle is 60 degrees. The effect of using a 60-degree hole on a 90-degree center is shown in Fig. 134. The result of such an application is that the bearing will be concentrated on a line *AB*, causing rapid wear of the outer end of the hole, and a cutting of the dead center.

The size of center holes varies with the weight of the work and the character of the operation. Heavy work and rough turning require large center holes, while small work and fine turning can be done without countersinking deeply. As bearing surfaces in cast iron must be large to be satisfactory, center holes in cast iron are likely to give trouble by unequal and rapid wear. When heavy turned work in cast iron must be very accurate, it is well to drill a hole in each end, drive in a plug of wrought iron or mild steel, and form the center holes in the plugs thus driven.

When the piece to be turned has been put in place, the dead center should be oiled and screwed up into position. It should be tightened so that there is no lost motion, and yet allow the work to rotate freely.

Chuck Method. The turning of shafts and bars is not, however, the only kind of work to be done on a lathe. Pieces can be turned

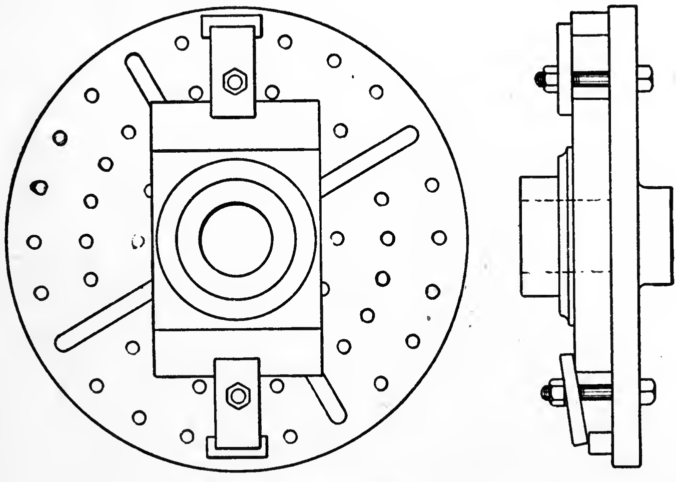


Fig. 135. Work Clamped to Faceplate

that are thin, that have holes through the center, or which are so shaped that they cannot be held upon the centers. In such cases it becomes necessary to hold the work firmly without distortion. This may be done by use of the lathe chuck.

Faceplate Method. Still another method of holding a piece to be worked is that shown in Fig. 135. The piece is clamped to the faceplate. When this is done, there should be a bearing on the faceplate immediately beneath the clamping strap. For example, consider Fig. 136. Suppose a disc having four feet on one side is to be faced off on the front. The clamps should be placed directly over the feet, as in *B*. If they are placed between the feet at *EE*, the work will be sprung out of shape, as shown by the dotted lines in *A*. Then, when the tool has done its work, the shape of the piece, while bolted to the faceplate, will be as shown in *C*. As soon as the pressure of the straps is removed, the elasticity of the

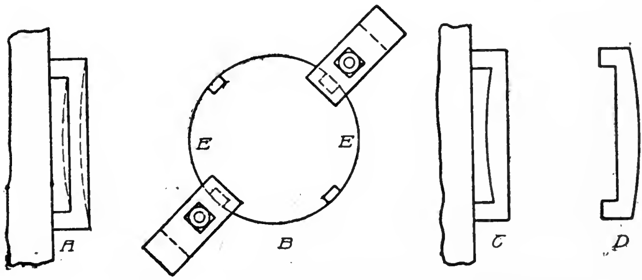


Fig. 136. Proper and Improper Method of Clamping Work

metal will cause the piece to assume the convex form shown in *D;* whereas, if the straps had been placed as shown in *B*, no distortion would have been produced.

An angle iron may be clamped on a faceplate, as shown in Fig. 137, presenting a surface parallel to the lathe axis, to which

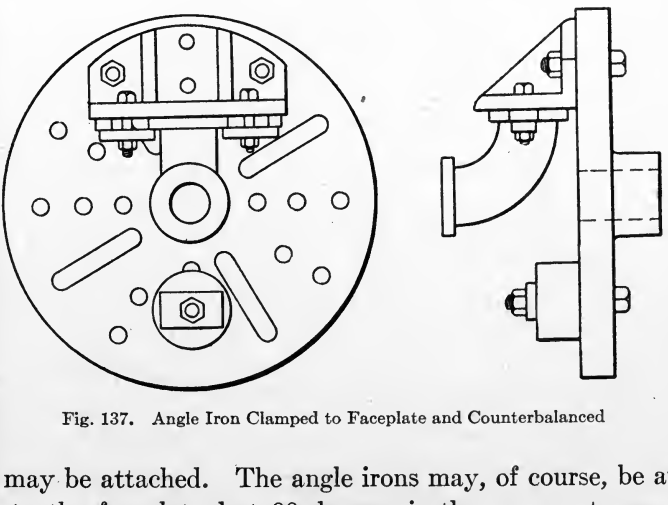


Fig. 137. Angle Iron Clamped to Faceplate and Counterbalanced

work may be attached. The angle irons may, of course, be at any angle to the faceplate, but 90 degrees is the one most commonly used. When work is held in this manner, it is desirable to counterbalance it, as is also shown in Fig. 137.

Adjusting Pieces to Center on Faceplate. Whenever a piece is to be turned on a lathe faceplate, it is necessary to adjust it so that its rough outline is approximately concentric with the lathe centers. This is done by bolting it lightly to the faceplate and running the lathe. While running, a piece of chalk is held so that the projecting portions will strike it. This marks the piece, and indicates the part that is farthest from the center. The lathe is then stopped, and the piece shifted, moving the chalk mark toward the lathe axis. This is repeated until the chalk makes a continuous mark around the whole circumference. The piece may then be considered to be centered.

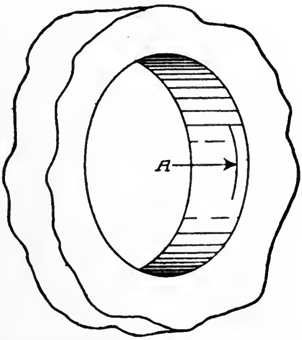


Fig. 138. Centering a Hollow Piece

Suppose it is necessary to center a piece having a hole that must run true. In this case the inside of the hole must be used as a guide. Let Fig. 138 represent the hole with the thin shell, and *A* a chalk mark made as described for centering by the outside. In this work the chalk mark must be removed away from the axis. A lathe tool may be used, as shown in Fig. 139, to center a piece that is to be bored.

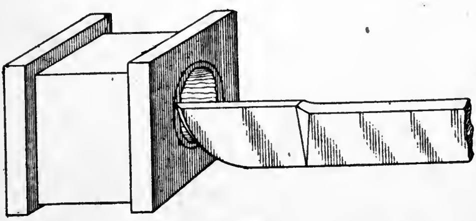


Fig. 139. Use of Lathe Tool in Centering Piece to Be Bored

Where a piece has already been turned, greater accuracy is demanded, and a surface gage may be used to advantage. Set the gage on the bed or carriage of the lathe, and place one of the points in contact with the work. Rotate the work as before, and note where the point touches the surface. This point is to be treated in the same way as the chalk mark explained in a preceding paragraph.

A still more accurate method of positioning a piece of turned work on a faceplate, is to use some form of graduated indicator, such as the Starrett indicator, shown in Fig. 140. This is held in the tool-post, the contact-point brought against the work until the indicating arm is at zero. If the work is now slowly rotated by hand, the indicator will show just where the work is out of true, and being graduated in thousandths of an inch, will also show how much.

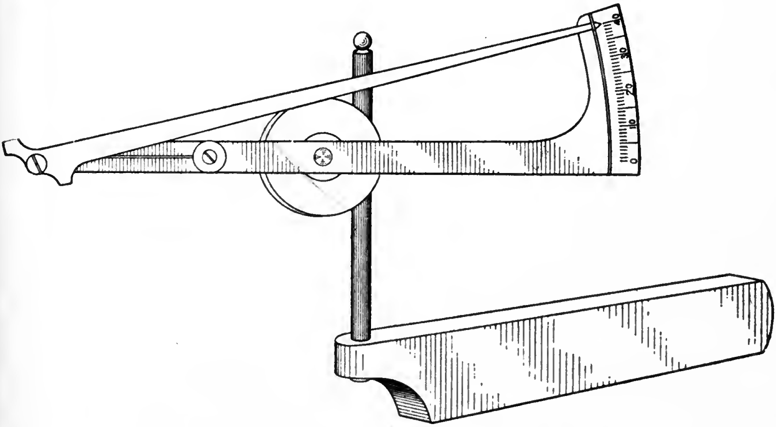


Fig. 140. Starrett Indicator Used for Centering Work

By careful adjustment, the piece may be centered to the degree of accuracy required.

Instead of locating a cylindrical surface concentric with the axis of the lathe, it often happens that a point is to be located in the

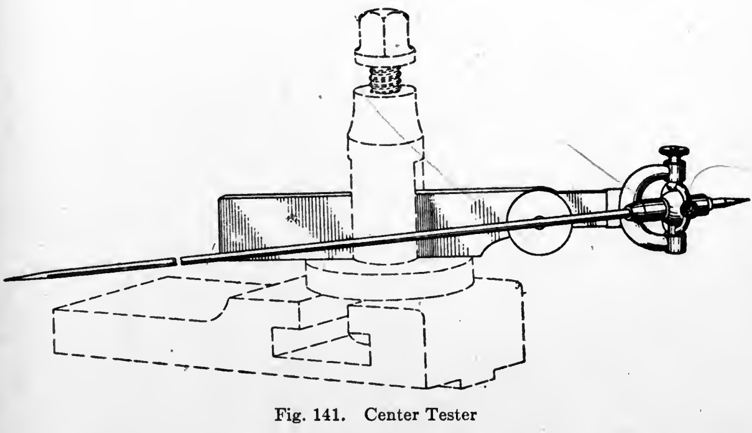


Fig. 141. Center Tester

axis. For this purpose, the center indicator, Fig. 141, is used. The free end of the short arm is placed in the point to be centered (usually a prickpunch mark), the fulcrum being held in the tool-post. When the work is rotated, the free end of the long arm not only shows the error, but magnifies it in proportion of the length of the short arm to the length of the long arm. By using a comparatively long arm, the point can be very closely centered.

Centering Finished Work. After making the center punch mark in the end of the piece, it is drilled and countersunk. This must be done very accurately, but frequently the drilled hole or the countersink will not be in the exact center, Fig. 142. This may be caused by uneven grinding of the drill, eccentric motion of the drill point (due to the inaccurate running of the spindle), or the distortion of the metal by the center punch. If the countersink is not exactly in the center, it must be drawn back to the center.

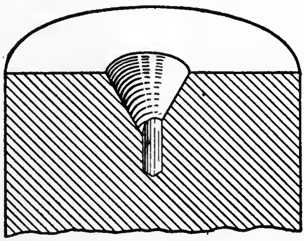


Fig. 142. Countersink off Center

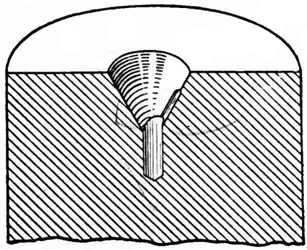


Fig. 143. Method of Drawing the Hole

This is generally done with a small round-nosed chisel and a hammer. The method of doing this is as follows: After making the center punch mark, the hole is drilled and then countersunk slightly. The work should now be stopped; and if the circumference of the conical hole is not concentric with the circumference of the piece, a groove should be cut down the side farthest from the outer circumference, as shown in Fig. 143. The depth of the groove, which should be near the center, depends upon the amount of eccentricity. The countersink is again started, and the groove drilled out. If the circle is not yet concentric, the process is repeated.

Turning. *Facing or Squaring Up.* The first operation usually performed on a piece of work when placed in the lathe is facing or squaring up the ends. This must be done to get a uniform bearing for the centers. The finishing of all surfaces at or nearly at right angles to the axis of the work, is classed as facing, and the side tool,

Fig. 123, is usually employed. For roughing cuts, the cutting face of the tool is placed at a slight angle to the work surface, in order to remove the metal quickly; but for finishing cuts it is placed nearly flat against the work, so that a light, thin chip may be taken.

Turning a Cylinder. Turning the cylindrical portions of the work is next done by the use of the diamond point or similar tool. Roughing cuts are taken to within about $\frac{1}{64}$ inch of the finished size, and a fine finishing cut reduces the work to the exact diameter. For roughing cuts common calipers should be employed for test measurements; while for finishing cuts, the micrometer caliper is more suitable. All measurements must be taken with the lathe at rest, as motion of the work renders close calipering impossible.

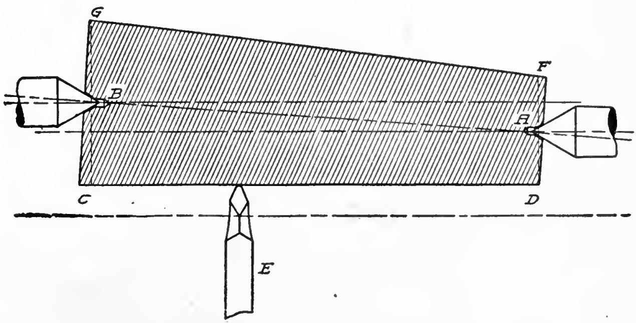


Fig. 144. Turning a Taper by Setting over Dead Center

Turning a Taper. It frequently happens that a piece must be turned tapering; that is, one end is to have a greater diameter than the other. There are three ways of accomplishing this result: (a) setting over the dead center, (b) the use of the compound rest, and (c) the use of the taper attachment.

Setting over Dead Center. Setting the dead center over is the more common method. Provision is generally made for moving the dead center laterally toward the front or rear of the bed according to the taper required. With the dead center set over, the tool will be at unequal distances from the live and dead centers, because its movement is parallel to the axis of the lathe. This is shown in Fig. 144. The piece to be turned is placed upon the centers A and B, and the dead center is moved from the axis a distance equal to the difference between the radii AD and BC.

This leaves the side DC parallel to the center line of the lathe; hence the tool will be fed along this line. The objection to doing work by this method is that the lathe centers do not have full bearings at the ends of the work, and the center holes are likely to wear out of their true positions.

If the taper is to be turned on a piece held by a mandrel, or if the taper is to extend but a part of the total length of the work, the amount of set-over for the dead center must be calculated in the same manner as though the taper were to extend the whole length of the mandrel or work. In other words, the amount of set-over for the dead center is determined by the distance between the centers and the rate of taper.

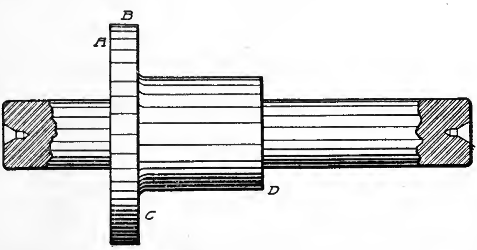


Fig. 145. Turning Taper on Piece Held by Mandrel

For example: Suppose the mandrel in Fig. 145 to be 16 inches long; and the piece of work CD, which is to be turned tapering, is 4 inches long; suppose also that the diameter at D is to be $\frac{1}{4}$ inch smaller than at C. Then, for one inch of length, the difference in diameters would be one-fourth of $\frac{1}{4}$ inch, or $\frac{1}{16}$ inch; and for a length of 16 inches, it would be sixteen times $\frac{1}{16}$ inch, or 1 inch. Since the set-over is equal to the difference of the radii, the set-over for the 16 inches would be one-half of 1 inch, or $\frac{1}{2}$ inch. This, then, would be the set-over for the work under consideration, and for any piece to be tapered at the rate of $\frac{1}{4}$ inch in 4 inches when held on a 16-inch mandrel. In accurate work, the distance to which the centers enter the mandrel must be considered.

The machinist generally sets over the dead center as accurately as possible and takes a roughing cut. The taper is then tested by a careful comparison of the diameters, or by trying it in a tapered hole of the proper angle, and setting the center more accurately. Setting over the dead center does not give accurate results, on account of the fact that the centers do not have a true bearing at the ends of the work. Naturally, the shorter the work, compared with the amount of set-over, the greater the inaccuracy because of the greater nearness of the centers.

EXAMPLES FOR PRACTICE

1. A tapered bushing 3 inches long and of 4 and $4\frac{1}{2}$ inches outside diameters, is driven on a 12-inch mandrel for turning. How much must the dead center be set out of line in order to do the work?

Ans. 1 inch

2. A connecting rod 6 feet long is to be turned tapering from the center to the neck back of the stub ends. This distance is 26 inches. The diameter at the center is to be 3 inches, and at the neck $2\frac{1}{2}$ inches. How much offset must be given to the dead center?

Ans. .692+inch

3. A shaft had a taper 2 feet long turned on one end. The large end of the taper was 4 inches in diameter, and the small end was

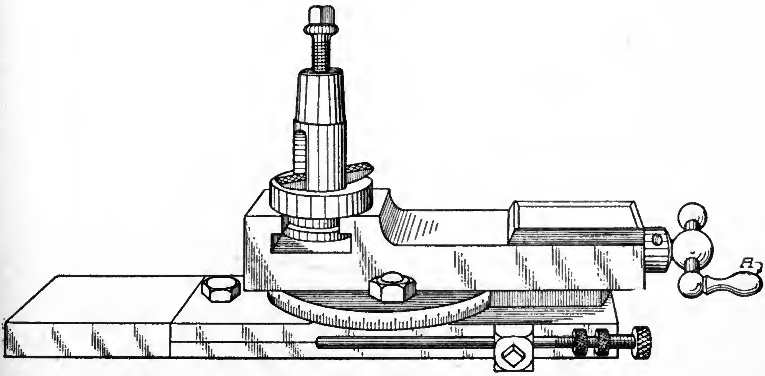


Fig. 146. Compound Tool Slide

3 inches in diameter. The dead center was set over 1 inch. How long was the shaft?

Ans. 4 feet

Compound Slide. In turning a taper with the compound slide, the work may be held in a chuck, on the faceplate, or between the centers. The compound slide, Fig. 146, is then set at such an angle that the direction of motion of the tool will coincide with the required taper. Several methods are employed for this adjustment of the rest. The tool is fed to the work by means of the feed-handle *A* attached to the compound slide.

Taper Attachment. The taper attachment, Fig. 147, is in the form of a guide which is bolted to the back of the lathe. It can be set at any desired angle with the axis of the lathe, the limit usually being a taper of about three inches per foot. The guide is graduated so that calculations based on the length of the work are unnecessary. A slide moving with the guide is attached to the cross-feed slide of the carriage. This cross-feed slide is loosened, and, while the carriage is moved by the feeding mechanism, the tool is moved in or out according to the direction of the taper.

One of the important points to be observed in turning tapers, is to have the cutting point of the tool exactly level with the work axis. If this is not done, the work will not be truly conical, and the rate of taper will vary with each succeeding cut.

In case an internal and an external taper are to be turned so as to form a fit, the internal taper should, if the character of the

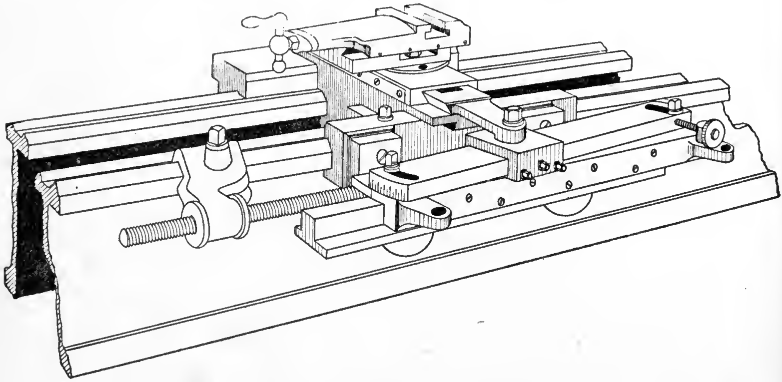


Fig. 117. Taper Attachment

work will permit, be made first. After this has been done, the external taper should be turned and tested several times during the process. The external taper is first turned as accurately by measurement as possible, taking care that the piece is made a trifle large. Draw a chalk line on the external taper, from one end to the other; press the tapers together, and give one of them a slight twist. On separating the tapers, the rubbing of the chalk will show where the work was in contact, and, by resetting the lathe and repeating the process, a very accurate fit can be obtained.

Turning Shafting. Shafting is usually turned $\frac{1}{16}$ inch less than the nominal diameter. For instance, instead of a shaft 2 inches in diameter, one of $1\frac{15}{16}$ inches in diameter is used. The reason is that iron of a nominal diameter of 2 inches, usually $\frac{1}{32}$

inch over size, can be used. Before turning a length of shafting, the rough bar should be carefully straightened. After the center holes have been drilled and the piece placed in the lathe, the work can be rotated, and the eccentric portions marked with chalk. When this has been done, the bar should be removed from the lathe and sprung back into true alignment. It is well to take two cuts in finishing shafting, one for the roughing cut, and one very fine finishing cut. The tool for the latter part of the work should be kept flooded with oil or with a solution of sal soda. If the work is light, a tool holder, carrying both the roughing and the finishing tools, may be used. This makes it possible to do the work in practically the same time as for one cut.

Preventing Spring in Shafting. As a length of shafting is likely to spring under the pressure of the tool, some method of preventing such action must be employed. A center rest can be used. It is, however, inconvenient, and must be frequently moved, or at times it will stand too far from the tools. Furthermore, as the rough bar will neither be truly round nor concentric with the centers, it is necessary to turn spots for the center rest. Spotting, however, takes considerable time, owing to the fact that very light cuts must be taken in order to avoid springing the bar. A good method is to have a ring attached to the tool holder; the internal diameter of this ring is that of the finished shaft. It is slipped over the tailstock center, and follows the finishing tool. It must, of course, be rigidly fastened to the tool holder. In this way the shaft is supported close to the tools; the ring also serves as a gage to measure the diameter of the shaft. If, for any reason, the tools turn to a larger diameter than the inside of the ring, notice is immediately served upon the workmen to that effect, by binding in the ring.

Eccentric Turning. The term "eccentric" is given to a rotating machine part which is used to "throw" a mechanism eccentric with its main center line. Eccentrics may be said to include all crank motions, also many cam motions. In general shop terms, however, an eccentric is a machine part having an outer circle which is off center or eccentric with its shaft.

In construction it may be machined as a part of its own shaft, or it may be so made as to slip onto a shaft in which case provision must be made for keying it to the shaft.

Throw of Eccentric. The throw of an eccentric may be taken as the radius of eccentricity or it may be taken to mean twice the radial eccentricity.

Machining Eccentrics. While eccentrics may be machined in a variety of ways, the accompanying text will consider the lathe

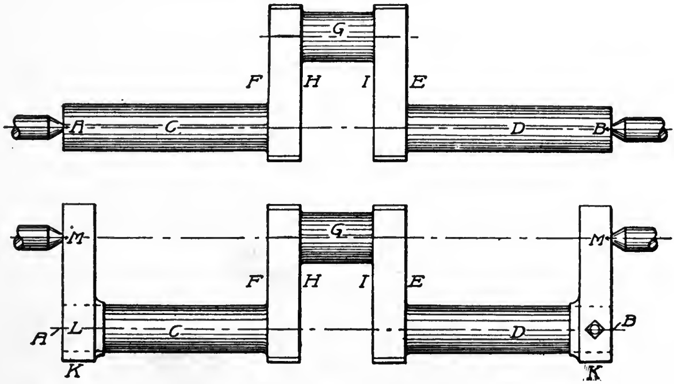


Fig. 148. Machining Crank Shaft

only. If the eccentric is of the simple form of two circles with their centers offset in relation to each other, the work must be done on a mandrel provided with two sets of centers, one pair for each circle, Fig. 149.

Eccentric Solid with Shaft. In this case if the throw of the eccentric is less than the radius of the shaft, both sets of work centers may be made in the shaft ends. Where the throw is too great to allow this, some provision must be made for the second set of centers.

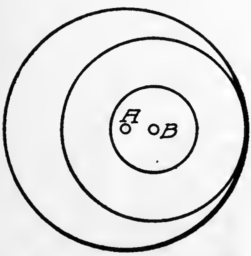


Fig. 149. General Shape of Eccentric

Two methods for doing this are in common use, (a) casting or forging lugs upon each end of the shaft sufficiently large to include the needed centers, (b) use of attachments for the shaft ends, the attachments themselves being provided with the desired centers.

Eccentrics Not Solid with Shaft. Eccentrics of this sort are usually those which have a hole chucked through their center of throw. Such eccentrics are usually finished upon mandrels having two sets of centers. Fig. 150 shows such a mandrel. Work centers

A and *A′* are those to be used while the throw surfaces are being machined. *B* and *B′* the centers used while constructing the mandrel. With such a mandrel as this driven into the provided hole,

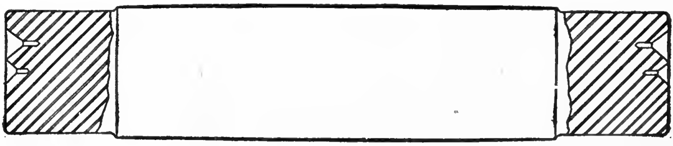


Fig. 150. Mandrel for Holding an Eccentric

work can be done upon surfaces which are *concentric* to the axis of the mandrel or which are *eccentric* with it.

Using a Faceplate or Work Chuck. Eccentrics can and often are machined by mounting them upon a suitable faceplate or by holding the work in a suitable chuck. Previous to mounting the work upon the faceplate for eccentric turning, it is usual to face off a surface to set squarely on the front face of the plate, as in Fig. 151.

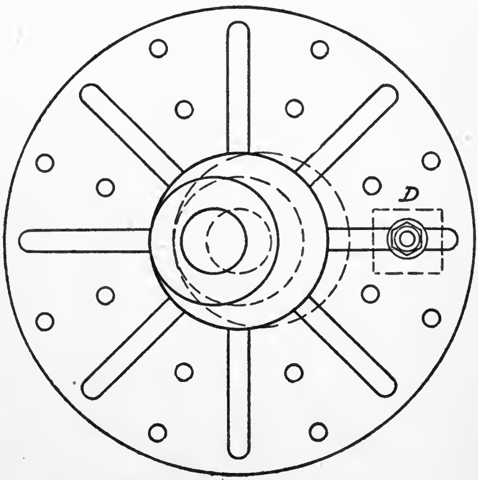


Fig. 151. Piece Mounted on Faceplate for Eccentric Turning

Crank-Shaft Turning. This is a special kind of eccentric turning in which the throws are termed crank pins and the remaining bearings are the shaft proper. In Fig. 148 is shown a simple crank shaft with a crank pin *G* and regular bearings *CD*.

It is customary to rough turn the bearings *C* and *D* previous to machining the crank-pin bearing *G*. The order of operations is as follows: Locate, drill, and ream work centers in ends *A* and *B*. Square ends *A* and *B* to the correct overall length. Rough turn *C* and *D*. Rough square *E* and *F*. Place attachments *K* and *K* on the ends of bearings *C* and *D* in position to machine crank-pin bearing *G* as shown. Rough turn *G*. Rough and finish square

H and *I* to gap dimensions. Finish surface *G* to dimensions. Remove attachments *K* and *K* and with work again mounted on centers *A* and *B*, finish square surfaces *E* and *F*, and finally finish to accurate dimensions surfaces *C* and *D*.

Attachments K and K. These are often known as jigs and are made and used in a variety of forms. Those shown in Fig. 148 are suitable for a single-throw crank, while those used in turning or grinding multiple-throw cranks may be circular in form and provided with several work centers. In all cases it means simply the provision of work centers opposite to and in alignment with the surface to be machined. It is self-evident that the same results can be obtained by casting or forging lugs or flanges upon the ends suitable for the various work centers.

Handling Shaft Surfaces. In turning surfaces *C* and *D*, if the shaft is slender or of considerable length, use a center rest on surface *D* while working surface *C*, to assist in its support and reverse for surface *D*.

If necessary, struts may be placed between the jigs and cheeks of the shaft while machining surface *G*. In this manner, the whole piece may be steadied somewhat.

Drive the work, when surfaces *C* and *D* are being machined, with a common lathe dog. Use some sort of a faceplate stud when machining surfaces *E*, *F*, and *G*.

Boring Bars. The boring of holes sometimes calls for a length and strength of tool that cannot be readily attained with the ordinary boring tool. A great deal of such boring is done with double-headed tools. These tools are held in bars, and cut at each end. An ordinary form of such tool is shown in Fig. 152. The tool *A* is turned and fitted so that when placed in the bar it is central with the centers of the latter. It is held in position by the key *B*. It cuts at each end. Such a tool may be made to do very rapid work. It is extensively used for boring in places where a piece of work must be duplicated a great number of times.

Tools of this kind are also used for finishing. After the cut has been started, the tool should not be stopped until the cut has been completed. If it is stopped, there will be a ledge in the bore at that point. The reason for this is found in the springing of the metal and the contraction due to cooling while at rest. The tools used for finishing usually have a broad surface. Those used for the roughing cut are narrower; they wear more rapidly than the finishing tools, and are usually adjustable. An excellent example of the use of boring bars is found in the boring of engine cylinders. Special machines are used for such work. The greater portion of the work is done with a boring bar such as that shown in Fig. 153. It consists of a heavy bar *A*, upon which there is a stiff traveling head *B*.

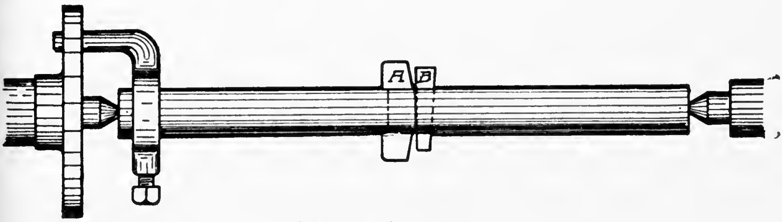


Fig. 152. Boring Bar

The latter carries the tool *C*, which may or may not be capable of a transverse adjustment. The head moves longitudinally on the bar, and is held, adjusted, and fed by the screw *D*. At one end of the screw, there is a star wheel *E*, by which it is turned. As the bar revolves, one arm of the star strikes against a stop *F* at each revolution. This turns the screw by an amount proportional to the number of arms in the star. For example, if there are six arms

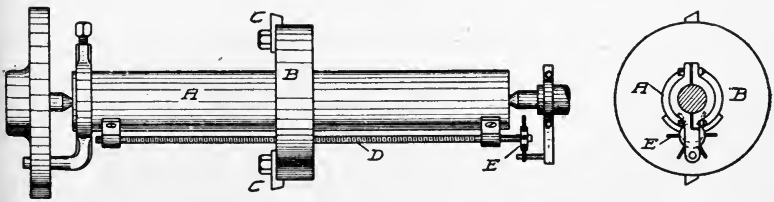


Fig. 153. Special Boring Bar for Boring an Engine Cylinder

in the star, the latter will be turned one-sixth of a revolution for each revolution of the boring bar. As the screw turns, it moves the head along the bar by an amount proportional to the pitch of its thread and the arms in the star. This forms the feed of the tool. For example, if a star has four arms, and is keyed to a screw of eight threads to the inch, then, for each revolution of the bar, the head will be advanced $\frac{1}{32}$ of an inch. Another form of boring bar is shown in Fig. 154.

Boring bars with fixed tools are also used. In such cases the work is caused to travel beneath the bar as it is turned. A case of this kind occurs in the boring-out of brasses for railroad cars.

In general, it may be stated that all heavy work should be machined in the position which it is eventually to occupy. This is to overcome its tendency to spring out of shape under the influence of its own weight. In small articles this tendency is inappreciable. For large pieces it is sometimes quite apparent.

Screw Cutting. The tools used for cutting threads are called screw-cutting tools. These tools are used in the lathe in the same manner as the diamond-point and round-nosed tools. The cutting edge of the tool must be of the same contour as the space between the finished threads.

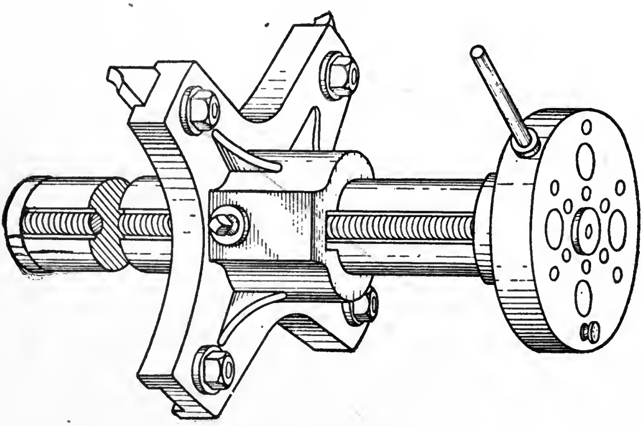


Fig. 154. Boring Head

Types of Threads. There are five types of screw-threads commonly used in this country: the V-thread, shown in Fig. 155, has the form of an equilateral triangle, with an angle of 60 degrees. It is sharp at the top and bottom. This thread is difficult to cut, because of the trouble experienced in keeping the point of the tool sharp.

The Sellers, Franklin Institute, or United States Standard is a modified form of V-thread, shown in Fig. 156. This thread has an angle of 60 degrees, with the top and bottom flattened for one-eighth of its depth.

Another form in common use is the square thread, shown in Fig. 157. The thread and space are of the same width. This

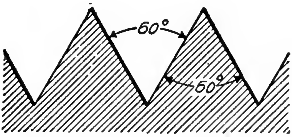


Fig. 155. Section of V-Thread

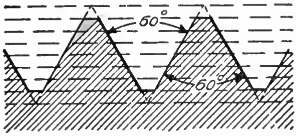


Fig. 156. Sellers, Franklin Institute, or United States Standard Thread

thread is used where heavy work is done, such as in jack-screws and presses.

The Whitworth thread is similar to the United States Standard, the slight differences being as follows: the sides form an angle of 55 degrees instead of 60 degrees, and the top and bottom are rounded instead of flat.

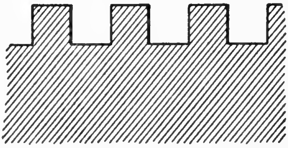


Fig. 157. Square Thread

The fifth type, the Acme thread, is somewhat similar to the square form. The difference is that the sides incline $14\frac{1}{2}$ degrees from those of the square thread. This form of thread is much used for lathe lead-screws and for giving motion to sliding parts of fine instruments, because the thread is simpler to construct than the square form, and the lost

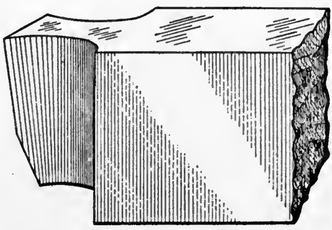


Fig. 158. Side View of Tool for Cutting Square Threads

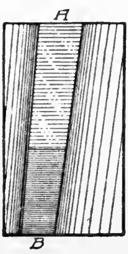


Fig. 159. Square Thread Tool Showing Inclination of Thread to Body

motion can be taken up by simply closing the nut halves nearer together.

Cutting Tool for Square Threads. The tool used for cutting square threads is shown in Figs. 158 and 159. It is of the proper

TABLE III*

U. S. Standard Threads, Bolts, and Nuts

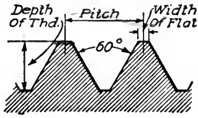
The Tap Drill Diameters in the Table Provide for a Slight Clearance at the Root of the Thread in Order to Facilitate Tapping and Reduce Tap Breakages. If Full Threads Are Required Use the Diameters at the Root of the Threads for the Tap Drill Diameters Instead.

U. S. STANDARD SCREW THREAD

$$\text{Pitch} = \frac{1}{\text{No. of Th'ds. per Inch}}$$

$$\text{Depth of Th'd.} = 0.6495 \times \text{Pitch}$$

$$\text{Width of Flat} = \frac{\text{Pitch}}{8}$$



Diameter	Number of Threads per Inch	Diameter at Root of Thread	Diameter of Tap Drill	Area in Square Inches		Tensile Strength at Stress of 6000 Pounds per Square Inch	Working Strength at Stress of 6000 Pounds per Square Inch	Dimensions of Nuts and Bolt Heads				
				of Bolt	at Root of Thread							
$\frac{1}{4}$	20	0.185	$\frac{13}{64}$	0.049	0.026	160	......	$\frac{1}{2}$	0.578	0.707	$\frac{1}{4}$	$\frac{1}{4}$
$\frac{5}{16}$	18	0.240	$\frac{1}{4}$	0.076	0.045	270	......	$\frac{19}{32}$	0.686	0.840	$\frac{5}{16}$	$\frac{19}{64}$
$\frac{3}{8}$	16	0.294	$\frac{5}{16}$	0.110	0.068	410	......	$\frac{11}{16}$	0.794	0.972	$\frac{3}{8}$	$\frac{11}{32}$
$\frac{7}{16}$	14	0.345	$\frac{23}{64}$	0.150	0.093	560	......	$\frac{25}{32}$	0.902	1.105	$\frac{7}{16}$	$\frac{25}{64}$
$\frac{1}{2}$	13	0.400	$\frac{27}{64}$	0.196	0.126	760	......	$\frac{7}{8}$	1.011	1.237	$\frac{1}{2}$	$\frac{7}{16}$
$\frac{9}{16}$	12	0.454	$\frac{15}{32}$	0.248	0.162	1000	......	$\frac{31}{32}$	1.119	1.370	$\frac{9}{16}$	$\frac{31}{64}$
$\frac{5}{8}$	11	0.507	$\frac{17}{32}$	0.307	0.202	1210	260	$1\frac{1}{16}$	1.227	1.502	$\frac{5}{8}$	$\frac{17}{32}$
$\frac{3}{4}$	10	0.620	$\frac{41}{64}$	0.442	0.302	1810	680	$1\frac{1}{4}$	1.444	1.768	$\frac{3}{4}$	$\frac{5}{8}$
$\frac{7}{8}$	9	0.731	$\frac{3}{4}$	0.601	0.419	2520	1210	$1\frac{7}{16}$	1.660	2.033	$\frac{7}{8}$	$\frac{23}{32}$
1	8	0.838	$\frac{55}{64}$	0.785	0.551	3300	1790	$1\frac{5}{8}$	1.877	2.298	1	$\frac{13}{16}$
$1\frac{1}{8}$	7	0.939	$\frac{31}{32}$	0.994	0.694	4160	2470	$1\frac{13}{16}$	2.093	2.563	$1\frac{1}{8}$	$\frac{29}{32}$
$1\frac{1}{4}$	7	1.064	$1\frac{3}{32}$	1.227	0.893	5350	3470	2	2.310	2.828	$1\frac{1}{4}$	1
$1\frac{3}{8}$	6	1.158	$1\frac{7}{32}$	1.485	1.057	6340	4260	$2\frac{3}{16}$	2.527	3.093	$1\frac{3}{8}$	$1\frac{3}{32}$
$1\frac{1}{2}$	6	1.283	$1\frac{11}{32}$	1.767	1.295	7770	5500	$2\frac{3}{8}$	2.743	3.358	$1\frac{1}{2}$	$1\frac{3}{16}$
$1\frac{5}{8}$	$5\frac{1}{2}$	1.389	$1\frac{27}{64}$	2.074	1.515	9090	6630	$2\frac{9}{16}$	2.960	3.623	$1\frac{5}{8}$	$1\frac{9}{32}$
$1\frac{3}{4}$	5	1.490	$1\frac{17}{32}$	2.405	1.746	10470	7830	$2\frac{3}{4}$	3.176	3.889	$1\frac{3}{4}$	$1\frac{3}{8}$
$1\frac{7}{8}$	5	1.615	$1\frac{21}{32}$	2.761	2.051	12300	9470	$2\frac{15}{16}$	3.393	4.154	$1\frac{7}{8}$	$1\frac{15}{32}$
2	$4\frac{1}{2}$	1.711	$1\frac{49}{64}$	3.142	2.302	13800	10800	$3\frac{1}{8}$	3.609	4.419	2	$1\frac{9}{16}$
$2\frac{1}{4}$	$4\frac{1}{2}$	1.961	$2\frac{1}{64}$	3.976	3.023	18100	14700	$3\frac{1}{2}$	4.043	4.949	$2\frac{1}{4}$	$1\frac{3}{4}$
$2\frac{1}{2}$	4	2.175	$2\frac{15}{64}$	4.909	3.719	22300	18500	$3\frac{7}{8}$	4.476	5.479	$2\frac{1}{2}$	$1\frac{15}{16}$
$2\frac{3}{4}$	4	2.425	$2\frac{31}{64}$	5.940	4.620	27700	23600	$4\frac{1}{4}$	4.909	6.010	$2\frac{3}{4}$	$2\frac{1}{8}$
3	$3\frac{1}{2}$	2.629	$2\frac{11}{16}$	7.069	5.428	32500	28000	$4\frac{5}{8}$	5.342	6.540	3	$2\frac{5}{16}$
$3\frac{1}{4}$	$3\frac{1}{2}$	2.879	$2\frac{15}{16}$	8.296	6.510	39000	34100	5	5.775	7.070	$3\frac{1}{4}$	$2\frac{1}{2}$
$3\frac{1}{2}$	$3\frac{1}{4}$	3.100	$3\frac{11}{64}$	9.621	7.548	45300	40000	$5\frac{3}{8}$	6.208	7.600	$3\frac{1}{2}$	$2\frac{11}{16}$
$3\frac{3}{4}$	3	3.317	$3\frac{3}{8}$	11.045	8.641	51800	45000	$5\frac{3}{4}$	6.641	8.131	$3\frac{3}{4}$	$2\frac{7}{8}$
4	3	3.567	$3\frac{5}{8}$	12.566	9.963	59700	50100	$6\frac{1}{8}$	7.074	8.661	4	$3\frac{1}{16}$
$4\frac{1}{4}$	$2\frac{7}{8}$	3.798	$3\frac{27}{32}$	14.186	11.340	68000	58000	$6\frac{1}{2}$	7.508	9.191	$4\frac{1}{4}$	$3\frac{1}{4}$
$4\frac{1}{2}$	$2\frac{3}{4}$	4.028	$4\frac{3}{32}$	15.904	12.750	76500	66000	$6\frac{7}{8}$	7.941	9.721	$4\frac{1}{2}$	$3\frac{7}{16}$
$4\frac{3}{4}$	$2\frac{5}{8}$	4.255	$4\frac{5}{16}$	17.721	14.215	85500	74000	$7\frac{1}{4}$	8.374	10.252	$4\frac{3}{4}$	$3\frac{5}{8}$
5	$2\frac{1}{2}$	4.480	$4\frac{9}{16}$	19.635	15.760	94000	82500	$7\frac{5}{8}$	8.807	10.782	5	$3\frac{13}{16}$
$5\frac{1}{4}$	$2\frac{1}{2}$	4.730	$4\frac{13}{16}$	21.648	17.570	105500	93000	8	9.240	11.312	$5\frac{1}{4}$	4
$5\frac{1}{2}$	$2\frac{3}{8}$	4.953	$5\frac{1}{32}$	23.758	19.260	116000	103000	$8\frac{3}{8}$	9.673	11.842	$5\frac{1}{2}$	$4\frac{3}{16}$
$5\frac{3}{4}$	$2\frac{3}{8}$	5.203	$5\frac{9}{32}$	25.967	21.250	127000	114000	$8\frac{3}{4}$	10.106	12.373	$5\frac{3}{4}$	$4\frac{3}{8}$
6	$2\frac{1}{4}$	5.423	$5\frac{1}{2}$	28.274	23.090	138000	124000	$9\frac{1}{8}$	10.539	12.903	6	$4\frac{9}{16}$

* Reprinted from *Machinery*.

thickness at the cutting edge, but is somewhat narrower back of this point. The sides of the tool are inclined to the body, as shown at *AB*, Fig. 159; the amount of this inclination varies with the pitch of the thread and the diameter of the piece on which the thread is to be cut. To find the inclination, draw an indefinite straight line *AB*; and at right angles to it draw *CD*, Fig. 160. Make the length of *CD* equal to the circumference of the thread to be cut, measured at the root of the thread. On *AB*, lay off from *C* a distance *EC* equal to the pitch; then draw *ED*. This line will represent the angle of the side of the thread. The angle of the side of the cutting tool must be a little greater for clearance.

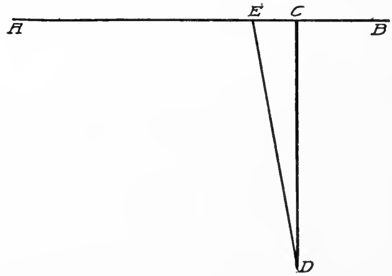


Fig. 160. Diagram of Clearance Angle

Cutting Tool for Inside Threads. For cutting inside threads, the shape of the cutting edge of the tool should be the same as for cutting an outside thread, and the tool must be made so that the cutting edge alone touches the work. This is accomplished by bending the tool as shown in Fig. 161, and giving it considerable clearance.

Cutting Standard Screw-Threads. When screw-threads are to be cut, the pitch used depends upon the outside diameter of the bar. A standard which has been generally adopted in the United States, is known as the United States Standard. Table III gives the outside diameter of the screw from $\frac{1}{4}$ inch to 6 inches in diameter, with the number of threads per inch to be cut.

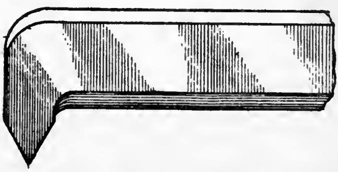


Fig. 161. Internal Threading Tool

When setting the tool for any form of thread, the tool point must be exactly level with the work axis, and a line at right angles to the axis of the lathe must bisect the angle of the tool point. In order that these conditions may be fulfilled, a thread or center gage, Fig. 162, is used. In this tool, the angles *A*, *B*, and *C* are made exactly 60 degrees. The two opposite sides are parallel. The angles *A*, *B*, and *C* are used when grinding and setting the tool.

The sides of the former are made to touch all along the edge of the tool. For setting the tool, the upper parallel side is held against the face of the work in a horizontal position. The tool is then set so that its sides touch along the edges of the notch *B*. The angle *C* may be used to gage the thread after it is cut.

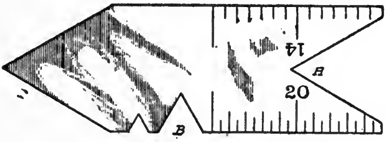


Fig. 162. Thread or Center Gage

The pitch measurement of fine threads is a difficult matter where an ordinary rule is used and the threads between the inch marks are counted; for this purpose pitch gages, Fig. 163, are very often used. The gages are short screw-sections on thin sheets of metal. To ascertain the pitch of any thread, set the gages over it successively until one is found that exactly fits. The figures stamped thereon will give the number of threads per inch.

Lathe Adjustment for Cutting Threads. The cutting of a thread demands that there shall be a certain definite ratio of motion between the rotation of the work and the travel of the carriage. For example, if a screw having a pitch of $\frac{1}{4}$ inch—or with four threads to the inch, as it is usually stated—is to be cut, the work spindle must make four revolutions while the carriage is moving one inch along the bed. If the screw is to have eight threads per inch, the work spindle must make eight revolutions to each inch of motion of the carriage or tool; if six threads, then six revolutions to the inch of motion, etc.

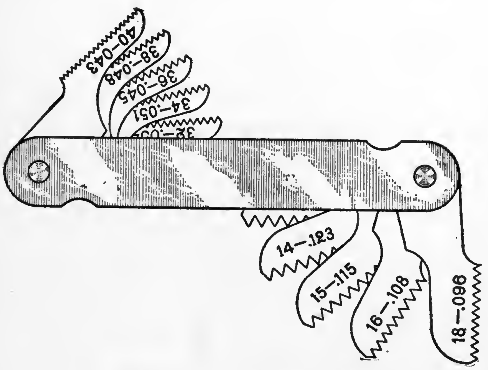


Fig. 163. Screw Pitch Gage

If, then, the apron lead-screw has four threads to the inch, it is evident that the speed of rotation of the spindle and of the screw must be the same, in order to cut a screw of four threads to the inch. In other words, for each revolution of the lead-screw, the carriage moves the distance of the pitch of the same, or $\frac{1}{4}$ inch. Hence the gears

J and *L*, Fig. 95, must have the same number of teeth. When a screw of eight threads per inch is to be cut, the spindle must make twice as many revolutions as the lead-screw. Then, for each revolution of the spindle, the lead-screw makes half a revolution, and thus moves the carriage $\frac{1}{8}$ inch. In this case, the screw gear *L* must have twice as many teeth as the stud gear *J*. For six threads, the ratio of revolutions between spindle and screw is $1\frac{1}{2}$ to 1. This requires $1\frac{1}{2}$ times as many teeth in the screw gear *L* as in the stud gear *J*.

Selecting the Gears. The rule for finding the gears to be used on the spindle and lead-screw is: Multiply the number of threads on the lead-screw and the number of threads to be cut, by the same number; the products will equal the numbers of teeth on the gears to be used.

Suppose the lead-screw has four threads per inch, and ten threads per inch are to be cut. Multiply both numbers by any convenient number, such as 6. Then the gears should have 24 teeth and 60 teeth.

Let a = Number of threads per inch on the lead-screw
b = Number of threads per inch to be cut
c = Any convenient number

Then $a \times c$ = Number of teeth of gear on stud
$b \times c$ = Number of teeth of gear on lead-screw

If the gears thus found are not at hand, multiply by some other number. Thus, suppose gears of 60 and 24 teeth were not available; multiply 4 and 10 by any other number that would give the number of teeth of the gears at hand.

Another way to find the gears is to remember that the number of threads to be cut is to the number on the lead-screw as the number of teeth on the screw gear is to the number of teeth on the stud gear.

EXAMPLES FOR PRACTICE

1. The lead-screw has a pitch of $\frac{1}{4}$ inch. What is the ratio of gears to be used to cut a screw with 9 threads to the inch? If one gear has 24 teeth, how many should the other have?

Ans. $\begin{cases} 1:2\frac{1}{4} \\ 54 \text{ teeth} \end{cases}$

4 : 9 :: 24 : x
2 1/4 x 24 = x 54 teeth

2. The lead-screw has a pitch of $\frac{1}{4}$ inch. What is the ratio of gears to be used to cut a screw with 16 threads to the inch?

Ans. 1:4

3. The lead-screw has a pitch of $\frac{1}{3}$ inch. What is the ratio of gears to be used to cut a screw with 12 threads to the inch?

Ans. 1:4

In these cases the actual number of teeth on the gears to be used is obtained by multiplying the ratio by some common multiple. Thus, in Example 1, multiplying by 10 gives 40 teeth for the stud gear, and 90 for the screw gear

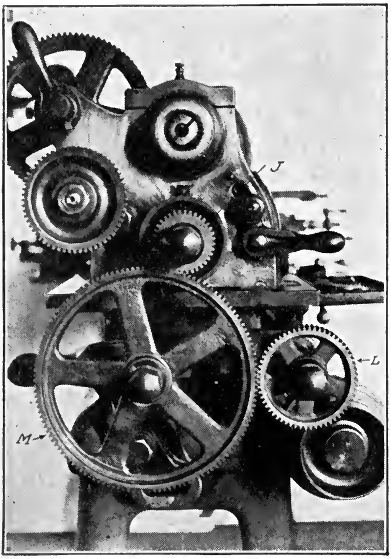


Fig. 164. Simple Lathe Gearing

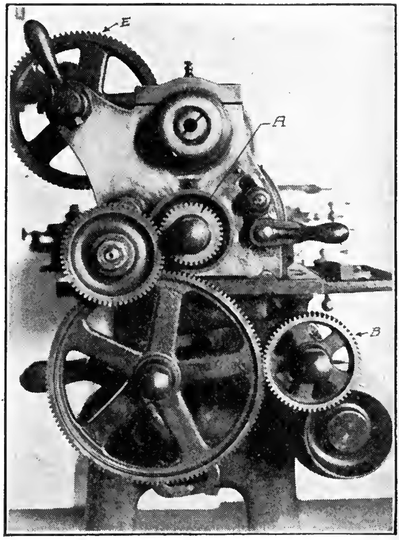


Fig. 165. Compound Lathe Gearing

In Example 2, multiplying by 20 gives 20 teeth for the stud, and 80 for the screw gear; and the same result is obtained by using the same multiple for Example 3.

Every screw-cutting lathe is provided with a set of change gears from which selections can be made. In order to facilitate the choice of the gears to be used, a gear table, often cast in raised letters is screwed to the front piece of the headstock. This table shows the gears to be used for cutting such threads as may be listed in the table.

Compounding Gears. It is sometimes necessary to cut a screw for which there are no gears which make a direct connection, in which case the simple gearing shown in Fig. 164 cannot be used. This necessitates the compounding of the gears on the intermediate spindle as shown in the set-up, Fig. 165. The stud is represented by A and the screw by B. Suppose, with a lead-screw having three threads to the inch, it is desired to cut a screw having thirteen threads to the inch. This makes the ratio of teeth on the spindle gear to those on the screw as 3 to 13. The work can be done with spindle gears having 15, 30, or 45 teeth, with screw gears having 65, 130, and 195 teeth, respectively. If it is found that there are no gears having 15, 45, 130, or 195 teeth on hand, compounding must be resorted to. To determine the gears to be used, it must be remembered that *the product of the numbers of teeth of the driving gears must be to the product of the numbers of teeth of the driven gears, as the number of threads per inch on the lead-screw is to the number to be cut.* In this case it is as 3 to 13. Multiply each of these figures by any convenient multiple. In the example in hand, let the multiple be 200. Then,

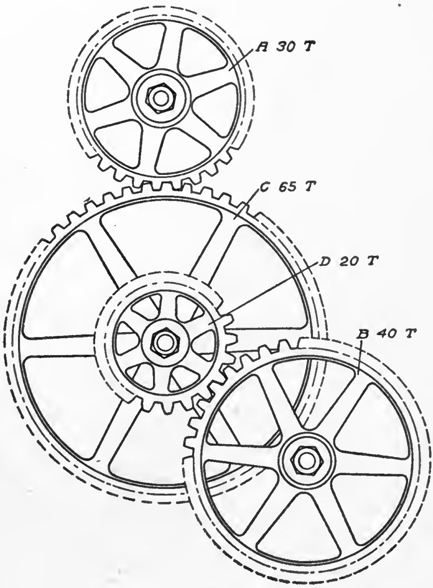


Fig. 166. Change-Gear Set-Up

$$\frac{3\times200}{13\times200}=\frac{3\times2\times2\times2\times5\times5}{13\times2\times2\times2\times5\times5}$$

Select from the factors thus obtained two sets, each of which, when multiplied together, will give products equal to the number of teeth that are on hand.

Thus, in the numerator, we may take 3×2×5, and 2×2×5, giving 30 and 20 as gears that are to be used as the spindle and intermediate drivers, respectively.

For the denominator, take 13×5, and 2×2×5×2, or 65 and 40, for the driven gears of the intermediate stud and the screw, respectively. Placing these in position as in Fig. 166, we have

Gear *A* with 30 teeth
Gear *C* with 65 teeth
Gear *D* with 20 teeth
Gear *B* with 40 teeth

EXAMPLE FOR PRACTICE

It is desired to cut a screw with 11 threads to the inch on a lathe having a lead-screw with a pitch of $\frac{1}{4}$ inch. The gears available have 30, 40, 45, 50, 55, 60, 65, 70, 80, 90, and 100 teeth, respectively. What ones are to be used, and where?

Ans.	Spindle	40 teeth
	Intermediate driven	55 teeth
	Intermediate driver	50 teeth
	Screw	100 teeth

The preceding examples may be taken as applying to either right- or left-hand threads. The change or direction in the travel of the carriage is obtained by shifting the handle at its right center, Fig. 165, thus reversing the rotation of the lead-screw.

The following description of the method of cutting a V-thread will suffice to illustrate the cutting of any form, with the slight changes which are necessary in the other forms because of the shape of the tool employed:

First set the cutting point so that a line at right angles to the lathe axis bisects the tool angle, and so that the tool is exactly at the height of the center.

The relation between the rotary motion of the work and the axial traverse of the tool, determines the pitch of the thread being cut; and the mechanism connecting the work and the tool must be of a positive character.

Owing to the lost motion of backlash in the mechanism connecting the tool and the work, the tool cannot be returned to the starting point for a new and deeper cut by simply reversing the lathe. The tool must first be withdrawn, the lathe reversed, the tool returned to the starting point, and then advanced for the new cut.

To place the tool for the new cut with accuracy, a stop or graduated device is provided.

When the work is removed from the lathe for testing, care should be taken in replacing, to get the tail of the dog in the same slot in the faceplate that was used to cut the original thread; this can be done by marking or otherwise indicating the slot.

Hand-Chasing. The ordinary methods of cutting screws have already been described. Where great accuracy is not necessary, the threads may be chased by hand. A chaser, or chasing tool, differs from the ordinary thread-cutting tool, in that it has a number of cutting points instead of but one. When a chaser is operated by a power feed, it is customary to have a shaft revolve at the same rate or at an even multiple of the rate of the lathe spindle. This shaft carries a master thread into which a section of a nut drops. The handle connected with the nut carries the chasing tool. When the nut is in contact, the tool is cutting. At the end of the cut, the tool is lifted out, and with it the nut disengages with the thread.

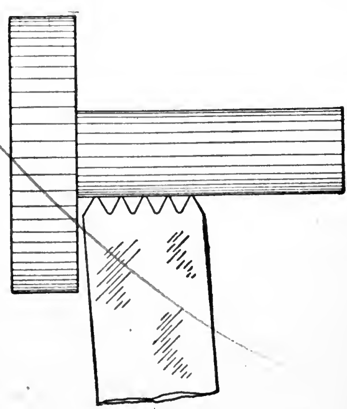


Fig. 167. Hand Chaser Cutting Outside Thread

Hand-chasing requires a great deal of skill in order that a good piece of work may be done. The chasing tool has a number of points, as shown in Fig. 167. The work must be run rapidly in the lathe. The tool is held in both hands, and is supported on a rest similar to that shown for the hand-turning tools in Fig. 90. The first left-hand tooth of the chaser is brought lightly against the right-hand edge of the work. The handle is given a quick twist from left to right, throwing the teeth in the opposite direction. It is well, after the first twist, to stop the lathe and examine the work. If the operation has been properly performed, the second tooth will be found to have entered the groove made by the first. A short length of thread will have been cut out, the pitch being the same as that of the chaser. If this is correct, the lathe may again be started and the chaser applied as before. On the second trial the thread may be run to its full length. The finishing of the thread is done by merely repeating the operation. A fine cut is taken with each application of the chaser for the whole length of the thread, until the full depth has been cut. In doing this work, the rear or right-hand side of the chaser should be pressed more firmly against the piece being cut than the front, because the threads with which that portion of the tool is engaged are more deeply cut than at the front. In addition to cutting, these teeth also guide those in front. The reason for running the lathe at a high rate of speed, is that the movement of the chaser is less likely to be checked or thrown aside by seams or inequalities in the density of the metal than it would be if the lathe were to run slowly. Inside threading may be done by means of the inside chaser shown in Fig. 168.

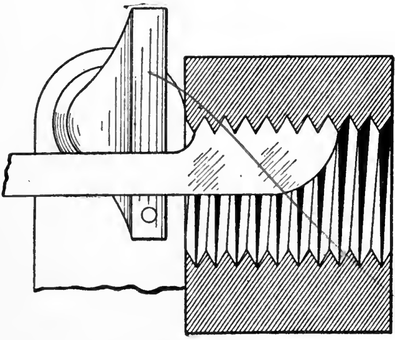


Fig. 168. Hand Chaser Cutting Inside Thread

Drilling in the Lathe. The lathe can also be used for drilling. When such work is to be done, the drill may be held in the spindle, and the work forced up against it by the screw of the tailstock; or the work may be revolved, and the drill forced in by the tailstock screw. When the first method is followed, the drill may be put into a socket prepared for it in the spindle of the lathe, or the drill may be held by a drill chuck, as shown in Fig. 169. This chuck may be used in the tailstock to hold twist drills, or to hold flat drills which are forged from round stock. Flat drills made from flat stock are centered at the rear end, and held against, and fed forward by, the dead center. In this case, a slotted rest held in the tool-post, as in

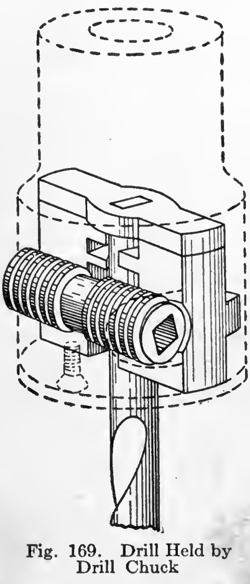


Fig. 169. Drill Held by Drill Chuck

Fig. 64, Part I, prevents the drill from turning, and aids in starting the drill true.

When the drill is held in the headstock, the work may be fastened to the carriage and fed against the drill, or it may be held by means of a suitable device used in the tailstock. For this purpose the drill

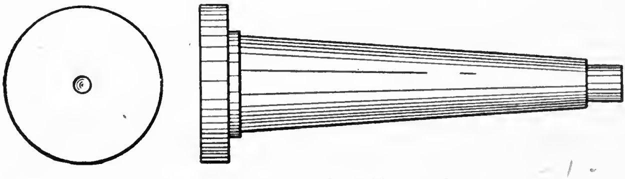


Fig. 170. Drill Pad for Flat Work

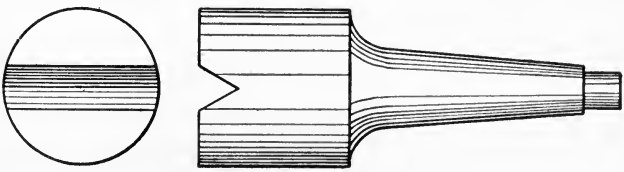


Fig. 171. Drill Pad with V-Center for Holding Round Stock

pad, shown in Fig. 170, may be used, especially if the work is flat. The V-center, shown in Fig. 171, is used when it is desired to drill through the axis of a piece of round stock. The shape of the groove prevents the work from turning; and the angle, being always in the axis of the lathe, determines accurately the location of the hole.

Fig. 172. Flat Drill of Simplest Type

DRILLERS

Drilling Operation. Where holes are to be cut through metal using a rotating tool with the cutting edges at its point, the operation is known as drilling and the cutting tools are termed drills. These tools may be of the simplest type, as for example, Fig. 172, or they may be of the more elaborate type shown in Fig. 173, known as a twist drill. While it is evident that any machine having a rotating spindle may be used to drill holes, it is more usual to do this in a machine designed especially for and equipped to do this work.

Drilling machines of the horizontal type are sometimes made, but the more common type is known as the vertical drilling

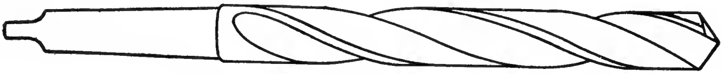


Fig. 173. Typical Tapered Shank Twist Drill

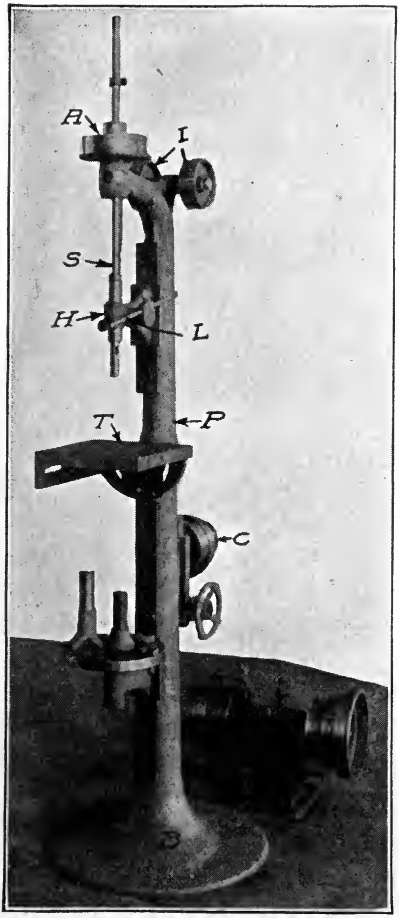


Fig. 174. Sensitive Driller
Courtesy of Washburn Shops, Worcester, Massachusetts

machine, often called a drill press. These have 1, 2, 3, or more spindles in a great variety of sizes, weights, and designs, many of which are made for purposes of special drilling only. The ones shown will be those of the kind commonly found in the ordinary machine shop

While it is common practice to designate both the drilling machine and the cutting tool as drills, for convenience of description in the accompanying text, the machine will be termed a driller and the cutting tool as a drill. It may also be said that this practice is meeting with general favor.

Sensitive Driller. In Fig. 174 is shown a drilling machine designed for use with the smaller sizes of drills on work under conditions which render it necessary to "feel" what the cutting lips are doing. It will be noticed that there are no trains of gearing present in the spindle driving mechanisms and that the tool is pressed or fed into the work by using the simplest and most direct device possible, a lever, a pinion and shaft, and a rack which engages the pinion. This is the simplest form of effective drilling machines and is known as a sensitive driller. In the cut, Fig. 174, *B* is the base, *P* the post, *T* the table, *S* the spindle, *H* the head bracket, *C* back-cone pulley, *I* the idler pulleys, *A* the spindle pulley, and *L* the hand or feed lever. It will be noted that the construction permits the upper or square table to be swung out of position, allowing the lower or round table bracket to be put into a position for using this extra table and the crotch and cup centers. The nose of the spindle is bored out at its axis to what is known as a No. 1 Morse taper. Drills fitted with this taper can be used direct, or straight shank drills may be used in a drill chuck having a standard No. 1 Morse taper stem or shank to fit the spindle.

Power Feed Driller. The heavier types of these machines are usually provided with back gearing similar to that employed in engine lathes. The power feed is obtained by suitable spindles and trains of gearing which drive the rack and sleeve by using a pinion, as in the hand feed machine.

The essential differences between this machine and the smaller type are: (a) its heavy rigid frame and moving parts; (b) its range of spindle speed changes made possible by the cones and back gears; (c) its spindle feed by power gearing instead of a hand lever; (d) its greater spindle driving power gained largely by use made of the back gears; and (e) its sub-base for holding the heavier work.

While the machine shown in Fig. 175 is belt driven, as relates to its stepped cone pulleys, the work spindle *S* is gear driven and gear fed. The trains of gearing, which rotate the spindle and which provide for feeding it downward, are, as in all modern geared machines, so covered as not to be plainly visible. The back gears are engaged at all times, but are brought into active driving service by operating a clutch *B* through use of the clutch lever *C*. The smaller spindle *A* passes downward through a cone of gears located in the gear box *G* to a train of gearing which is mounted upon the head bracket. The head bracket carries not only the work spindle sleeve and feed rack, but, besides these, has mounted on its frame the power and the hand feed mechanisms. The hand feed is operated by rotating the hand wheel *H*. The power feed is controlled

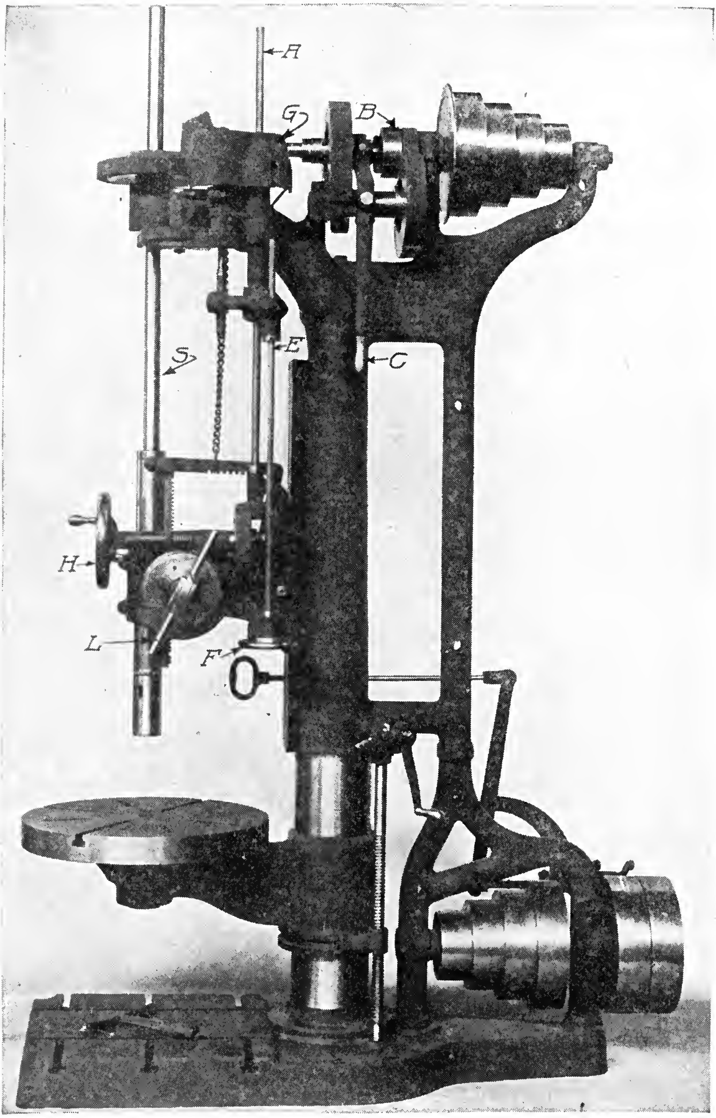


Fig. 175. Standard Power Feed Driller
Courtesy of Reed-Prentice Company, Worcester, Massachusetts

by the clutch lever L. The changes of feed from fine to coarse are made by means of a slip key actuating the cone feed gears through the shaft E and the smaller hand wheel F.

Multiple Spindles. Drilling machinery, both horizontal and vertical, is sometimes provided with more than one spindle. In the smaller drillers of the vertical type, the spindles are fixed in their relative positions, and are not intended to be operated simultaneously, the work passing from one spindle to another. The true

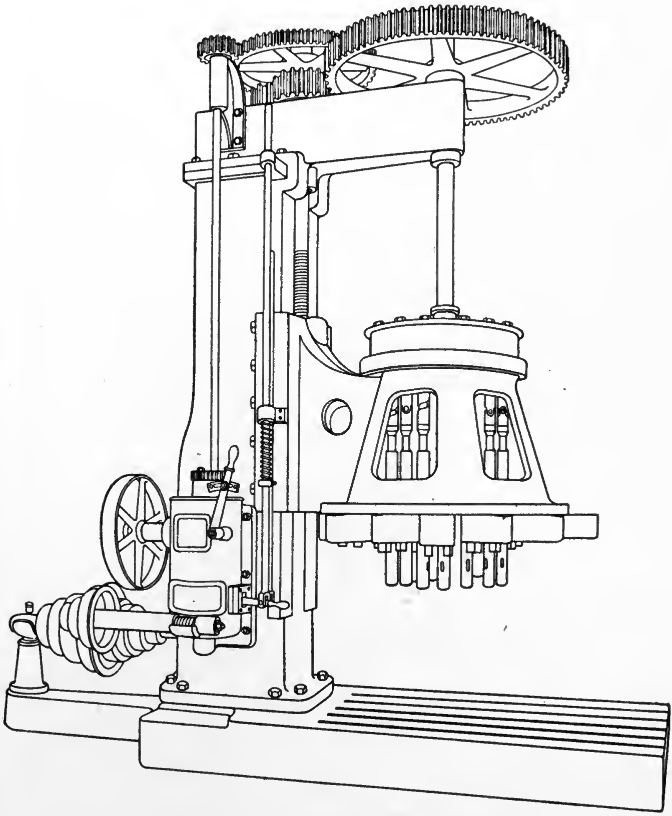


Fig. 176. Typical Multi-Spindle Driller

multi-spindle driller, Fig. 176, is for the purpose of drilling several holes at one time and in any relative position within the limits of adjustment of the machine.

Radial Driller. Another form of driller, known as the radial, is being extensively used. It is shown in Fig. 177. The drill spindle is carried on the horizontal arm, and is arranged to be set and run at any position on this arm. At the same time, the arm may be swung around and clamped in any vertical or horizontal position about the upright. These drillers are usually employed on heavy work where several holes, differently positioned, are to be drilled.

In the case of the driller shown in Fig. 175, the work is usually light, and can be readily shifted so that the position of the holes can be brought beneath the drill. In heavy work such as machine

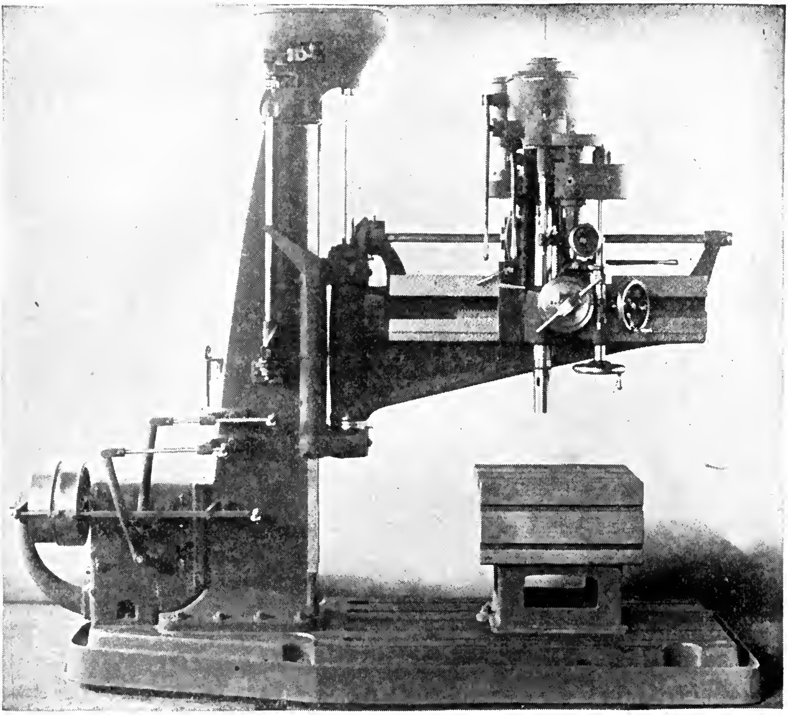


Fig. 177. Radial Driller with Four-Foot Arm for Heavy Duty
Courtesy of Reed-Prentice Company, Worcester, Massachusetts

frames, however, this cannot be done. It is therefore necessary to be able to shift the drill and place it in a position to do the work. The radial driller affords the means of doing this.

Universal Radial. Where the vertical spindle carrying the drill can be rotated in the vertical plane, holes cannot only be drilled in any position, but also at any angle. Such a driller is called a universal radial.

Laying Out. The position of the holes is usually laid out for the guidance of the man at the driller. The work is best done as shown in Fig. 178. The center punch mark, indicated by *A*, shows the location of the center hole. The circle upon which the prickpunch marks *BBBB* are placed, gives the location of the circumference of the hole. To drill the hole, place the point of the drill in the center punch mark *A*, and drill into the metal until the center punch mark has been slightly enlarged, as shown by the circle *C*. Then raise the drill and examine the work. If the countersink, or hole whose circumference is indicated by the

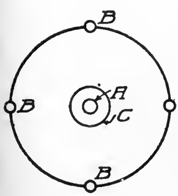


Fig. 178. Layout for Drilling Hole

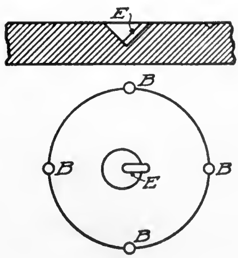


Fig. 179. Chiseling Countersink when not Concentric

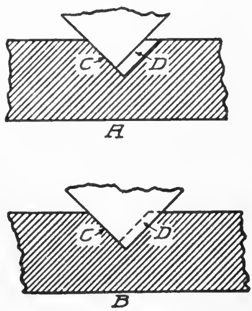


Fig. 180. Action of Groove in Making Drill Hole Concentric

circle *C*, is exactly concentric with the outer circle *BBBB*, then the drill may be put down and the hole drilled.

Owing, however, to various causes, it is not often that the circle will be concentric. This may be caused by one of three conditions, an uneven grinding of the drill; a distortion of the metal by the center punch; or an eccentric motion of the drill point, due to a lack of trueness in the running of the spindle.

When the countersink is not concentric, the drill must be drawn back to the central position. The method employed is shown in Fig. 179. A round-nosed chisel is used to cut a groove *E* down the side of the countersink, on the side that is farthest from the circle *BBBB*. The depth of this groove depends upon the amount of eccentricity of the countersink and the depth to which it has been drilled. The drill is then run down again and the groove drilled out. The action of this groove is as follows: as the drill turns, one cutting edge is supported, and is working into the face *C*, Fig. 180. At the same time, the cutting edge is opposite the groove *E*. The drill, therefore, springs into the groove, as shown. The lip then catches on the edge of the groove and cuts it away, making the hole elliptical, and shifting the center of the drill toward its proper position. As the drill sinks deeper, both lips are in contact with the faces *C* and *D*, and it has no further tendency to shift.

When the groove has been drilled out, the drill must be again raised, to ascertain whether or not the countersink is concentric with the outer circle *BBBB*. If not, another groove must be cut, and the process repeated until the drill is correctly positioned, when the hole may be drilled. The prickpunch marks *BBBB* are put on the outer circle in order to indicate its position in case of the obliteration of the line itself.

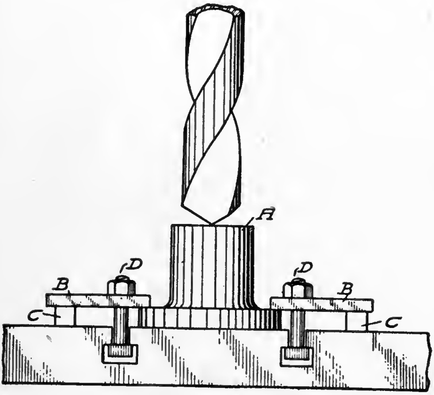


Fig. 181. Work Clamped to Table by Straps for Accurate Hole-Drilling

A twist drill will usually clear its hole of chips. For deep holes, this may not always occur. It is then necessary to withdraw the drill and clean out the hole. This can be done by a piece of wire bent at the end; also by using a blowpipe made of a small tube, and bent to enter the hole, so that the chips will not blow up into the operator's face. Holes in cast iron are more likely to need cleaning than holes in wrought iron or steel. Where flat drills are used, it is always necessary to clean the holes at frequent intervals, as such drills have no tendency to raise the chips and clear the holes.

Holding the Work. A matter to receive due consideration is that the work must be held rigidly on the work table while being drilled. This may be done in two ways. If the holes are to be drilled with great accuracy, the work must be clamped to the table. This is often done by means of straps, as shown in Fig. 181. In this figure, a gland *A* is shown clamped to the table by the straps *BB*. One end of the strap rests upon the flange of the gland and the other upon any convenient piece of metal C, of the proper thickness. The bolt D is put up through a hole in the table as close to the work as possible. When the nuts are screwed down, they then put the greatest available pressure on the work, and hold it fast. The strap B is made of flat iron. It has one or more holes drilled in it to permit the passage of bolts.

Another method of holding work in the drill press is by means of a post. This is shown in Fig. 182. It consists of a post A, set loosely in one of the holes in the table. As the drill is forced against the work, it tends to turn the latter with it. When the work strikes the post, it is stopped and held while the hole is drilled. This will not hold the work perfectly steady. It allows the latter to move with the eccentricity of the motion of the drill, but it is in very common use where extreme accuracy is not essential. For example, where a finished bolt is to be used with a driving fit, the work must be securely fastened so that the diameter of the hole may be true. Where a machine bolt made of rough iron is to be used, the hole is drilled $\frac{1}{16}$ inch larger than the nominal size of the bolt. Here accuracy is not even attempted; a variation of $\frac{1}{32}$ inch in the diameter of the hole is of no account. Therefore, in such cases, the work may be allowed merely to rest against the post.

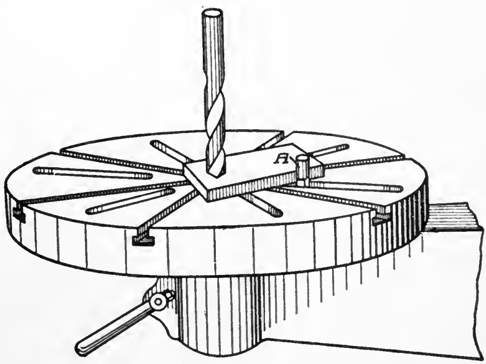


Fig. 182. Use of Table Stud for Drilling

This question of holding the work does not apply to drills of the multi-spindle class, Fig. 176. Evidently the tendency of one drill to rotate the work is counteracted by the action of another drill.

An angle iron forming a right angle with the work table, is used in many cases to support the work where the hole cannot be properly located by the use of the table alone. The clamping of the work to the angle iron must be very rigid to resist the pressure of the drill. A tilting table is sometimes used, so that the holes may be drilled at any required angle. At least one manufacturer is putting on the market a horizontal drilling machine which can drill five sides of a cube at any angle, with but one setting of the work.

Tapping. Drilling machines may also be used for tapping. This requires a reversing device for backing out the tap. The backing-out is done at a much higher speed than the tapping. The tap is held in a friction head that will slip when the tap strikes the bottom of the hole. The use of collapsing taps, especially on diameters of one inch and over, renders the backing-out unnecessary, and quickens the operation. Studs may be set by the same device, so that cylinder flanges may be drilled, tapped, and the studs set, without removing the work from the machine. Duplicate drilling by means of jigs will be considered later.

PLANERS

As the name indicates, the planer is used for finishing flat surfaces. In the ordinary planer, the work is moved, and the tool is at rest. A common form of this tool is shown in Fig. 183. It consists of a bed *A*, upon the upper surface of which suitable guides or ways are planed. The platen *B* is made to travel back and forth upon these ways. The platen has a rack on its under surface, into which the gear *C* meshes. This gear is driven by a train of gears from the shaft carrying the pulley *D*. The tool is carried on the tool-head *E*, where it can be given a slight vertical motion or feed. This tool-head may be fed across the machine by the screw in the cross-rail *F*. The latter may be raised and lowered by the shaft and gearing shown at the top. This gearing turns two vertical screws running in nuts attached to the cross-rail.

The reciprocating motion of the planer table is obtained as follows: The pulleys *D* and *G* run loose on the shaft, and are driven in opposite directions by belts from an overhead countershaft. The center pulley is fixed to the shaft, and either belt may be moved over on this pulley by the belt-shifters *J*, which are moved in opposite directions by a connection with the shifting lever *I*, connected with them by suitable mechanism inside the bed, and acted upon by the reversing dogs *H H*, which are adapted to be adjusted at any point in the length of the table, according to the position of the work and the length of the stroke desired.

The planer shown in Fig. 183 has but one head for holding a tool. In large planers it is customary to have two heads on the cross-rail, so that two tools may be cutting simultaneously, thus doubling the capacity of the machine. The vertical feed of the tool is also operated automatically; and in a planer having two heads, both vertical and lateral feeds are independent of each other.

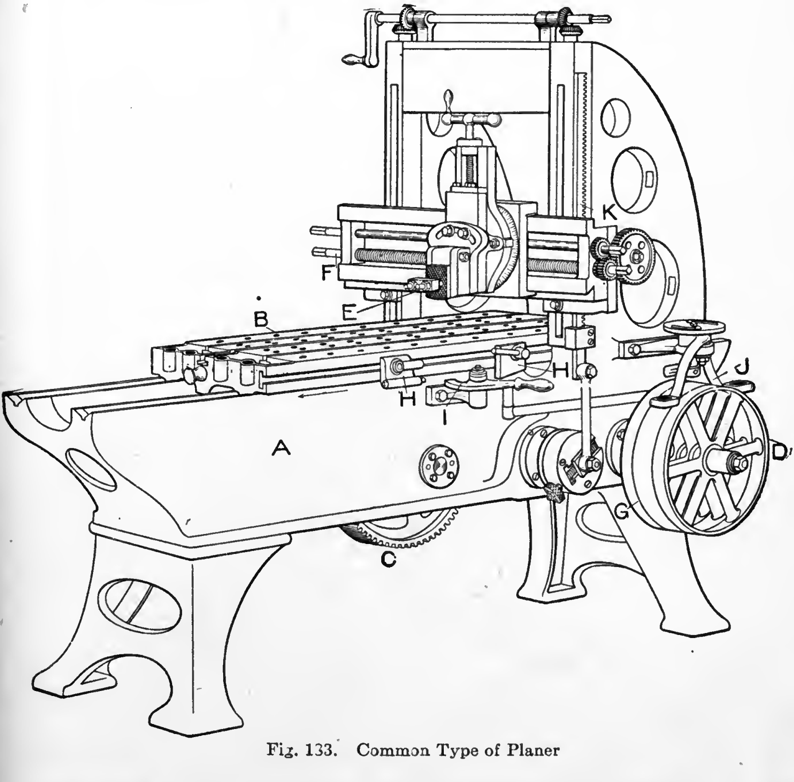


Fig. 133. Common Type of Planer

Fig. 184 shows a large planer equipped with two heads on the cross-rail, and a still further equipment of two heads with automatic vertical feeds on the side posts. Thus arranged, the machine is capable of handling very large work, and of keeping four tools cutting simultaneously. The table-operating mechanism within the bed is substantially the same in nearly all except some special planers. In this planer, there is a driving belt on each side of the machine, one running the table forward, and the other backward, the rod carrying the belt-shifters passing entirely through the machine.

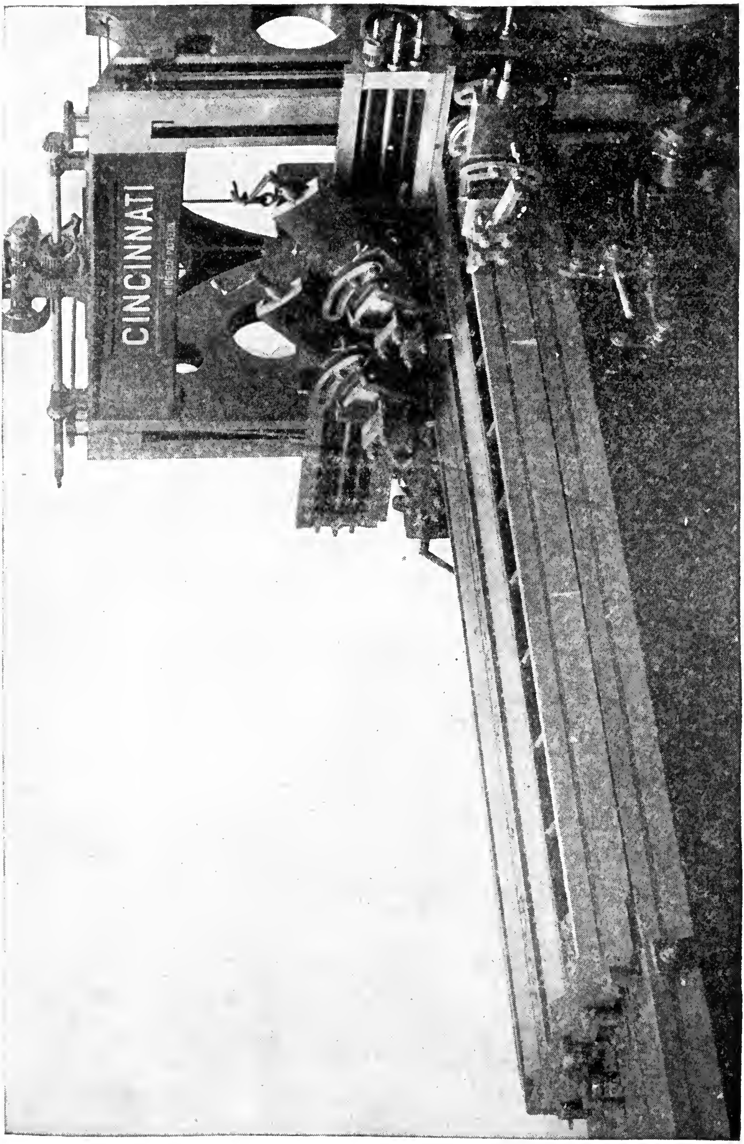


Fig. 184. Large Planer with Two Heads on Cross-Rail and Two Heads on Side Posts
Courtesy of Cincinnati Planer Company, Cincinnati, Ohio

The speed of travel forward of the table is the ordinary cutting speed; while, to save time, the return or backward movement is as fast as the driving mechanism will permit. The ratio of forward to backward speeds will be from 2 to 1 (in very large planers), to 4 to 1 (in small planers).

Ordinarily the tool cuts only when the platen is moving toward the right, Fig. 183. As a result of this condition, the platen is made to move more rapidly toward the left than toward the right. This is accomplished by varying the speeds of the pulleys *D* and *G*. The usual ratio of the speeds of these pulleys is 2 to 1 or 3 to 1.

The feed of the tool is accomplished by a friction clutch driving the vertical rack *K*. This acts only at a point near the end of the travel of the platen. It is so arranged that any reasonable vertical or horizontal feed may be given to the tool.

The machine is driven by three driving pulleys placed side by side on the same shaft, the central one of the three being keyed to the shaft. The reversal of the motion of the platen is obtained by shifting one or the other of the belts onto the central pulley.

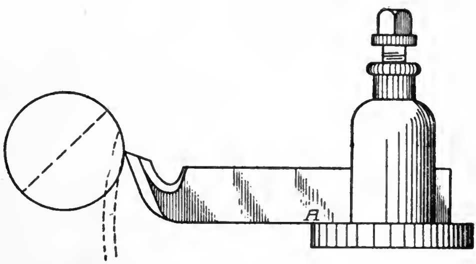


Fig. 185. Lathe Tool Improperly Set Up

Planer Tools. The tools used with planers do not differ essentially from those described for lathe work. The same rules apply regarding the holding of the tool. It should project as short a distance as possible beyond the point of support. When there is an excessive projection, care should be taken that the tool is so set that it will not spring into the work. On the lathe this can be prevented by setting the point of the tool on a line with the center. In Fig. 185 the tool tends to spring and turn about the point *A* as a center. The dotted line at the point shows how this tends to throw it into the work. The same thing is shown in the planer tool in Fig. 186. This tendency can be overcome by forging the tool so that the cutting point is behind a perpendicular from the point of support, as shown by the dotted lines in Fig. 186. In the latter case, the spring of the tool tends to take it out of the work.

Holding the Work. The work is usually held on the planer by clamping it down with straps in a manner similar to that shown in Fig. 181. Where the whole upper surface is to be planed over, holes are sometimes drilled in the sides, into which the rounded ends of straps are set.

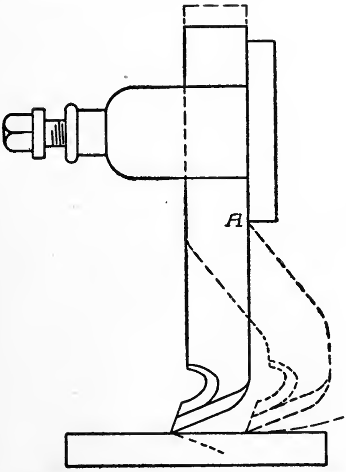


Fig. 186. Incorrect and Correct Setting for Planer Tool

Fig. 187 shows the manner of clamping down a machine bed *A*, by the use of straps *BB* having the ends bent downward so as to avoid the use of the loose blocks *C* as shown in Fig. 181. In addition to the straps, there must be plugs *C* placed in the circular holes in the planer table, which take the thrust due to the action of the cutting tool, and prevent the bed *A* from moving on the table. In planing the pedestal *D*, it will be necessary to provide still further support, which is done by the brace *E*, placed against the plug *F*, and adjusted to the proper length by the screw and check-nut at *e*.

It is impossible to give more than general directions for clamping work on a planer. A great variety of blocking, clamps, and bolts

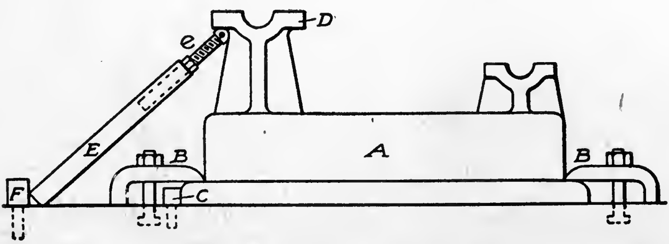


Fig. 187. Method of Clamping Down Planing Machine Bed and Supporting Work

may be used, such attachments being suited to the work in hand. It should be sufficient to say that the work must be carefully set, strongly clamped and braced to prevent movement by the tool; and the clamping should not distort the work. As all castings and forgings change their shape when the surface is removed, it is considered good practice to release the clamps before the finishing

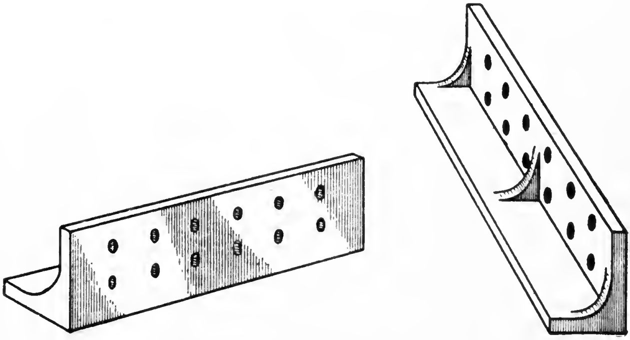


Fig. 188. Angle Irons or Knees

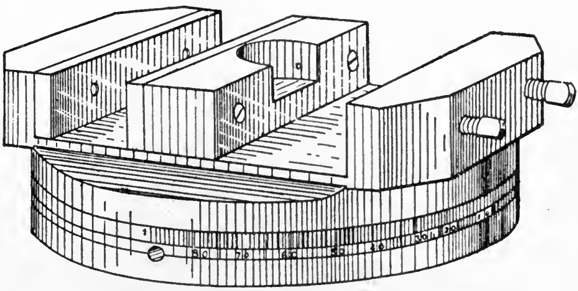


Fig. 189. Planer Chuck for Holding Work

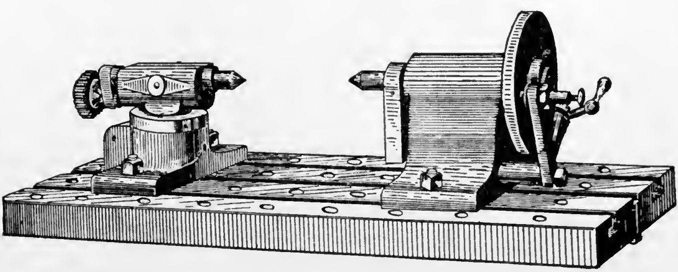


Fig. 190. Planer Centers

cut, in order that the piece may assume its final shape, and then reclamp it without distortion.

Angle irons or knees, as shown in Fig. 188, may be considered as an auxiliary table with a surface at right angles to the main table. Many useful applications of these holding devices will suggest themselves.

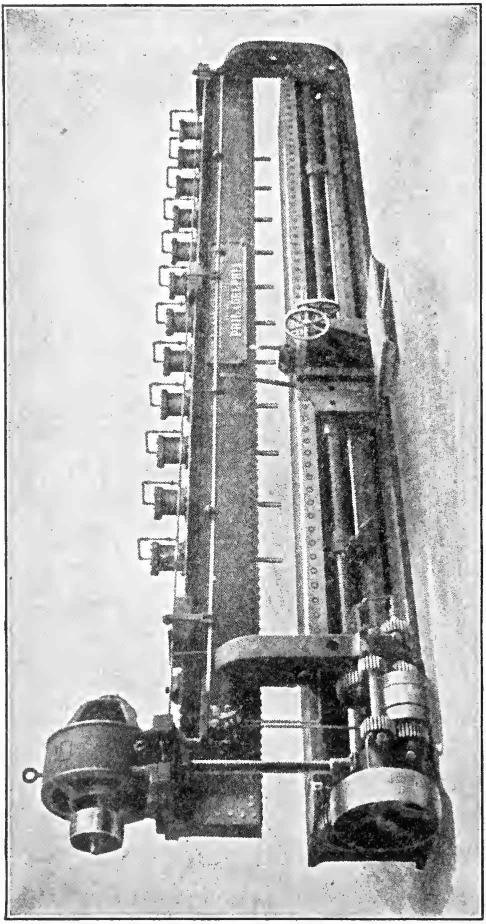


Fig. 191. Plate Planer with Pneumatic Jacks
Courtesy of William Sellers & Company, Philadelphia, Pennsylvania

Another method of holding work is by using a *planer chuck,* such as is shown in Fig. 189. In use the chuck is bolted to the platen, and the work is held between the chuck jaws.

Planer centers, as illustrated in Fig. 190, are very useful in machining parts where accurate circular spacing is desired, or where projecting lugs prevent the work surface turning in a lathe.

Plate Planer. A special form of planer extensively used in boiler shops and shipyards is the plate planer, Fig. 191. It is used for planing the edges of long plates. The plate is securely fastened between the 12 pneumatic jacks and the bed. The tool is held in the carriage seen in the center, which is moved to and fro by the screw, which in turn is driven by the electric motor through the gearing at the left. For starting, stopping, and reversing the direction of the carriage, a shifting rod is arranged along the front of the machine, as shown in the illustration; handles may be moved to positions of convenience for the operator while working on plates of various lengths. The tool holder is so arranged that by the use of one tool, a beveled or a straight cut may be taken in either direction. On the saddle is carried a platform from which the operator may have a constant view of the tool.

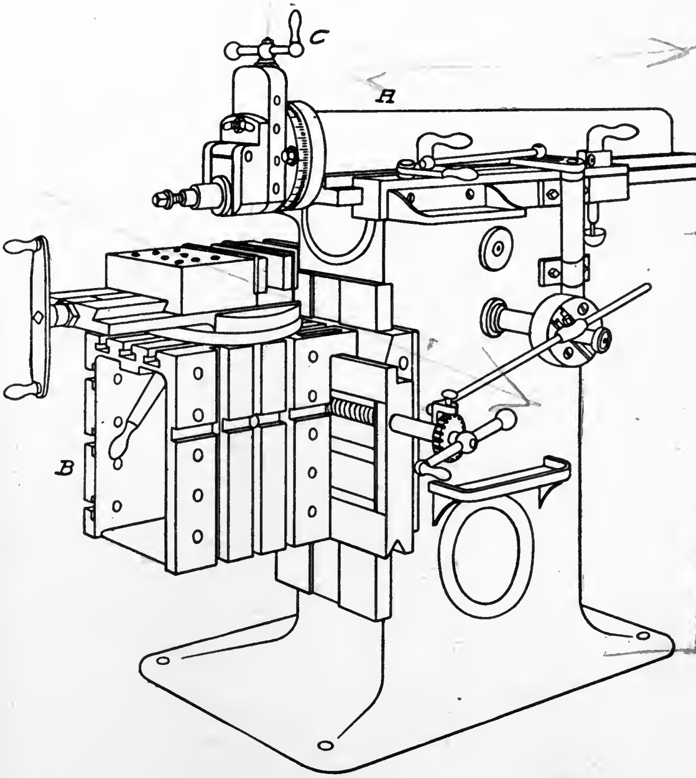


Fig. 192. Typical Pillar Shaper

SHAPERS

For the lighter jobs of planing, the shaper, or shaping planer, Fig. 192, is extensively used. It possesses the advantage of rapidity of action. In this machine, as in the plate planer, the tool reciprocates while the work is at rest. A suitable mechanism causes the ram *A* to move to and fro. When moving toward the left, the tool is

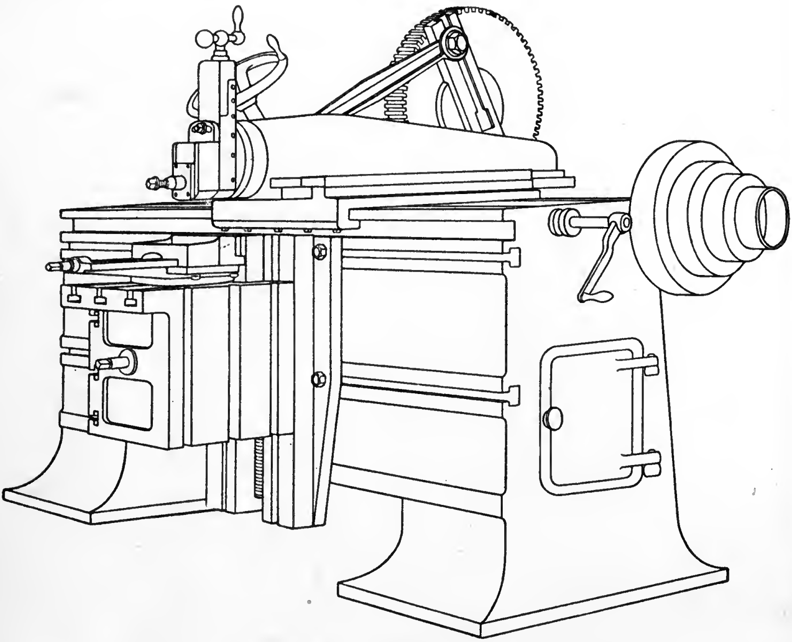


Fig. 193. Traverse Shaper

cutting. As in the ordinary planer, the speed of the cutting stroke is less than the return.

The piece is held on the work table *B*, which may be adjusted to any convenient height suited to the work being done. The tool is also allowed a limited vertical adjustment in the slide by turning the handle *C*. This is the ordinary method of obtaining the vertical feed.

The horizontal feed is obtained by moving the table *B* sidewise. In some shapers it can be moved vertically to feed to or from the tool; in other machines the horizontal feed is obtained by causing the tool with the reciprocating parts to move sidewise.

The style of machine shown in Fig. 192, is called the pillar shaper; but where the tool and ram move sidewise, it is called the traverse shaper, Fig. 193. The character of the work done

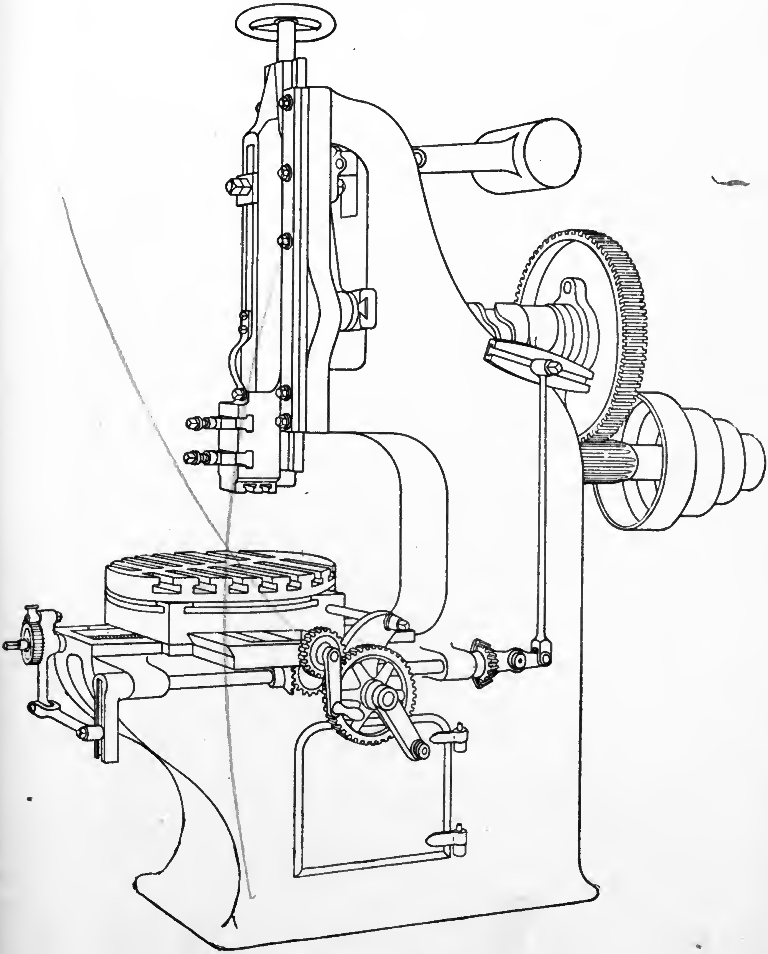


Fig. 194. Vertical Slotter

on the shaper is the same as that done on the planer; but as a rule the shaper is used for the smaller and more delicate parts which could not be handled quickly on the planer. The shaper has the additional advantage of a change of speed, which allows small

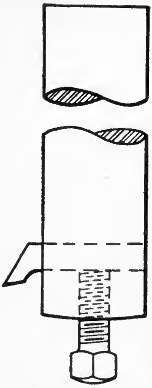


Fig. 195. Bar for Slotting Locomotive Trains

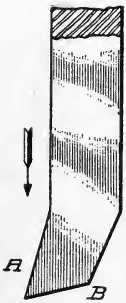


Fig. 196. Slotting Tool for Cutting Keyways

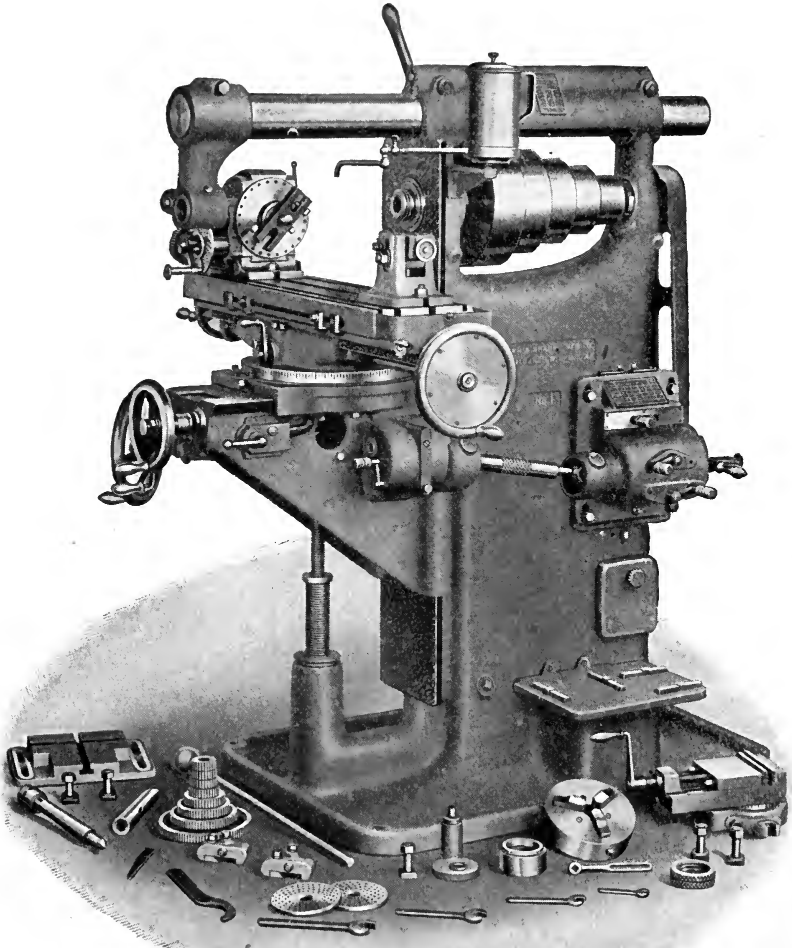
Fig. 197. Slotting Tool with Large Rake

pieces, especially of the softer metals, to be machined at a maximum rate.

Slotter. Another machine tool which is not used as commonly as its many good qualities would seem to warrant, is the slotter, Fig. 194. It is in reality a shaper with the tool reciprocating vertically instead of horizontally. It is used for working on heavy pieces, and especially in places where an irregular contour is to be formed. The thrust on the tool is vertical, and it and the machine must be very stiff. The work done frequently partakes of the nature of forming the inside of a hole where the tool must project the whole length of the cut below the bottom of the head. Such a case is that of the slotting of locomotive frames. The best type of tool for such a class of work is a strong bar, as shown in Fig. 195. The bar is held in the tool head just as any tool would be. Near the lower end, it carries the cutting tool, which may be fastened by a set screw or wedge. Such a tool should always be used when it is possible. It has the advantage of being stiffer and less likely to spring than a common forged tool.

The tool used in a slotting machine differs from that used in the lathe or planer, in that the direction of the cutting motion is different. Fig. 196 illustrates a slotting tool used for doing such work as the cutting of keyways in the hubs of pulleys. It will be seen that if the tool is moved in the direction of the arrow, the face *B* becomes the one against which the chip bears. It therefore corresponds to the top of the lathe tool. The sharper the slope given to the face *B*, the keener the edge, just as increasing the top rake of the lathe tool increases its sharpness. The face *A* must also be cut away as indicated. This corresponds to the clearance of the lathe or planer tool. It is quite possible, at times, to give these tools a larger amount of rake. Such a form is shown in Fig. 197. The shape of these tools is such that they are very strong in the direction of the thrust, besides having a keen cutting edge.

The slotter has automatic feeds of three kinds—namely, lateral, transverse, and circular—hence a considerable variety of work can be done upon it. The stroke of the vertical ram which carries the tool can be made any length of cut from zero to full stroke, and its location with relation to the work table can be adjusted according to the height of the work to be done. Like the shaper, it has a quick return after the cutting stroke, and it is provided with four changes of speed. This renders it available for quite a large range of work.



HEAVY UNIVERSAL MILLING MACHINE

Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

MACHINE SHOP WORK

PART III

POWER=DRIVEN TOOLS—(Continued)

MILLING MACHINES

Milling Machine vs. Shaper and Planer. The operation known as milling differs so radically from the removal of metal by methods previously described, that it merits much more careful and lengthy discussion than has been devoted to the other methods. Owing, also, to its increasing importance and general use, it calls for a somewhat detailed discussion. While milling is coming rapidly into favor as a means of doing work formerly done on the shaper and planer, it does not follow that the shaper and planer are to be entirely abandoned. There has been a tendency to belittle the planer and shaper in favor of the milling machine. This tendency is not altogether warranted even by the rapid and economical method of milling. There is a large class of work which can be done as accurately —and in many cases as cheaply—by means of a single-pointed tool such as is used in the planer and shaper.

Simple Milling Operations. The fundamental difference between planing and milling lies in the character of the tool employed. The planer uses a fixed single-pointed tool, with a reciprocating motion either of the tool or of the work. Milling is performed by the use of a rotating tool with several cutting points. This rotary multiple cutter is the basis of all milling operations; and, as the saw may be taken as a good example of such a cutter, so the work done by the circular saw in cutting metal may be said to be an example of milling, Fig. 198. The ordinary milling cutter is nothing more than a saw which has exceptionally broad teeth and in which the contour of the cutting blades is made to suit the work in hand.

It was but a step to make a saw wide enough to cover a considerable surface, or to have a thick saw with a suitably formed cutting edge. Several saws of different shapes and sizes can be mounted in a gang on an arbor, and perform operations which it would be hard to duplicate on the shaper or planer. Even in the present age of special machines for milling, a great deal of work of this character is still performed by the method indicated.

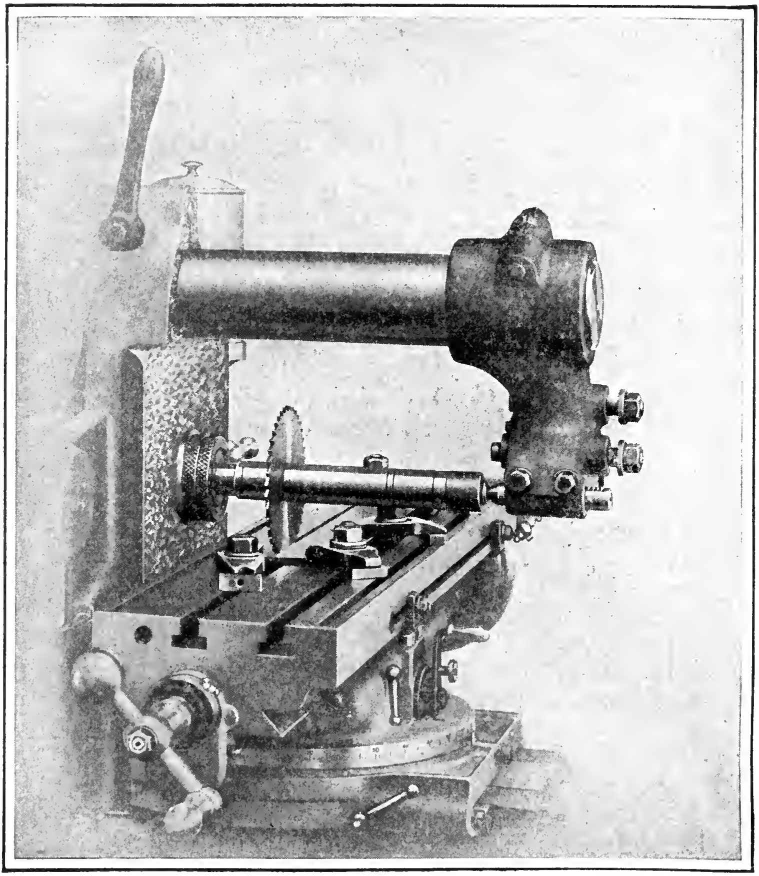


Fig. 198. Sawing Flat Stock
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

One of the great advantages of milling is the certainty of exact duplication—a feature of prime importance in the manufacture of interchangeable work.

About the first machine built exclusively for milling was the so-called Lincoln miller, Fig. 199, which consists essentially of a bed carrying the equivalent of the headstock and tailstock of a lathe, with means for rotating the cutter arbor, which is carried directly by the headstock spindle, and steadied and supported by the tailstock. There is also provided a table upon which the work can be fastened either directly or by means of a vise; and an automatic feed

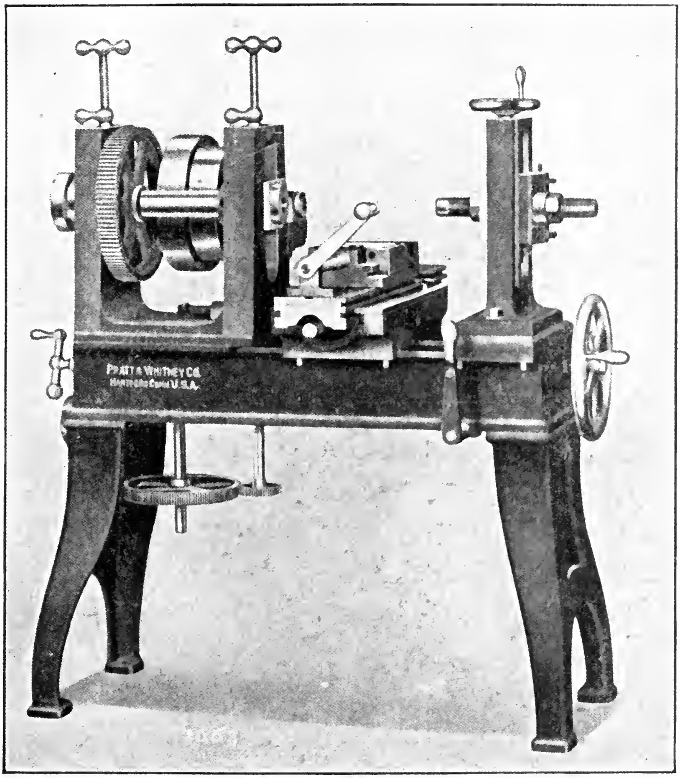


Fig. 199. Lincoln Milling Machine
Courtesy of Pratt and Whitney Company, Hartford, Connecticut

across the machine at right angles to, and below, the cutter arbor. This type of machine in various designs is much used in modern manufacturing.

MILLING CUTTERS

Classification. As the type of cutter used determines, in a large measure, the design of the machine itself, it will be better at this point to take up a description of some of the different cutters, in order that the adaptation of the machine to the cutter may be clearly seen.

Cutters are classified according to their form or the use to which they are put, some of the more common types of these devices being as follows:

1. Slitting
2. Grooving
3. Fluting
4. Straight
5. Angle
6. Double-angle
7. Straight mill
8. Spiral mill
9. Nicked-tooth spiral mill
10. Side mill
11. Straddle mill
12. Straight end mill
13. Spiral end mill
14. T-slot mill
15. Formed mill
16. Inserted blade
17. Inserted-tooth facing
18. Inserted-tooth surfacing
19. Shell mill
20. Fly or single-tooth cutter

This classification does not include any of the cutters used in cutting gears, racks, spirals, helical gears, ratchets, sprocket-wheels,

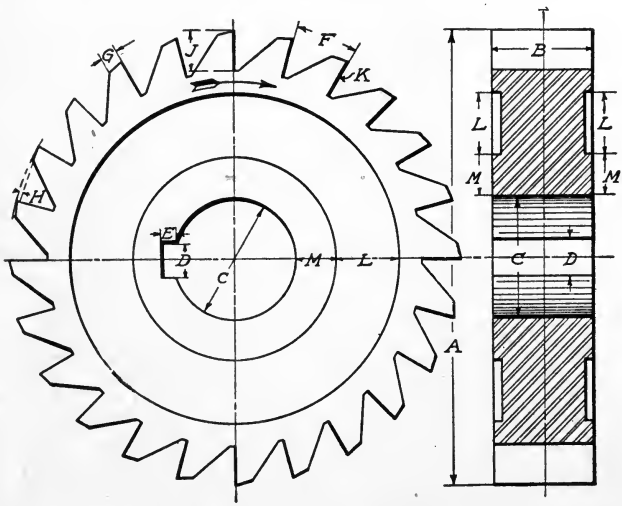


Fig. 200. Details of Ordinary Milling Cutter

and similar work, which is usually considered as gear-cutting work. However, ratchet teeth may be cut with an angle cutter; brass gears, with a single-tooth or fly cutter, properly formed; and some others may be applied to a variety of uses, the cutter, in fact, not infrequently displaying a remarkable adaptability to the varying conditions of work and material.

Fundamental Characteristics. The several details of an ordinary milling cutter are shown in Fig. 200. *A* is the outside diameter; *B*, the thickness (or in mills such as shown in Fig. 201, the length); *C*, the diameter of the hole; *D*, the width of keyway; *E*, the depth of keyway; *F*, the pitch of the teeth; *G*, the top of the teeth or land; *H*, the backing-off or clearance, either on the lands or on the side of the cutter; *J*, the depth of the teeth; *K*, the face of the teeth; *L*, the relieving recess made for the purpose of reducing the surface to be ground; and *M*, the hub. The direction of revolution is indicated by the arrow.

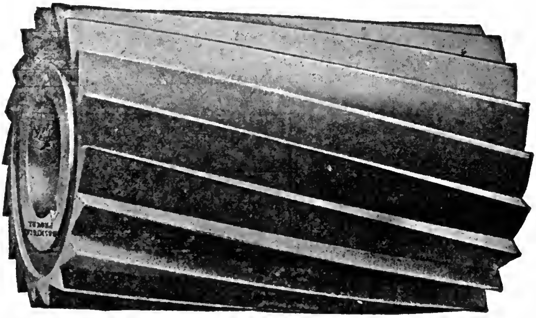


Fig. 201. Milling Cutter with Spiral Teeth
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Cutter Arbor. Fig. 202 shows the usual form of cutter arbor, in which *A* is the taper shank fitting the taper-reamed hole in the milling-machine spindle; *B* is the flattened portion or tang fitting in the cross-slot and preventing the arbor from turning; *C* is a nut used in withdrawing the arbor from the hole when it has been forced tightly into it; *D* is a collar formed upon the arbor, against which loose collars or the cutter itself are forced when placed upon the arbor at *E* and confined by the clamping nut *F*. The end *G* is finished as a journal or bearing for an outer support attached to or forming a part of the overhanging arm of the milling machine. In the outer end is drilled and reamed a center hole for a similar purpose.

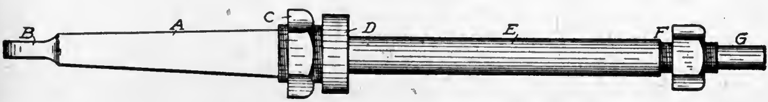


Fig. 202. Ordinary Form of Cutter Arbor

Fastening Cutter in Arbor. Cutters are prevented from turning upon the arbor in any one of four ways—namely, first, by a key in the keyway *DE*, Fig. 200; second, by being clamped between loose collars on the arbor; third, by being threaded and screwed on the arbor; and fourth, when the cutter is quite small and the work light, by a large-headed screw, slotted for the screwdriver, and tapped into the end of the arbor. In the latter case, the thread must be

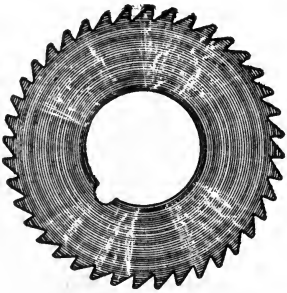


Fig. 203. Screw-Slot Cutter

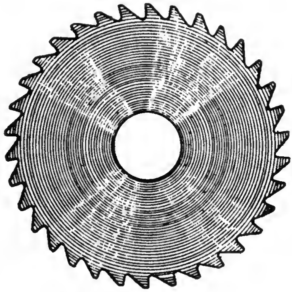


Fig. 204. Slitting Saw

right- or left-handed, according to the direction of revolution, so that the torsional strain of the work will tend to keep the cutter screwed tightly against the shoulder.

Usually cutters are made right-handed; that is, if held so that the side which goes against the collar on the arbor is toward the eye, the cutter should turn in the same direction as the hands of a clock.

Locating Position of Cutter. To locate the cutter in the proper position on the arbor to suit the work to be done, loose collars of various thicknesses are used on the arbor, placing as many on each

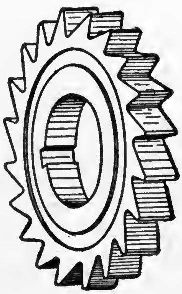


Fig. 205. Plain Milling Cutter

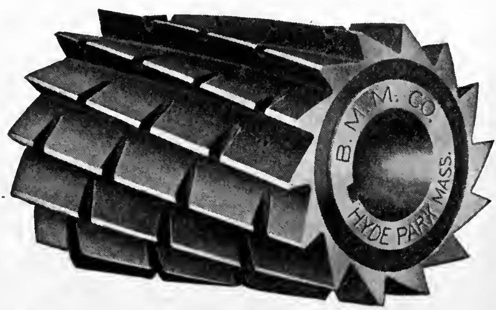


Fig. 206. Spiral Cutter with Nicked Teeth for Heavy Cuts
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

side of the cutter as are necessary to fill the space between the fixed collar *D*, Fig. 202, and the clamping nut *F*. The cutter and loose collars must have smooth, true, and parallel faces; otherwise the arbor will be sprung when the clamping nut is screwed up, and will not run true.

Plain Milling Cutters. Screw-slotting cutters, Fig. 203, and slitting saws, Fig. 204, are saws of a special type. The true milling cutter, Fig. 205, has a face much wider in proportion to its diameter than the common slitting saw. It is for the production of surfaces, rather than for a thin saw kerf in separating pieces of metal. These plain cutters are made in a large number of diameters and lengths, and are all designed for the generation of plane surfaces.

Spiral Cutters with Solid or Nicked Teeth. As we have seen in the case of reamers, heavy cuts can be taken more easily when the

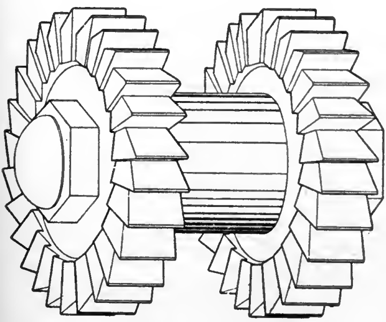


Fig. 207. Side Milling Cutters Mounted as a Heading or Straddle Mill

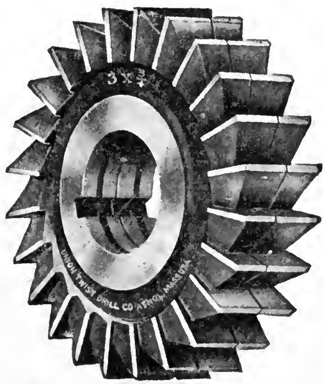


Fig. 208. Interlocking Cutter with Four Teeth Cut Away
Courtesy of Union Twist Drill Company, Athol, Massachusetts

chip is broken up in small pieces; therefore, in milling cutters designed for roughing, it is customary to nick the teeth, Fig. 206, in such a way that the stock left by one tooth may be taken out by the following tooth. This makes the cutting easier. A plain cutter of any considerable length, with teeth formed by straight grooves, will not often make a smooth surface because of the varying pressure of the cutter as one tooth after another leaves the work. To avoid this springing tendency, cutters are made with spiral teeth, Fig. 201, either right- or left-hand, so that there is practically a uniform distribution of pressure at all points during the cut.

Side Milling Cutters. When it is desired to mill the side of a piece, it is necessary that there should be teeth on the side of the cutter. Such cutters are usually made comparatively narrow and with teeth on both sides, as shown in Fig. 207. These side milling

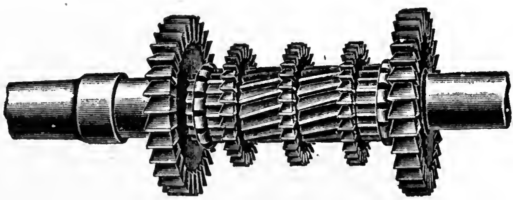


Fig. 209. Gang Cutter

cutters are often sold in pairs. When mounted together, as in Fig. 207, they are often used to mill off both sides of a piece of work,

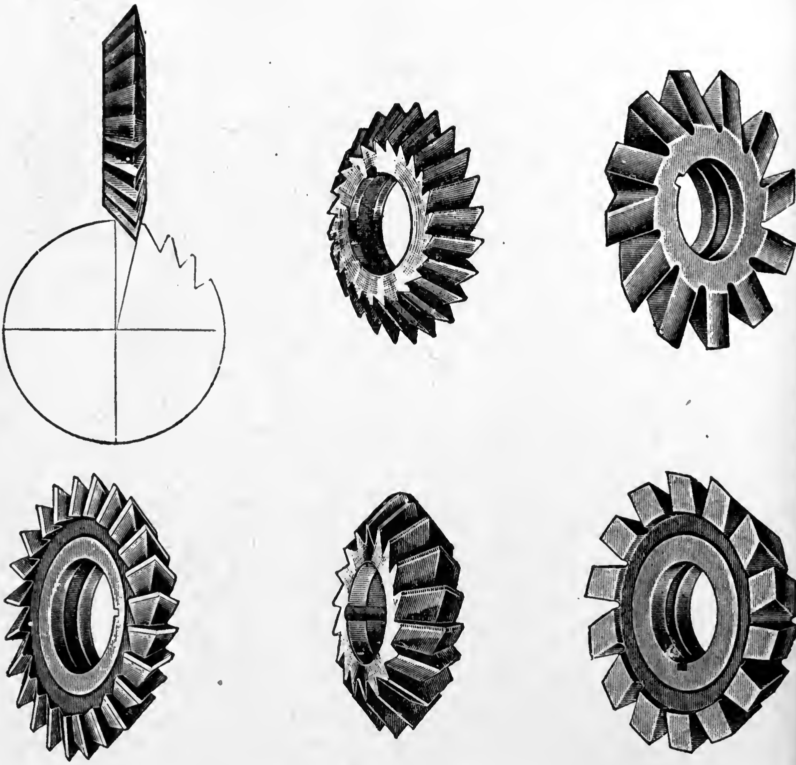


Fig. 210. Forms of Angle Cutters

as, for example, a bolt-head; and they are therefore called heading or straddle mills.

Interlocking Cutters. If two cutters of the same diameter are mounted together, it is difficult to mill a surface which will not show the line of separation of the cutters. This can be avoided by making the ends of the cutters, where they come together, of such a shape that they interlock one with the other. This feature of interlocking, Fig. 208, is especially valuable when cutting slots which must be of a definite width. An ordinary cutter will wear away by use or by grinding, and thus lose its correct size. The thickness of the interlocking cutters can be maintained, however, by means of very thin washers; and, owing to the interlocking of the cutters, no space will show between them.

Fig. 211. Cutter with Inserted Teeth
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

Gang Mills. Cutters may be mounted in gangs of great variety and combination, a typical one being shown in Fig. 209. These cutters may be of any desired form, and can be made to produce a variety of shapes.

Angle Cutters. The so-called angle cutters, Fig. 210, are often employed in the manufacture of other milling cutters. When used in making spiral cutters, they must have an angle on both sides, the customary angles in such cases being 40 degrees, 43 degrees, 45 degrees, or 48 degrees on one side, and 12 degrees on the other. The common single-angle cutters vary from 40 degrees to 80 degrees, either right- or left-hand. Double-angle cutters, as shown in the center of the lower row, Fig. 210, can be had with either 45 degrees, 60 degrees, or 90 degrees included angle.

Inserted-Tooth Cutters. Only such cutters as are made from a single piece of tool steel have been so far considered. In large cutters, however, the cost of the steel becomes an important item, and there is the ever-present danger of losing a large amount of labor by breakage when hardening. To make an economical, serviceable cutter of large size, it is customary to use a cast-iron body with inserted tool steel teeth. There are several different methods of inserting and holding these teeth. Usually, when the inserted tooth

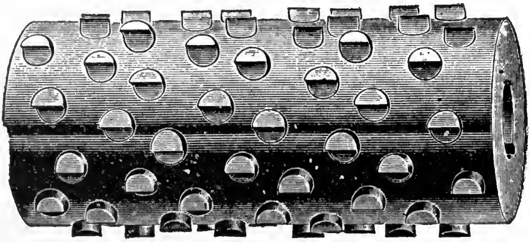


Fig. 212. Form of Inserted-Tooth Cutter Called Slabbing Cutter

is in the form of a blade, they are held by taper pins or screws, Fig. 211. These blades are renewable, the cast-iron body being used many times.

Another form of inserted-tooth cutter consists of round, hardened steel pins driven into holes in a cast-iron body. This cutter is also permanent in form, Fig. 212, as broken teeth cannot be replaced; and, when the teeth are worn almost down to the body, the whole cutter is thrown away.

Form Cutters. Brief mention has been made of cutters to generate irregular contours. These cutters are known as form cutters, and, except in certain shapes, such as quarter- and half-rounds, are not carried in stock, but are made only to order. There is such a large variety of forms for which such cutters may be used

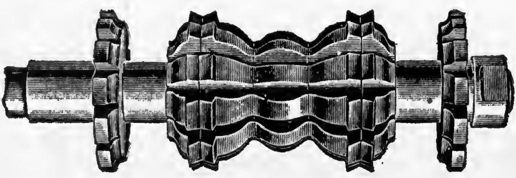


Fig. 213. Gang of Form Cutters

that it is impossible to give more than typical examples. The form shown in Fig. 213 consists in reality of several cutters, some of them of ordinary shapes and sizes, with others of special forms, the whole making a gang cutter whose object is very apparent.

Among the standard shapes of form cutters are some which are now carried in stock for producing certain tools requiring cutters of definite yet peculiar form. Among these may be mentioned cut-

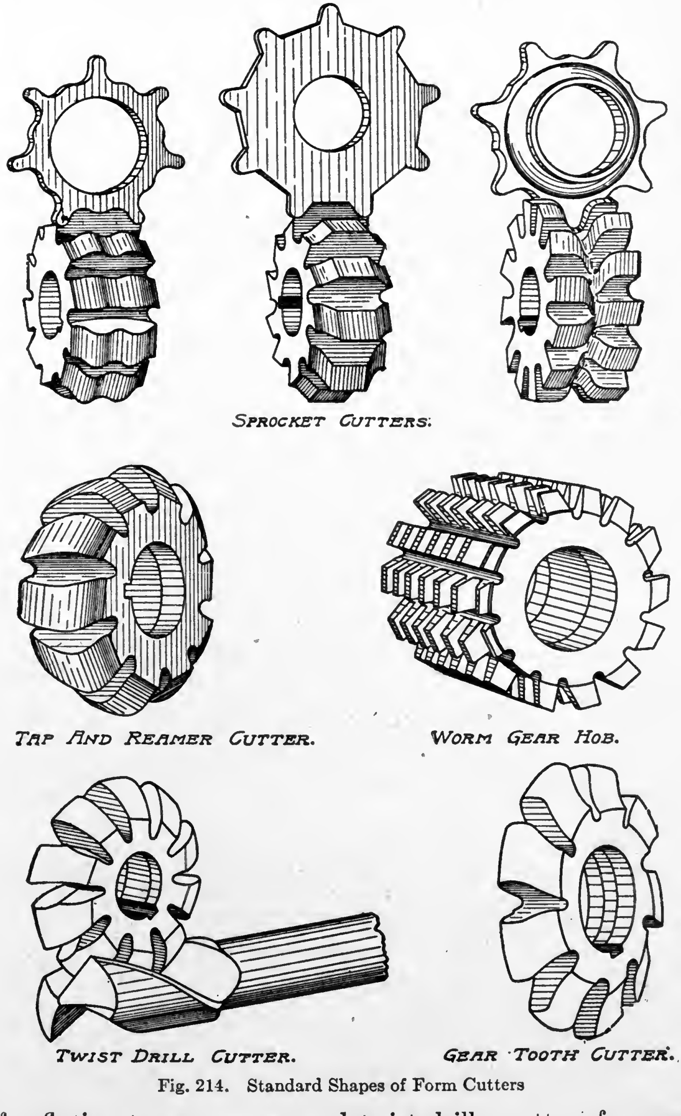


Fig. 214. Standard Shapes of Form Cutters

ters for fluting taps, reamers, and twist drills; cutters for sprocket and gear teeth; and cutters known as hobs, for the production of worm gears, Fig. 214.

End Mills. All the cutters thus far mentioned are provided with central holes, and are intended to be mounted on an arbor

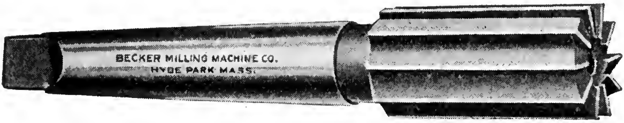


Fig. 215. Ordinary Form of End Mill
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

which is carried by the milling machine spindle and supported in some suitable manner at the outboard end. There is an entirely different class of cutters, however, which are supported by the spindle only, and which are provided with teeth at the end of the cutter. These are known as end mills. They are made in a great variety of shapes and sizes, the ordinary end mill, Fig. 215, being cylindrical, with either a right- or left-hand spiral.

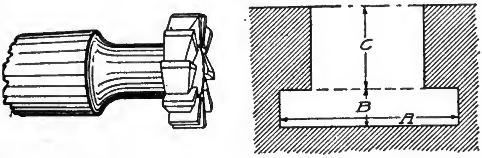


Fig. 216. T-Slot Milling Cutter and Section of Slot

T-Slot Cutter. A special form of end mill for making T-slots is called the T-slot cutter, and is, in reality, a small side milling cutter carried by a small central stud, as shown in Fig. 216.

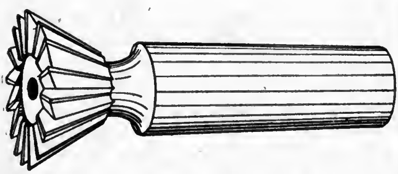


Fig. 217. Dovetail Milling Cutter

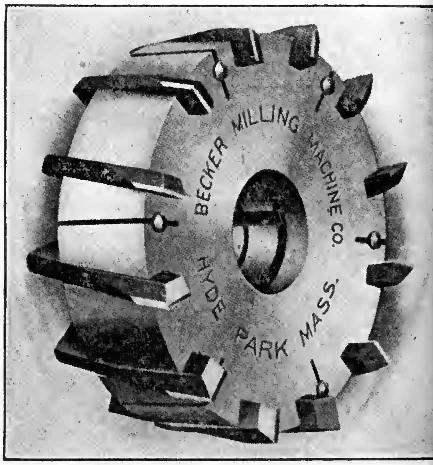


Fig. 218. End Mill with Inserted Teeth
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

Dovetail Cutters. Dovetail cutters, Fig. 217, and cutters of various angles for making ratchets, are merely variations of the end mill.

When end mills are made of large size, they can be furnished with inserted teeth, Fig. 218, similar to those described. The heaviest end mills for the milling machine are sometimes made as large as fifteen to twenty inches in diameter, the cast-iron body being screwed directly onto the nose of the spindle, making a very powerful and fast-cutting tool.

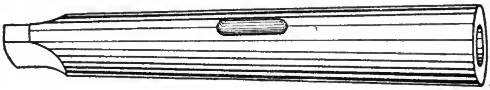


Fig. 219. Taper Collet

Methods of Mounting Milling Cutters. The plain milling cutter is mounted on an arbor in a way very similar to that in which its spindle, prototype, the circular saw, is mounted.

Where the cutter teeth are formed integral with, or fastened to, the taper shank, as in the case of end mills, the shank, if it be of a proper size, is placed directly into the taper hole in the spindle. In many cases, however, the taper shank of the cutter is much too small to fit the spindle hole; and taper collets, Fig. 219, are used to bush down the spindle hole to the proper size. Of course, it is necessary that the axes of the outer and inner tapers should coincide; otherwise the cutter will not run true. In some cases it is necessary to use two collets, one within the other, before introducing the cutter shank.

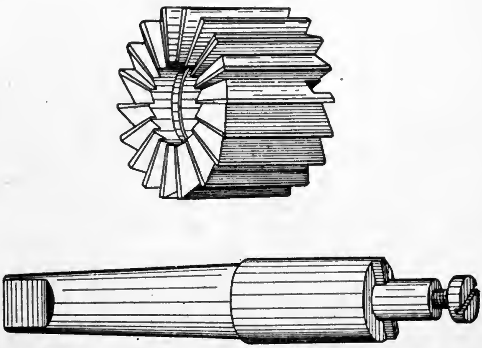


Fig. 220. Shell End Mill and Taper Shank for Holding It

When shell end mills, Fig. 220, are used, a special form of taper shank is employed which can take several different sizes of cutters. The construction is so obvious from the illustration that explanation is unnecessary.

End mills, having taper shanks, rely largely on the friction of the taper for holding in position, although being driven by a tongue at the end of the shank. Therefore cutters of this description should not have a spiral in a direction which would tend to pull the cutter out. This is not a serious objection when using the cylindrical portion of the cutter; but when using the end of the cutter, it means that the teeth can have no rake, and must scrape rather than cut the work. In order to use a leading spiral on the cutter, the shank must be held positively in the spindle. This usually is accomplished by inserting in a threaded hole at the rear end of the shank, a rod which extends through the hollow spindle and brings up against a collar on the outside. This can be set up solidly, and all danger of loosening-up of the cutter shank will be avoided.

When the cutter is small, as compared with the diameter of the spindle taper, a screw collet may be used, as the friction of the collet will be greater than the tendency of the leading spiral to move the cutter from the spindle. These screw collets are commonly made of machine steel, while the end mills are made from tool steel. The short, steep taper and threaded end are shorter than the long taper shank, resulting in a cheaper cutter.

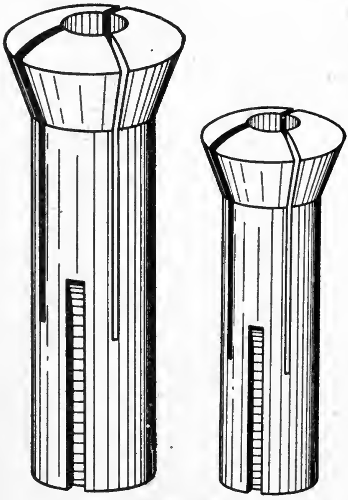


Fig. 221. Typical Spring Collets

One of the best means for holding small end mills with straight teeth is by the use of spring collets, Fig. 221, which can firmly grasp the straight shank of the cutter. When cutters are to be changed frequently, this is a particularly satisfactory method, although it will not answer for roughing cuts where cutters of large diameter are used, as the torque will be too great for the jaws of the collet to prevent turning.

An ordinary drill chuck can be held in the spindle by means of a taper shank, and furnish a means of holding straight-shank drills and other small straight-shank tools.

A very convenient method of holding certain tools consists in fitting a three-jawed universal lathe-chuck to the threaded nose of the spindle, thus enabling straight-shank tools of large size to be held firmly and accurately. Cutters of any kind are rarely held in chucks on the milling machine, but a large number of other small tools can be held advantageously.

TYPES OF MILLING MACHINES

Bench Miller. In taking up the subject of machines devoted especially to milling, it is well to consider that the transition from

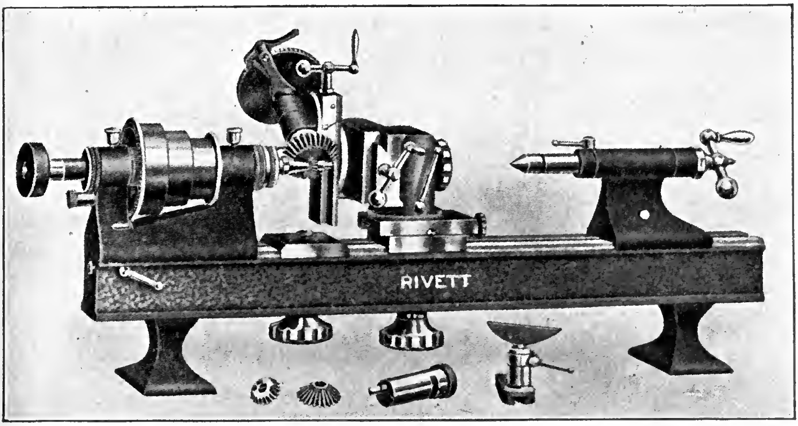


Fig. 222. Rivett Lathe with Milling Attachment
Courtesy of Rivett Lathe Manufacturing Company, Boston, Massachusetts

milling in the lathe to the special milling machine was bridged by an attachment to the lathe by which the functions of the milling machine are well served. This is especially noticeable in the milling attachment attached to bench lathes, Fig. 222, said attachment being mounted on the bed of the lathe and the spindle provided with a milling cutter. This arrangement is used for simple milling operations. Such devices led to the introduction of the bench miller, Fig. 223, which is naturally intended for small work only, and therefore is not provided with automatic feeds, hand-feeding by means of levers being used.

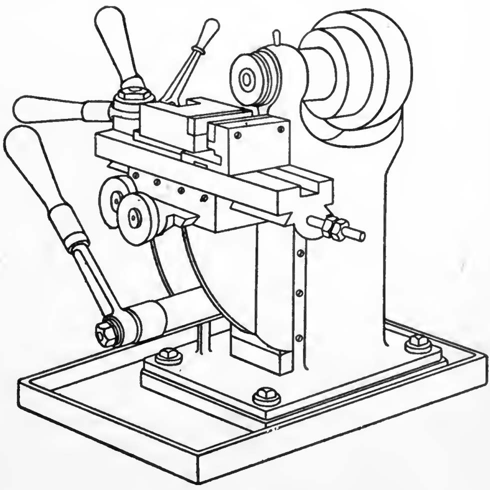


Fig. 223. Bench Miller

Horizontal Milling Machine. The horizontal milling machine, Fig. 224, consists of a frame or box structure carrying a horizontal spindle in the upper portion, together with brackets or an overhanging arm to steady the spindle. The front of the frame is carefully machined and hand-scraped at right angles to the spindle; and there is mounted on the front a knee, the upper surface of which is parallel to the spindle in the horizontal plane and capable of move-

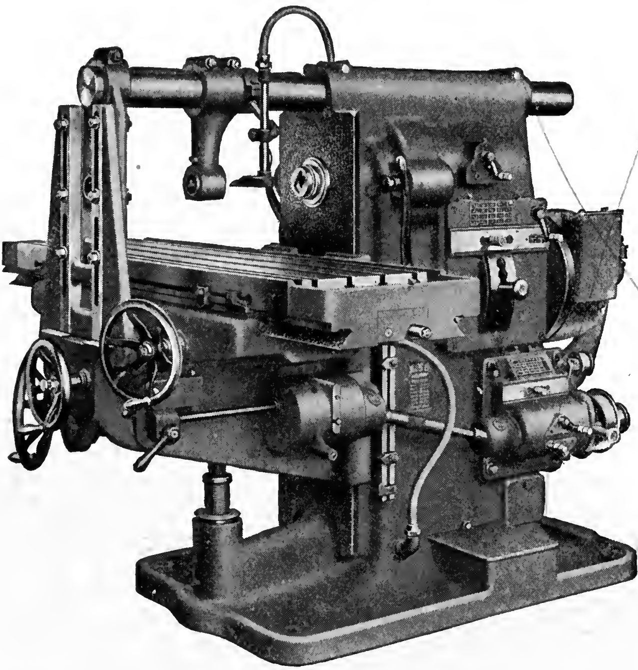


Fig. 224. Horizontal Milling Machine—Column Type
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

ment in a vertical direction. This knee carries what is known as the saddle, the upper portion of which is also parallel to the spindle. The movement of the saddle is toward and from the frame of the machine, and therefore parallel to the spindle. The saddle, in turn, carries the table, to which the work is attached by means that will be described. The upper surface of the table is parallel to the spindle, and the table movement is at right angles to the spindle in the horizontal plane.

The combination of these three motions at right angles to the spindle in the vertical plane, parallel to the spindle in the horizontal plane, and at right angles to the spindle in the horizontal plane, gives to the milling machine what is known as its range. It allows any portion of the table to be brought under the cutter at any distance covered by the vertical feed.

Micrometer Graduations. It will be seen, therefore, that one of the principal advantages of the milling machine is its wide range

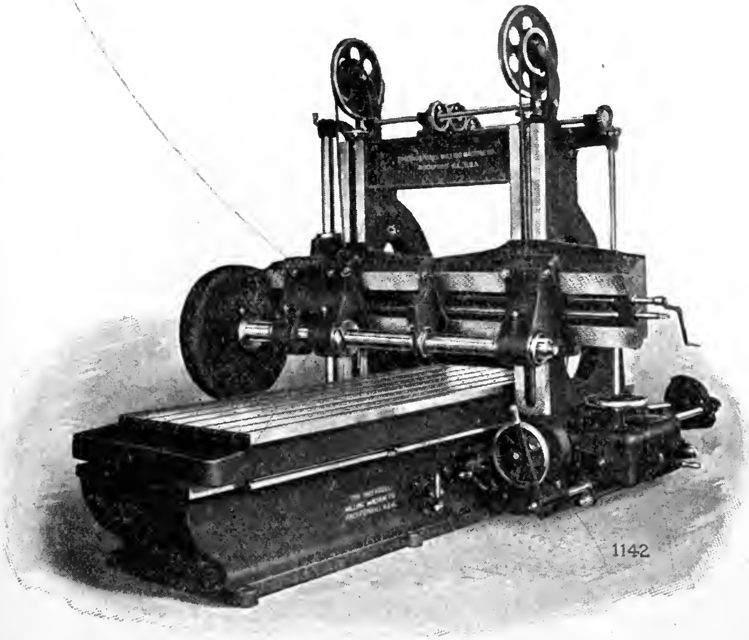


Fig. 225. Slabbing Miller—Planer Type
Courtesy of Ingersoll Milling Machine Company, Rockford, Illinois

of working capacity, and the accuracy with which the table can be placed with relation to the cutter. This accuracy is obtained by means of graduated dials on the feed-screws, which are read directly to .001 inch, and, by estimation, to .00025 inch. For many years the milling machine was the only tool which supplied these micrometer graduations, but they are now applied to nearly every class of machine tool in which accurate adjustment is necessary. A common method of graduation is by the use of a screw with a pitch of $\frac{1}{5}$ inch and with 200 graduations on its dial. In some cases, a screw with a pitch of $\frac{1}{4}$ inch is used with 250 graduations, but it is always safe to assume that the single graduation on a milling machine means a movement of .001 inch

Avoiding Backlash Error. Lost motion or backlash between the screw and its nut, in any of these adjustments, is a cause of frequent error, and should always be considered. Even for a machine in

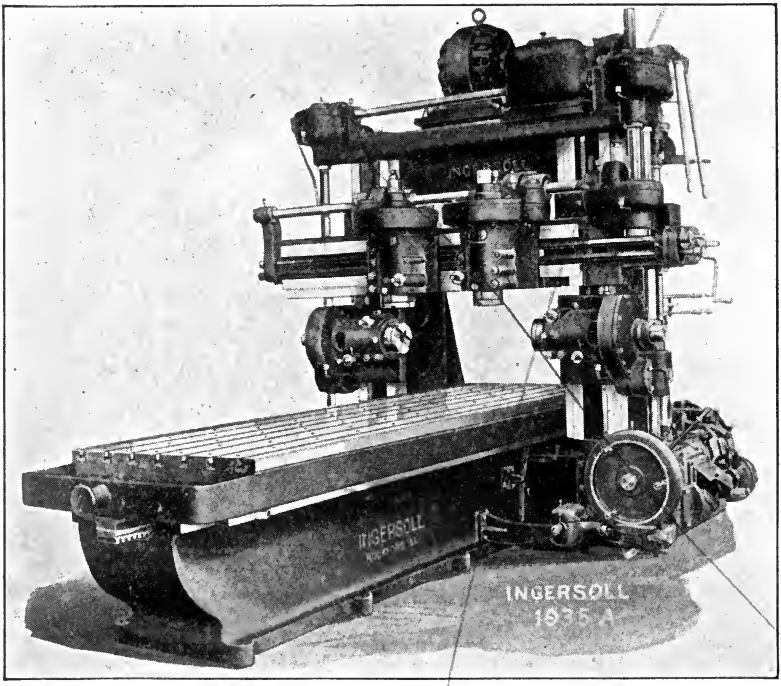


Fig. 226. Planer Type Four-Spindle Milling Machine
Courtesy of Ingersoll Milling Machine Company, Rockford, Illinois

excellent condition, when the motion of the screw is reversed, the screw will turn through an angle giving the equivalent of about .005 inch movement of the part being fed along, but with no actual movement of the part. As an example, if, in moving the table from the column, the operator carries it .003 inch too far, it will not suffice simply to turn the dial back three graduations. The table should be brought back several hundredths of an inch, and again advanced to within .003 inch of its former position. In order to facilitate the quick and accurate reading of these dials, they are arranged so that they can be readily set to zero whenever desired.

Distinction between Plain and Universal Millers. The movements above described for the adjustment of the work are those necessary for what is termed a plain milling machine. In order to

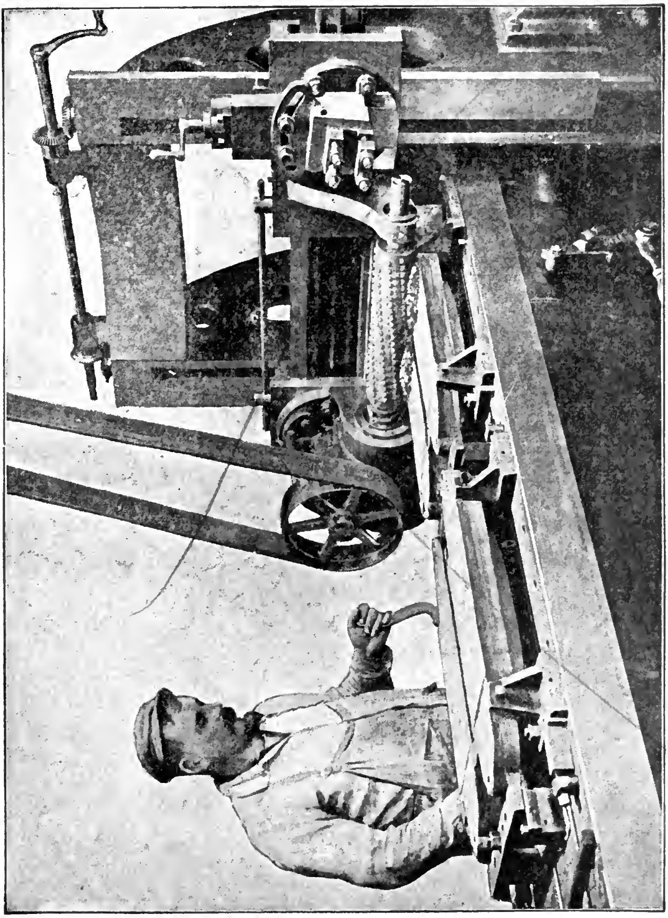


Fig. 227. Planer Equipped with Horizontal Milling Attachment

have a universal milling machine, Fig. 224, it is necessary that the table be so arranged that it can be swung upon the saddle in the horizontal plane, so that its feeding movement is not at right angles to the axis of the spindle. Universal milling machines usually have a total working angular movement of 90 degrees, 45 degrees on either side of the normal position.

While the milling machine developed from the lathe, through the Lincoln miller, to the standard horizontal universal machine, its development for work on which heavy cuts are necessary took an opposite course.

Planer Type Milling Machines. The slabbing miller, Fig. 225, is of the planer type, the cross-rail carrying a rigidly supported cutter, while the table has the comparatively slow feed required for milling. This type of machine is especially valuable where broad surfaces are to be machined on pieces of work which are of such shape that they can be readily and uniformly supported to withstand the cut. Another milling machine of the planer type, having four spindles, is shown in Fig. 226. It is designed for very heavy work.

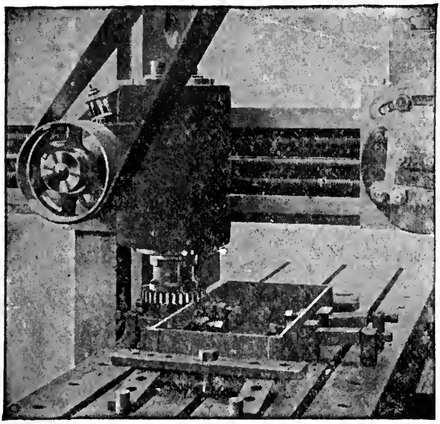


Fig. 228. End Milling Attachment on Planer

Especial Care Necessary to Keep Work True. In order to produce true work by heavy milling, it is not only necessary that the work shall be supported as already outlined, but also that the cut be nearly uniform in depth and width. If the section of the cut varies greatly, or, even with uniform cut, if the work is irregularly supported, the metal will spring under the influence of the cutter, and it will be found that the work is not true. Therefore, work of a character that from its shape is especially liable to be distorted by the process of milling, may be machined to better advantage by the process of planing.

Milling Attachments for Planer. It is often desirable, from the point of view of economy of time, to combine the operations of milling and planing, and, with this end in view, milling attachments are made for the planer in a single machine, Fig. 227, and attached to the cross-rail. The changes required from the planer drive, are an extra belt to rotate the cutter, and a special countershaft to slow down the movement of the table. This attachment can carry a slabbing, gang, or formed cutter on an arbor for horizontal milling; or it can carry end mills, Fig. 228, by turning the attached head through 90 degrees, thus bringing the spindle to a vertical position. This last arrangement of the spindle is of great utility, as it allows cutters to reach down into places which would be inaccessible by any other means.

Vertical Milling Machines. *Vertical Head on Horizontal Machines.* The advantages of the vertical milling spindle are so

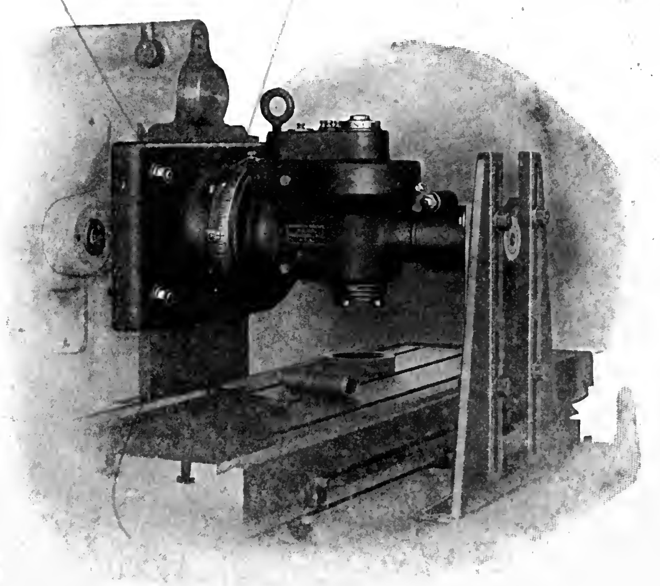


Fig. 229. Vertical Milling Head Attached to Horizontal Milling Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

evident that nearly all makers of horizontal machines furnish what is called a vertical head, Fig. 229. This vertical head is very rigidly supported on the column by means of the overhanging arm, so that cuts can be taken of as great depth as with the horizontal spindle. The vertical spindle can also be turned in the vertical plane, so that an end mill can be used at any angle with the table.

Vertical Spindles Only. There are several machines made in which the vertical spindle alone is employed, Fig. 230, there being no provision for a horizontal spindle.

Such machines are provided with the feed motions of the horizontal type, and also with a rotating table by which circular work can be done. A large amount of work formerly done in lathes

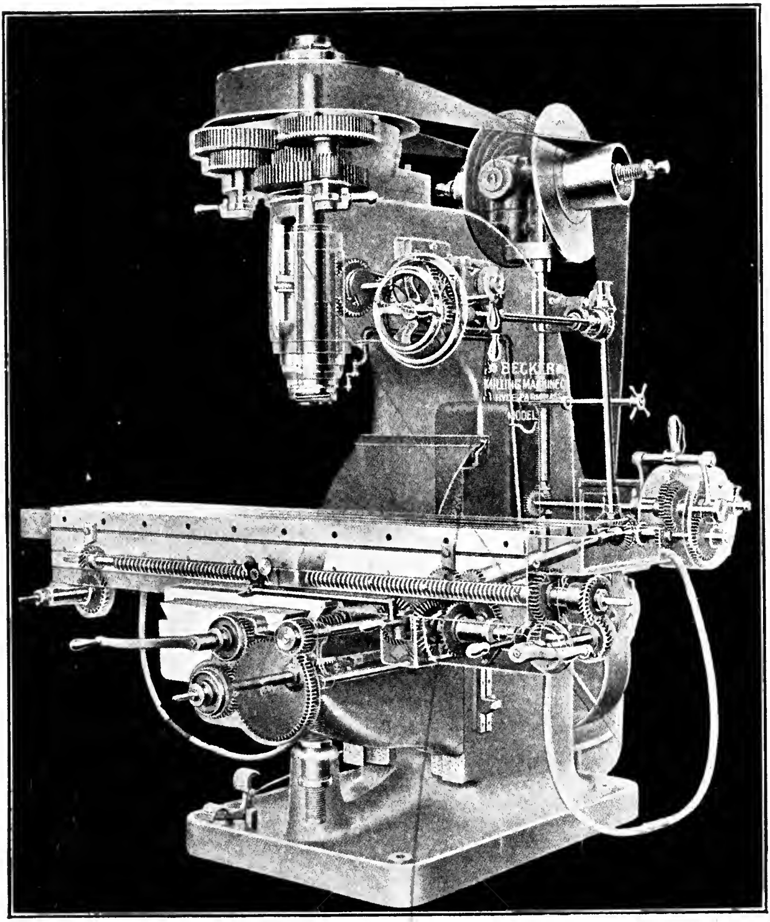


Fig. 230. Vertical Milling Machine with Working Parts Shown in Ghost
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

is now being done in vertical spindle machines, as well as many pieces formerly machined on planers and shapers.

Duplex Milling Machines. The duplex milling machine, Fig. 231, has both the horizontal and vertical spindles combined in one, which allows the spindle to be placed at any angle from horizontal to vertical, and combines all the good points of both machines. The head of the duplex miller can be moved out over the table so as greatly to increase the range of the machine; and this head is also provided with a drilling attachment whereby holes may be drilled at any angle.

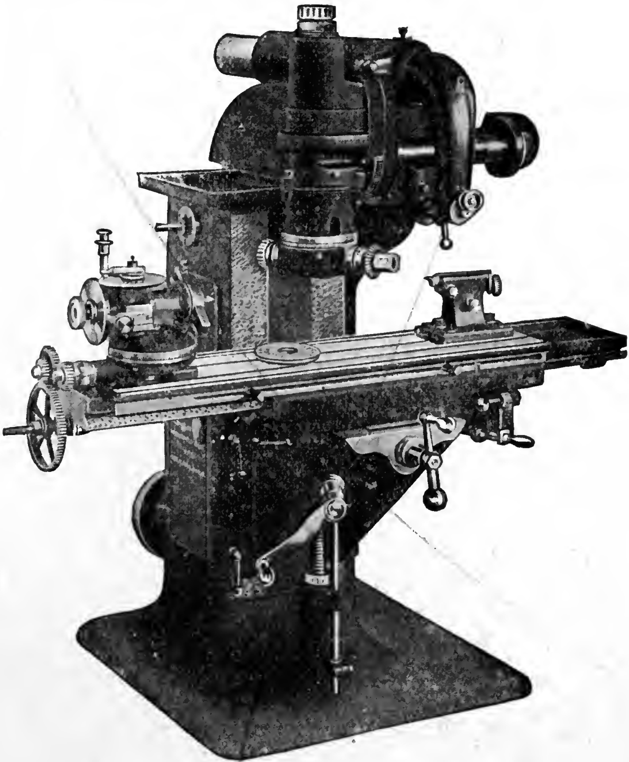


Fig. 231. Duplex Milling Machine Set for Cutting Spirals
Courtesy of Van Norman Machine Tool Company, Springfield, Massachusetts

MILLING OPERATIONS

Classification. These may be classified in a manner similar to the cutters themselves, whose names will suggest the kind of work for which they are adapted.

Plane Milling or Surface Milling. This is the machining of plain, flat, horizontal surfaces by means of cylindrical mills whose length is usually much greater than their diameters, the larger kinds being constructed with inserted blades or teeth.

Side Milling or Face Milling. This operation is the machining of vertical surfaces, or surfaces at right angles to the axis of the milling cutter.

Angle Milling. As the name suggests, this is the machining of a surface at some other than a right angle to the axis of the milling cutter.

Form Milling. The machining of some special cross-section generally composed of straight lines and curves, or wholly of curves, is called form milling.

Profiling. This operation is usually considered as machining the vertical edges of pieces of irregular contour, and is generally done with an end mill mounted in a vertical spindle. The exact form is generally determined by a templet or profile attached to the piece or to the fixture supporting it.

Care of Milling Cutters. This is a matter of much importance, since a worn or dull cutter will never produce good work, and a good cutter is soon spoiled by improper use or lack of care in handling. The cutting edge should always be sharp and keen; but it is of still greater importance that each edge should be exactly the same distance from the axis of rotation—or, in other words, that the cutters should run true. When this condition does not exist, the greater part of the work will fall upon two or three of the teeth, and these will be speedily ruined, while the others do little or no work.

Care should be taken to have the arbor run true; otherwise a cutter that is ground true will not run so. Therefore, cutter arbors should be examined and tested frequently to see that the portion upon which the cutter or loose collars rest runs true and is smooth, and not defaced by bruises from rough handling.

Grinding Milling Cutters. A good cutter-grinding machine is absolutely essential. It should have a well fitted and true spindle, and such attachments for holding cutters of various kinds as to be able to grind all the usual forms without important changes of mechanism. The centers for supporting arbors, and the devices for holding cutters not on arbors, should be well fitted and true. The machine should be equipped with such graduated circles as will enable the operator readily to set it for grinding all the usually required angles.

Fig. 232 shows a regular machine for this purpose. It is so arranged that various forms of cutters can be ground either when mounted upon cutter arbors or held in the machine fixture provided; and it has a number of well-designed attachments by which a considerable amount of general grinding can be successfully done.

In keeping milling cutters in order, they should be ground as soon as they become dulled, whether wanted for immediate use or not. It is more economical to have them always ready, as the emergency is likely to occur at a time when a cutter is wanted at once, and when there is not time to grind it properly.

Cutters should be kept sharp. A dull cutter will not only wear away more rapidly than a sharp one, but it will also do poor work;

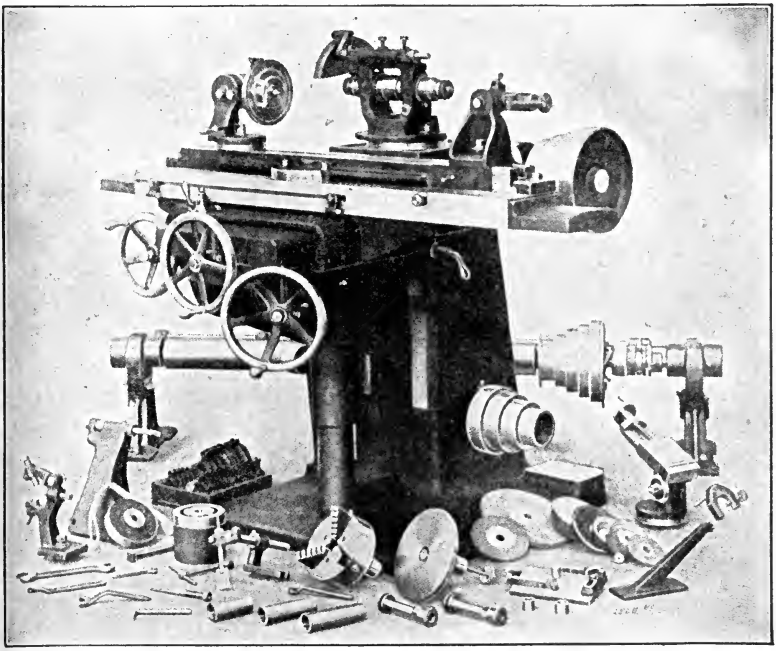


Fig. 232. "Cincinnati" No. 2 Universal Cutter and Tool Grinder
Courtesy of Cincinnati Milling Machine Company, Cincinnati, Ohio

it will take a great deal more power to drive it, and the milling machine will be more rapidly worn out.

Care should be taken, in grinding angular cutters, that the points are not heated so as to draw the temper. This very easily happens if considerable care is not used, the cutting edges becoming so softened as to be rapidly worn away and the cutter spoiled by use. Formed cutters are frequently affected in a similar manner. The excessive friction of a dull cutter will frequently generate a sufficient amount of heat to draw the temper of the teeth at the cutting edge.

In making the grinding machine ready to grind a cutter, it is necessary to see that the emery wheel runs perfectly true; and if it does not, it should be trued up before any grinding work is done. If the cutter is to be sharpened upon an arbor, the latter should be tested to ascertain if it runs true before putting the cutter on it. In grinding the cutter, light grinding cuts should be taken, and the cutter moved rapidly across the face of the wheel. The wheel should be the proper grade of emery, not finer than 90, nor coarser than 56. The coarser and softer the wheel, the higher may be the speed. It is not advisable to make the speed over 4,500 feet per minute at the outer edge of the wheel. The cutting edge of the wheel need not be over an eighth of an inch thick, in any case.

Preparing the Milling Machine for Work. The taper shank of the arbor and the hole in the spindle should be wiped clean and free from oil or grit. Should the outer end of the arbor be supported by a pointed center or a bushing, it will not be difficult to keep it in place; but if not so supported, it must be driven tightly into the spindle, using care that the flattened end or tang fits perfectly into the slot provided for it. If it is noticed that the arbor does not fit fairly into the spindle, it should be removed and examined to see that there are no dents or bruises on it, and that the tang is not too long or too thick, or the shoulders not cut back far enough to permit it to fit properly. When arbors work loose, it is on account of some one of these causes.

If the arbor does not run true when the cutter is mounted and the clamp-nut screwed up, the nut and collars should be removed and examined. Fine chips or dirt are likely to be found between the collars, or between them and the cutter, causing the arbor to spring when the clamp nut is screwed up. The parts should be cleaned and again put in place.

Cutting Speeds. *Conditions Governing Speed.* There are no hard and fast rules that will properly govern a majority of cases of the continually varying conditions of milling cutters, machines, and the material to be machined. In any case, much must be left to the judgment of the foreman and the operator. Prominent among the conditions that tend to vary the cutting speed are the following:

The cutter may be newly ground, keen, and sharp; or it may have been considerably dulled by use. While not dull enough to require grinding, it will not be safe to run it up to the speed of a sharp cutter. The teeth may be worn thin from long use and re-grinding, and not strong enough to stand the strain of maximum speed. The cutter may be of such a form—as a double-angle cutter—that the teeth will not bear the strain of full speed.

The machine may be well designed and built, and free from vibration; or it may be directly the reverse, a fast speed producing so much chattering as to spoil both work and cutter. The arbor may be large and stiff, or small and slender. In one case, a fast speed may be maintained; and in the other, both work and cutter would suffer. The driving gearing may be well designed and its teeth fit accurately with no backlash; or it may be poorly designed and made, or much worn, and cause much chattering on a fast speed. There are many other similar conditions.

The material may be of varying degrees of hardness and toughness, and of a great variety of forms. Some iron castings will be more severe on a cutter than tool steel would be. The scale on cast metal is very hard to cut through, and dulls the teeth of a cutter quickly. The varying hardness of steel, from that ordinarily found in the bar to that properly annealed, is great. The amount of carbon in steel is always a varying condition for which it is difficult to formulate rules. Therefore it is only possible to give rules that will meet a fair average of conditions.

In order to accommodate different sizes of cutters, maintain a uniform cutting speed, and also allow for difference in hardness of the material being worked, it is necessary that the milling machine should be supplied with several speeds. In the ordinary miller we usually have a four-step cone with back gears, which gives eight speeds with a single overhead belt. The countershafts for these machines are of the friction type, and are supplied with two driving pulleys driving in the same direction, but at different speeds, giving a total, including the back gears, of sixteen speeds for each machine.

Form of Cutter as Affecting Its Speed and Feed. A slitting cutter (practically a saw) may be run much faster than one of broad face.

A cutter of small diameter will cut faster than a large one, as the arc of action is much less.

Angle cutters must be run at lower relative speeds so as not to break off the slender points of the teeth.

The speed may sometimes be profitably increased without changing the rate of feed. Again, the speed should be decreased according to the conditions of the work.

There is no direct and constant ratio between speed and feed. Conditions may vary either one without changing the other.

A roughing cut will often work better with a moderate speed and a coarse feed. The smoothness of the work is not so important as taking off the surplus stock. With a finishing cut, the conditions are reversed and a fine feed is necessary.

Cutters with inserted blades will not usually stand as high a speed as solid cutters, particularly when the blades have a large cutting surface. This condition is emphasized when cutting rather hard and tough material.

If there is a comparatively small space for chips between the teeth of the cutter, a light cut must be taken, or a slower feed used, so that the chips will not clog the cutter.

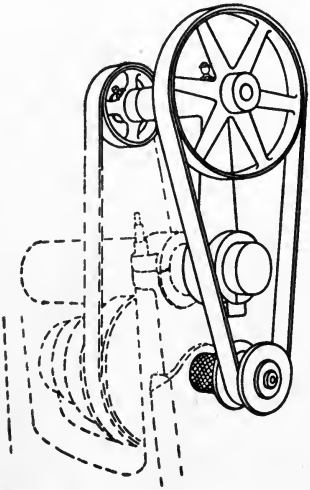


Fig. 233. High-Speed Attachment for Milling Machine

Speed Used on Particular Work or Material. The speed used on any particular work depends, as before stated, on the diameter of the cutter and the character of the work. Thus, with carbon steel cutters, the cutting speed will be 30 to 60 feet per minute. With high-speed steel cutters, double these speeds may be maintained if the drive of the machine is strong enough to pull the cut.

When using very small cutters, the machine itself will not usually give a speed which is high enough to suit the diameter of the cutter. For such work, a high-speed attachment, Fig. 233, is furnished, by which the small, light cutters may be driven at a suitable rate.

Of equal importance with the correct speed for the cutter, is the maximum feed or table speed, which is reckoned in inches per minute. A more logical method of designating the feeds, and one which has been adopted by several makers, is to give the advance of the table in thousandths of an inch for every turn of the spindle.

Based upon the use of the ordinary carbon steel cutters, the Brown and Sharpe Manufacturing Company have prepared the following statements regarding the speed of cutters:

It is impossible to give definite rules for the speed and feed of mills. The judgment of the foreman or man in charge of the machine should determine what is best in each instance.

As usually the highest possible speed and feed are desirable, it pays to increase them both until it is seen that something will break or burn, and then

TABLE IV

Speeds and Feeds for Milling Cutters*

Material	Speed (ft. per min.)	Feed (in. per min.)
Soft cast iron	60	$1\frac{1}{2}$
Hard cast steel	40	1
Wrought iron	45	1
Soft machine steel	36	$\frac{3}{4}$
Hard machine steel	24	$\frac{1}{2}$
Tool steel, annealed	30	$\frac{1}{2}$
Tool steel, not annealed	20	$\frac{1}{4}$
Soft brass	120	$2\frac{3}{4}$
Hard brass	100	$2\frac{1}{4}$
Bronze	80	$1\frac{1}{2}$
Bronze, gun metal	60	$\frac{5}{8}$
Vulcanized fiber (gray and red)	60	6

reduce to a speed and feed of safety. Sometimes the speed must be reduced, and yet the feed need not be changed.

The average speed on wrought iron and annealed steel, using carbon steel cutters, is perhaps 40 feet per minute, which gives about sixty turns per minute with mills $2\frac{1}{2}$ inches in diameter. The feed of the work for this surface speed of the mill can be about $1\frac{1}{2}$ inches per minute, and the depth of the cut about $\frac{1}{16}$ inch. In cast iron, a mill can have a surface speed of about 50 feet a minute while the feed is $1\frac{1}{2}$ inches per minute and the cut $\frac{3}{16}$ inch deep. In tough brass, the speed may be 80 feet, the feed the same as in cast iron, and the chip $\frac{3}{32}$ inch.

As small mills cut faster than large ones, an end mill, for example, $\frac{1}{2}$ inch in diameter, can be run about 400 revolutions per minute with a feed of 4 inches.

Addy, an English authority, gives as a safe speed for cutters of 6 inches diameter and upward:

Steel, 36 ft. per min., with a feed of $\frac{1}{2}$ in. per min.
Wrought iron, 48 ft. per min., with a feed of 1 in. per min.
Cast iron, 60 ft. per min., with a feed of $1\frac{2}{3}$ in. per min.
Brass, 120 feet per min., with a feed of $2\frac{2}{3}$ in. per min.

He also gives a simple rule for obtaining the speed:

The number of revolutions which the cutter should make when working on cast iron equals 240 divided by the diameter in inches.

In Table IV are given the average speeds in feet per minute of the periphery of the cutter, and the rate of feed in inches per minute for various materials.

Tables V, VI, VII, and VIII, have been prepared by the Brown and Sharpe Manufacturing Company, to give the speed, feed, and depth of cut that can be obtained with a machine similar to that illustrated in Fig. 224. It is understood that these speeds

*Attention is called to the seemingly slow speed and fast feed for vulcanized fiber. Practice, however, proves it to be correct.

TABLE V

Surface Milling of Cast Iron

Diameter of Mill (in.)	Revolutions per Minute	Speed of Cutter per Minute (ft.)	Depth of Cut (in.)	Width of Cut (in.)	Feed per Minute	
					In Scale of Cast Iron (in.)	Under Scale of Cast Iron (in.)
3	42	34	$\frac{1}{16}$	1	$6\frac{5}{8}$	$8\frac{7}{8}$
	42	34	$\frac{1}{2}$	1	$4\frac{1}{8}$	$6\frac{1}{2}$
	42	34	$\frac{1}{16}$	2	$6\frac{5}{8}$	$8\frac{7}{8}$
	42	34	$\frac{1}{2}$	2	$2\frac{1}{2}$	$4\frac{1}{8}$
	42	34	$\frac{1}{16}$	3	$6\frac{5}{8}$	$8\frac{7}{8}$
	42	34	$\frac{7}{16}$	3	$1\frac{3}{8}$	$2\frac{3}{16}$
$3\frac{1}{2}$	42	40	$\frac{5}{32}$	8	$4\frac{1}{8}$	$6\frac{1}{4}$
	42	40	$\frac{1}{8}$	$3\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$
$4\frac{1}{2}$	42	50	1	2	$4\frac{1}{8}$	$6\frac{1}{2}$
	42	50	1	4	$3\frac{1}{2}$	$4\frac{1}{8}$
	42	50	1	6	2	$2\frac{1}{4}$
	42	50	$\frac{1}{8}$	6	$4\frac{1}{8}$	$6\frac{1}{2}$
	42	50	$\frac{11}{32}$	12	$1\frac{3}{8}$	2

TABLE VI

Surface Milling of Soft Machinery Steel

Diameter of Mill (in.)	Revolutions per Minute	Speed of Cutter per Minute (ft.)	Depth of Cut (in.)	Width of Cut (in.)	Feed per Minute	
					In Scale of S.M.S. (in.)	Under Scale of S.M.S. (in.)
3	38	30	$\frac{1}{16}$	1	6	8
	38	30	$\frac{1}{2}$	1	$1\frac{1}{8}$	$1\frac{7}{8}$
	38	30	$\frac{1}{16}$	2	$2\frac{3}{8}$	$3\frac{1}{2}$
	38	30	$\frac{1}{2}$	2	$\frac{3}{4}$	$1\frac{1}{8}$
	38	30	$\frac{1}{16}$	3	$1\frac{1}{8}$	$1\frac{7}{8}$
	38	30	$\frac{3}{8}$	3	$\frac{3}{4}$	$1\frac{1}{8}$
$3\frac{1}{2}$	38	35	$\frac{1}{16}$	8	$1\frac{7}{8}$	3
	38	35	$\frac{1}{8}$	8	$\frac{3}{4}$	$1\frac{1}{8}$
$4\frac{1}{2}$	25	30	$\frac{1}{16}$	3	4	5
	25	30	$\frac{1}{16}$	5	$2\frac{1}{2}$	$4\frac{1}{2}$
	25	30	$\frac{3}{8}$	5		$\frac{1}{2}$
	25	30	$\frac{1}{16}$	10	$1\frac{3}{4}$	$2\frac{1}{2}$
	25	30	$\frac{3}{16}$	10	$\frac{1}{2}$	$\frac{7}{8}$

and feeds are those used when the milling cutters are made from a good grade of carbon tool steel. If the cutters used are made from the newer high-speed steels, these figures can be decidedly increased.

TABLE VII

End or Face Milling of Cast Iron

Diameter of Mill (in.)	Revolutions per Minute	Speed of Cutter per Minute (ft.)	Depth of Cut (in.)	Width of Cut (in.)	Feed per Minute	
					In Scale of Cast Iron (in.)	Under Scale of Cast Iron (in.)
$\frac{1}{2}$	382 382	50 50	$\frac{1}{16}$ $\frac{1}{8}$	$\frac{1}{2}$ $\frac{1}{2}$	23 7	35 11
1	191 191	50 50	$\frac{1}{16}$ $\frac{1}{2}$	1 1	30 3	40 $5\frac{1}{2}$
$1\frac{3}{4}$	109 109	50 50	$\frac{1}{8}$ $\frac{3}{4}$	$1\frac{3}{4}$ $1\frac{3}{4}$	17 $3\frac{5}{8}$	23 $4\frac{1}{8}$
5	42	55	$\frac{1}{4}$	5	$2\frac{5}{8}$	$4\frac{1}{8}$
16	10	45	$\frac{1}{4}$	16	$\frac{7}{8}$	1

TABLE VIII

Face Milling of Soft Machinery Steel

Diameter of Mill (in.)	Revolutions per Minute	Speed of Cutter per Minute (ft.)	Depth of Cut (in.)	Width of Cut (in.)	Feed per Minute	
					In Scale of S. M. S. (in.)	Under Scale of S. M. S. (in.)
$\frac{1}{2}$	237 267	35 35	$\frac{1}{16}$ $\frac{1}{4}$	$\frac{1}{2}$ $\frac{1}{2}$		
1	152 152	40 40	$\frac{1}{16}$ $\frac{1}{2}$	1 1	3	$4\frac{3}{4}$
$1\frac{3}{4}$	87 87	40 40	$\frac{1}{16}$ $\frac{3}{4}$	$1\frac{3}{4}$ $1\frac{3}{4}$	$2\frac{3}{4}$	$4\frac{1}{2}$ $1\frac{3}{4}$

Use of Oil on Machines and Work. The milling machine, and in fact all the machines of the shop can do efficient work only when they are well cared for. An important element is that they should be frequently cleaned and well oiled.

Great care should be exercised that chips do not get into the tapered holes in the spindles or between the arbor collars.

When at work on steel, the milling cutter is kept flooded with oil or a solution of sal soda, as already specified for lathe work.

Oil is used in milling to obtain smoother work, to make the cutters last longer, and, where the nature of the work requires, to wash the chips from the work or from the teeth of the cutters. Some lubricant is generally used in milling steel, wrought iron, malleable iron, or tough bronze. Frequently, when only a few pieces are to be milled, it is not used, and some steel castings are milled without a lubricant; also in cutting cast iron it is not used. For light, flat cuts it is often put on with a brush, giving the work a thin covering like a varnish. For heavy cuts it should be led to the mill from the drip can that is usually sent with each machine; or it should be pumped upon or across the mill when cutting deep grooves, milling several grooves at one time, or, indeed, in milling any work where, if the chips should stick, they might catch between the teeth and sides of the grooves, and scratch or bend the work.

The Brown and Sharpe Manufacturing Company recommend the use of lard oil in milling. Any animal or fish oil, however, may be used, and then separated from the chips by the use of a centrifugal separator or by dumping into a tank of water. In the latter method, the chips fall to the bottom and the oil rises to the top, whence it may be drawn off with but little waste.

Laying Out and Drilling Holes. One of the operations for which the miller is particularly adapted is in locating and drilling holes which require accurate placing. The graduated feeds of the milling machine allow the distances to be set off as closely as .00025 inch, and holes can also be drilled to a given depth with equal accuracy. In starting holes, it is best to use a spotting drill, Fig. 234, which is extremely rigid and perfectly true. The spot made should be of slightly greater diameter than the drill to be used. The drill should be what is known as reamer size—that is, $\frac{1}{64}$ inch below the standard—and the hole may then be reamed, either in one operation, using a standard reamer, or by first using a machine reamer which is about .005 inch under size, to be followed by the standard reamer. It is evident that holes thus drilled and reamed will be parallel, and, by using the vertical

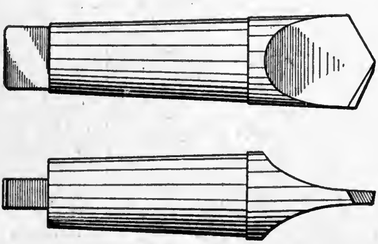


Fig. 234. Spotting Drill

head, holes can be drilled at right angles in like manner. When extreme accuracy in holes is demanded, a boring bar may be used in the spindle after the drill, in order to correct any error due to the running of the drill itself.

Splining Shafts. Another operation suited to the milling machine, although sometimes performed on the shaper or planer, is that of splining shafts. The slots in the table give the proper alignment to the shaft; the cutter can be set with correct relation to the axis without difficulty, and the spline cut full depth at one operation. The only objection to this form of spline is the curve at the end due to the shape of the cutter. An end mill in the vertical head can be used to remove this objectionable feature; and some splining machines are made, Fig. 235, which permanently carry both cutters, so that the work can be quickly shifted from one to the other.

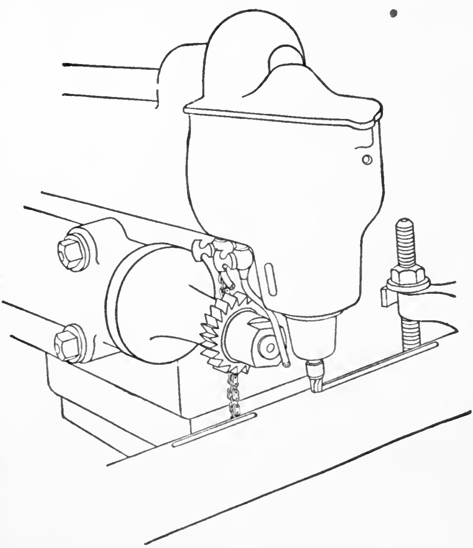


Fig. 235. Splining Arrangement with End Mill in Vertical Head

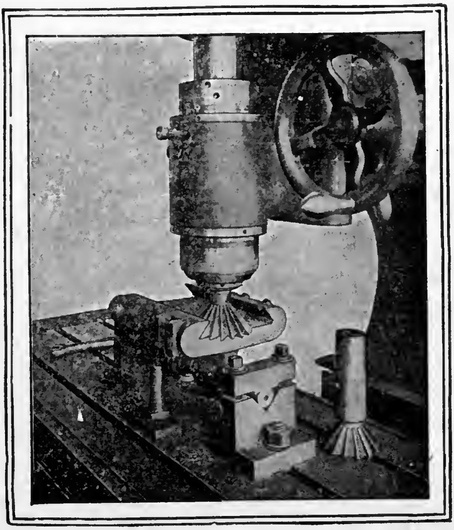


Fig. 236. Dovetail Cutter on Vertical Milling Machine

Making Dovetails. The operation of making dovetails, which is a delicate and expensive job on a shaper, is readily performed on the milling machine, especially of the vertical type, Fig. 236, the cutter being a form of end mill suited to the size and angle of the dovetail.

T-slots are cut in a similar manner, either directly from the solid, or by following a groove made with a plain cutter.

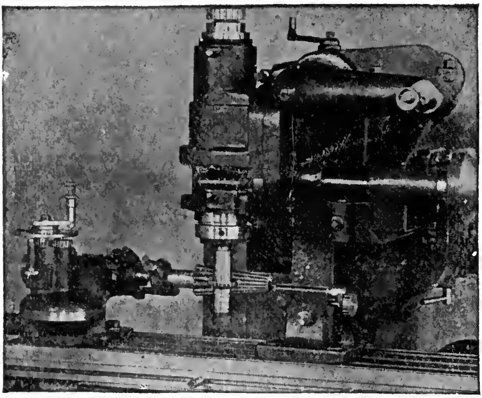


Fig. 237. Fluting Taper Reamer
Courtesy of Van Norman Machine Tool Company, Springfield, Massachusetts

Fluting Taps and Reamers. One of the common operations performed between centers is the fluting of taps and reamers, Fig. 237, which is done by the special cutters already referred to in Fig. 214. It will be noticed that the cutter should be set in such a way that the cutting edge of the tap or reamer will be radial. If left as an obtuse angle, the tool will simply scrape and not cut; while, if the tooth is undercut to any extent to correct this, it will often be so weakened as to be liable to break.

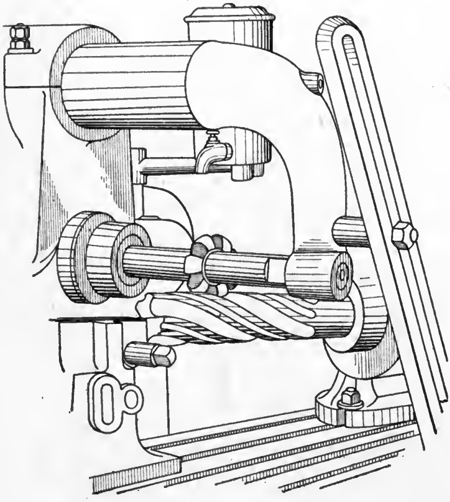


Fig. 238. Milling Spirals with Table at Angle

The flutes in twist drills and in spiral fluted reamers may also be cut between centers; but, if the cutter is carried directly by the spindle, the operation requires a universal machine. If the cutter be carried by a vertical or sub-head of any kind, a plain machine will answer for the purpose. The angle to which the table or vertical head must be set for spiral cutting, Figs. 238 and 239, is the angle between the axis and the development of the spiral. This angle can be closely determined by the following graphical method:

Construct a right-angled triangle having a base equal to the axial distance represented by one full turn of the spiral (this is the lead of the spiral), and a perpendicular equal to the circumference of the work, Fig. 240. Draw the hypothenuse of this triangle. If the construction has been carefully done, the

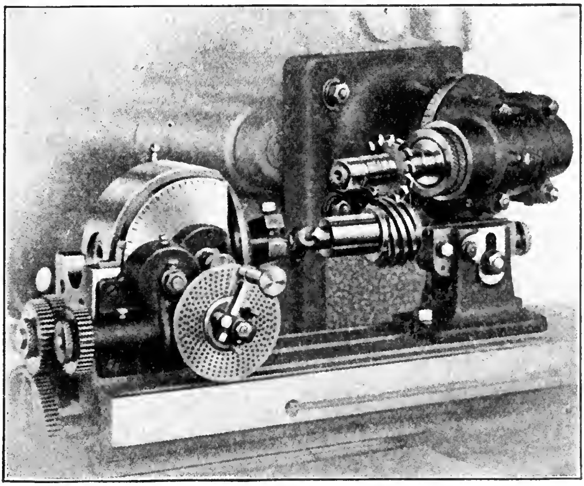


Fig. 239. Cutting Spiral with Milling Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

angle between the base and the hypothenuse may be closely determined by the use of a protractor, and will be the angle to which the table or head must be set.

This angle can be more closely and quickly determined by a very simple problem in plane trigonometry—namely, finding the tangent of the angle. To do this, divide the perpendicular of this triangle by its base, and obtain the value of the angle from a table of tangents.

Spirals. The cutting of spirals requires another operation which differs from ordinary work. In addition to the angular setting, the

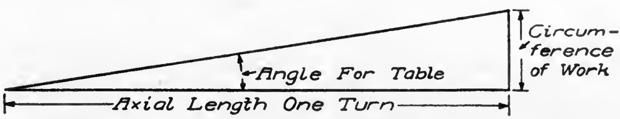


Fig. 240. Graphical Method of Determining Angle for Cutting Spirals

work must be rotated in order to produce the spiral, as well as fed forward to the cutter. This rotation of the work must be positive, which means geared; and one rotation of the work will, of course, equal the lead of the spiral, which is usually expressed as one turn in *n* inches. After cutting one spiral groove, the work is turned and indexed the same as in plain milling.

Cams. Both open and closed cams can be readily cut on a plain milling machine by the use of the cam-cutting attachment, Fig. 241, which nearly all makers are able to furnish. The outline of the cam is first laid out and worked down by hand on a plain disc, or male leader, as it is termed. This leader and a suitable blank are mounted,

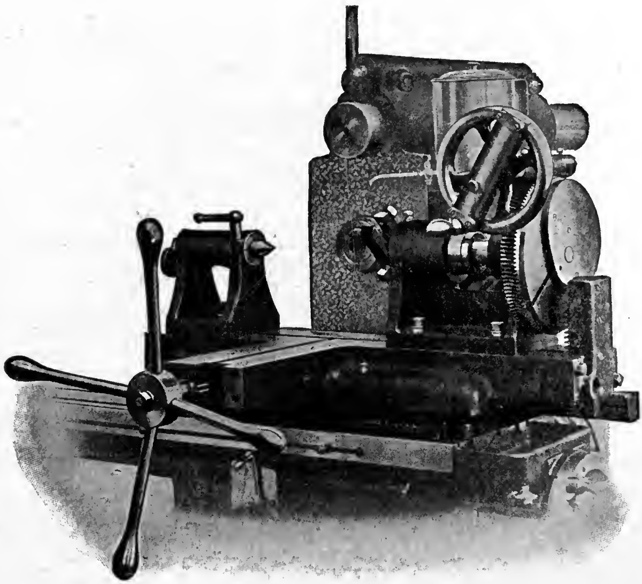


Fig. 241. Cam-Cutting Attachment for Milling Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

with their outlines coinciding, on the spindle of the cam-cutting attachment. A cam roll of the size to be used is mounted on a stationary roll stud; and an end mill of the same diameter, or enough larger for clearance, is mounted in the milling machine spindle directly opposite the cam roll. The spindle of the cam-cutting attachment is mounted on a carriage, which, by means of a weight over a pulley at the end of the milling machine table, is always kept with the leader in contact with the cam roll. A worm and worm gear are used for rotating the attachment, and thus the spindle approaches or recedes from the cam roll according to the shape of the leader. When cutting closed cams, it is sometimes desirable to use the hand-made male leader as a form from which to make a closed or female leader. This female leader will surround the cam roll in such a way

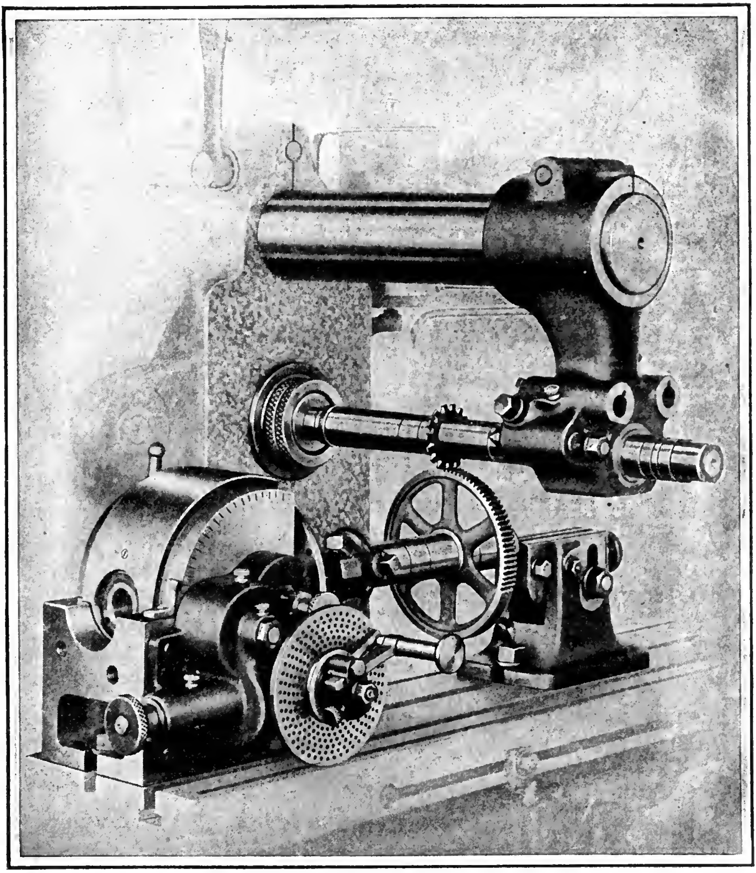


Fig. 242. Cutting Spur Gear on Milling Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

that, even if the weight should fail to act, no serious damage can be done to the blank. The cutting of face cams differs from the above method only in that the spindle of the attachment is at right angles to the spindle of the milling machine, instead of parallel to it. The leader and cam roll are used in the same manner as before.

Gears. The cutting of gears of all descriptions was formerly done on some type of milling machine, although now each type of gear may have its special and, in many cases, automatic machine.

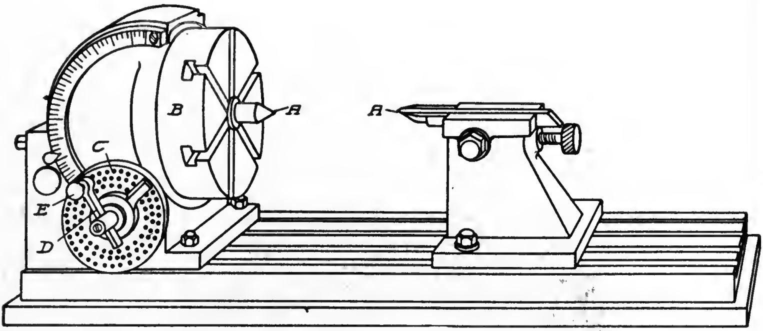


Fig. 243. Gear Cutter with Divided Head

Forms of Cutters. The cutters for milling spur and bevel gears are of two types, producing both the cycloidal and the involute tooth. For each pitch, the cycloidal system requires twenty-four cutters, while eight cutters usually suffice for the involute system. These cutters are plainly marked with the style of tooth, pitch, and number of teeth for which they are suitable. Some cutters are also marked with the full depth of the tooth expressed in thousandths of an inch, Fig. 279. The gear blanks, having been very carefully turned as to outside diameter, are mounted on an arbor between centers, and the cutter placed so that its central plane passes through, and is parallel to, the axis of the arbor. Clamp the saddle in this position; raise the table knee until the cutter, when rotating, just touches the outside of the blank. Using the table screw, move from under the cutter; using the graduated dial, raise the knee an amount equal to the whole depth of the gear tooth. With the exception of the indexing, the gear blank is now ready to be cut, Fig. 242.

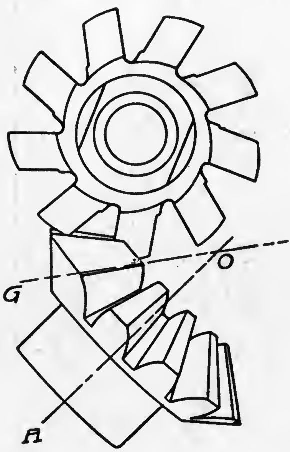


Fig. 244. Cutting a Bevel Gear

Use of Dividing Head. In order that the gear may be accurately and quickly set for cutting each tooth, a dividing head is used, which is shown in Fig. 243. The mandrel upon which the gear blank is mounted is held by the centers *AA*, and firmly dogged to the faceplate *B*. The index plate *C* is geared to the head spindle that carries

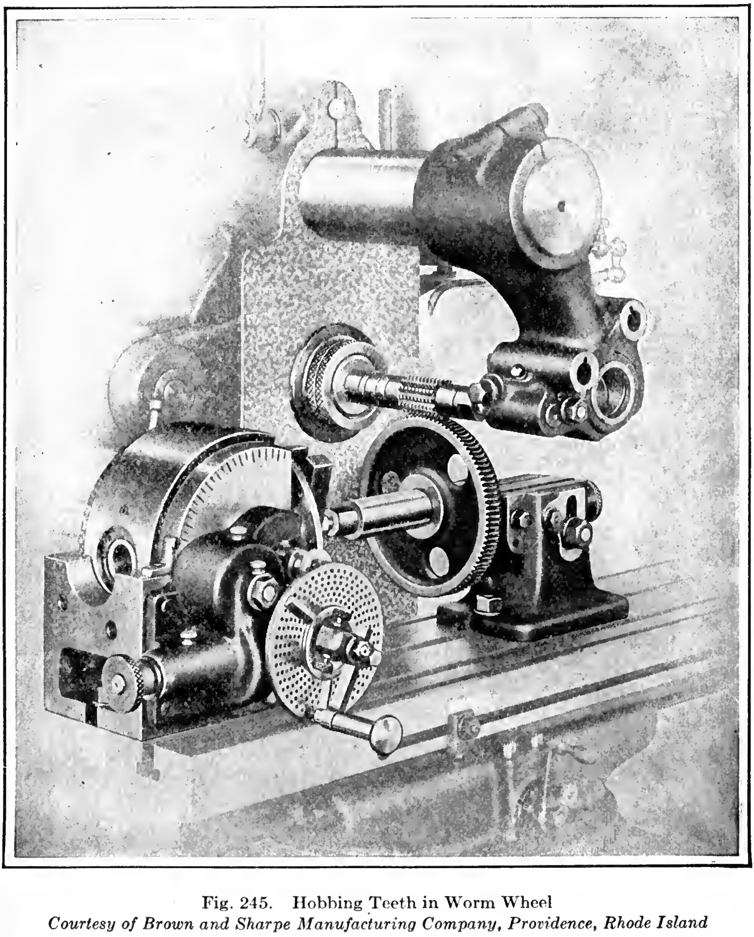


Fig. 245. Hobbing Teeth in Worm Wheel
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

the faceplate *B;* the index plate is provided with a number of holes. These holes are arranged in circles, each circle having a different number of holes, and these holes are accurately spaced at equal distances apart. The arm *D* carries a stem *E*, having a knurled head at one end and a pin at the other. The pin is held in one of the holes of the index plate by a spring. The arm D can be moved to any desired position relative to the index plate, and there fastened.

When a gear is to be cut, the arm D is shifted so that the pin is opposite a row of holes the number of which is the same as the number of teeth to be cut, or a multiple of that number. Thus,

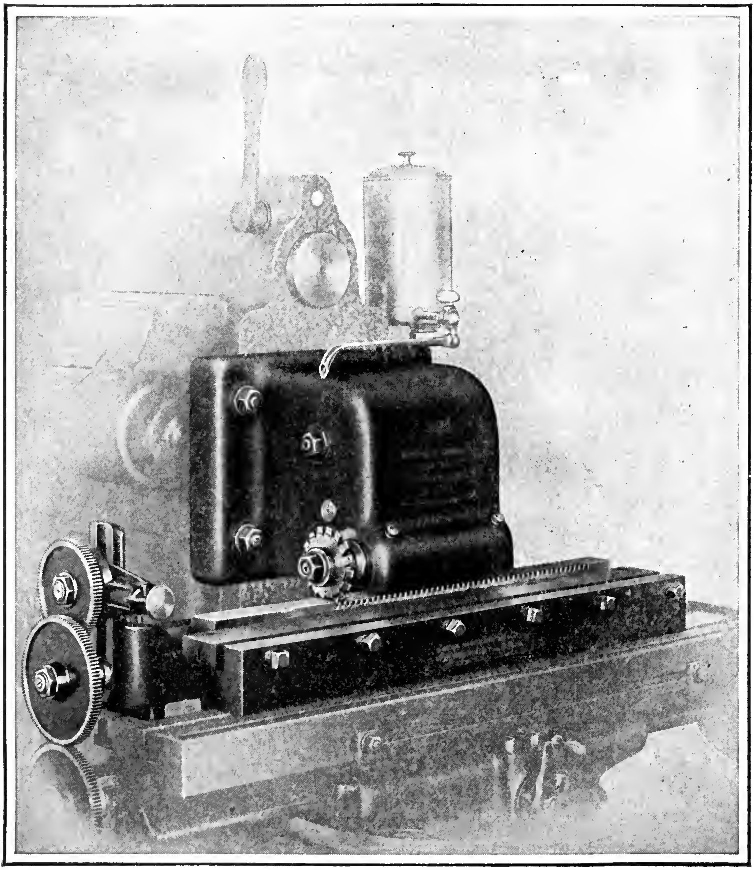


Fig. 246. Rack-Cutting Attachment on Milling Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

suppose a gear with 45 teeth is to be made. The pin may be set opposite the circle of 90 holes. Assuming that the ratio of revolution between D and B is 40 to 1; $\frac{1}{45}$ of a revolution at B requires $\frac{40}{45}$ of a revolution at D. The pin E must, therefore, be moved $\frac{40}{45}$ of 90 holes, or 80 holes, for each tooth cut.

Bevel Gears. Bevel gears are held on a taper-shank arbor in the dividing head, which is swung up to bring the bottom of the tooth parallel with the table, Fig. 244. As all parts of the tooth of a bevel gear are elements of a cone, it is evident that both the tooth and the space should vanish at the apex of the cone. No solid cutter, therefore, can do more than give an approximately correct shape to the tooth; for this reason two cuts are made in order more nearly to approach the desired contour.

Spiral Gears. Spiral gears are cut in the same manner as any other spiral—that is, by using the angular setting of the head or table with positive rotation of the work.

Worm Gears. Worm gears can be hobbed out by two different methods. A common method is to gash the blank with a stocking cutter; then mount it on an arbor held freely between centers, so that the hob, when sunk in the gashes, will rotate the blank. The blank is raised slowly against the rotating hob until the hob reaches the proper tooth depth. A more accurate method is by means of a train of gearing to rotate the blank positively at a speed corresponding to the pitch of the hob, and raise the rotating blank against the rotating hob until the proper tooth depth is obtained. This method requires no preliminary gashing, Fig. 245.

Rack Cutting. Rack cutting requires a special attachment, Fig. 246, so that the cutter spindle may be carried at right angles to the length of the table.

GRINDING MACHINE

Value of Grinding as Finishing Process. When greater accuracy than that obtainable on the milling machine or the lathe is required, recourse is had to grinding. This operation depends upon the abrasive or cutting qualities of emery, corundum, and carborundum. With work properly held to a solid grinding wheel, it is not difficult to attain great accuracy. By means of the grinding machine, parts may be economically finished, even in hardened steel that could not possibly be machined on such shop tools as the lathe, planer, or shaper. One type of machine used for this purpose is shown in Fig. 247. With such a machine, round surfaces may be ground so that the variation from the nominal diameter is less than .0001 inch.

Features of Grinding Process. The grinding machine illustrated in Fig. 247 consists of a strong base *A*, upon which there is mounted a headstock *B* and a tailstock *C*, similar in action to those of an ordinary lathe. Back of these is an emery wheel driven by a separate belt. The principle of operation for round surfaces, is that the part to be ground is put upon the centers, and driven exactly as in the ordinary lathe. The only additional precaution to be taken is that

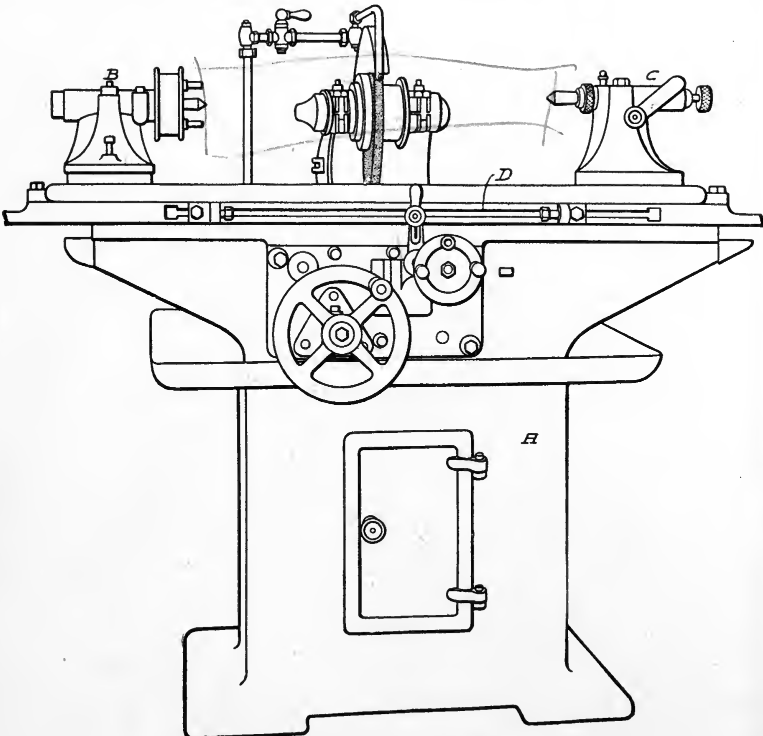


Fig. 247. Cylindrical-Grinding Machine

the driving apparatus should be secure, so that none of the parts are loose. This insures a continuous motion for the piece with no possibility of backlash. The piece runs toward the operator, and the emery wheel runs in the same direction. The two surfaces of wheel and work in contact are therefore moving in opposite directions.

The headstock and tailstock are mounted upon a traveling table *D*, which moves back and forth in the same manner as the platen of a planer. It is made to stop automatically at each end of the stroke.

When work is being done, the piece is centered, with its axis parallel to the line of travel of the table. With the piece and emery wheel in motion, the former travels to and fro in front of the wheel. The wheel is then gradually moved forward until it has ground the work down to the size required.

It is not intended that large amounts of metal shall be removed by this machine. Its object is to reduce to accurate dimensions the work that has already been turned in the lathe. The proper method to pursue is to turn the piece to as nearly the required diameter as possible in the lathe, care being taken that it is left a trifle large. This may be .01 inch on each 2 inches of diameter. The surplus metal may then be removed by grinding. In the machine illustrated in Fig. 247, the transverse movement of the wheel-stand is adjusted by a hand-wheel graduated to read to .001 inch on the diameter of the work. The machine is also provided with an automatic cross-feed, which gives a range of advance of the wheel varying from .00025 inch to .004 inch at each reversal of the table. This feed, furthermore, is so arranged that it can be automatically released at any point.

Finishing to Size after Casehardening. This method of finishing is also used for pieces that have been casehardened. Casehardening always warps the metal to which it is applied. Grinding is resorted to in order to reduce it to the proper shape. An example of this may be taken in the method used in the manufacturing of wrought-iron locomotive crank pins. The pin is forged and turned to as near the working size as possible. It is then casehardened and ground to exact alignment and dimensions.

Grinding is also used for truing work that comes from the lathe. The lathe does not turn its work round, owing to difference in the density of the metal, variation in the cutting speed, dulling of the tool, lost motion on the centers and in the spindle, and springing of the work itself due to pressure of the tool. The grinding machine remedies this to a great extent—partly because only a very slight pressure is brought against the work; partly because of the greater delicacy of adjustment of the grinding machine as compared with the lathe.

The method of grinding flat surfaces is practically similar to that used for round. The work is bolted to the table and moved to and fro beneath the emery wheel, which is given a transverse movement so as to cover the whole of the surface to be operated upon. The surface speed of the wheel may range from 4,500 to 6,000 feet per minute.

Action of Typical Grinder. Fig. 248 shows a typical surface-grinding machine built by the Brown and Sharpe Manufacturing Company, which is well adapted to the work of accurately grinding flat surfaces up to quite large dimensions. The work table travels

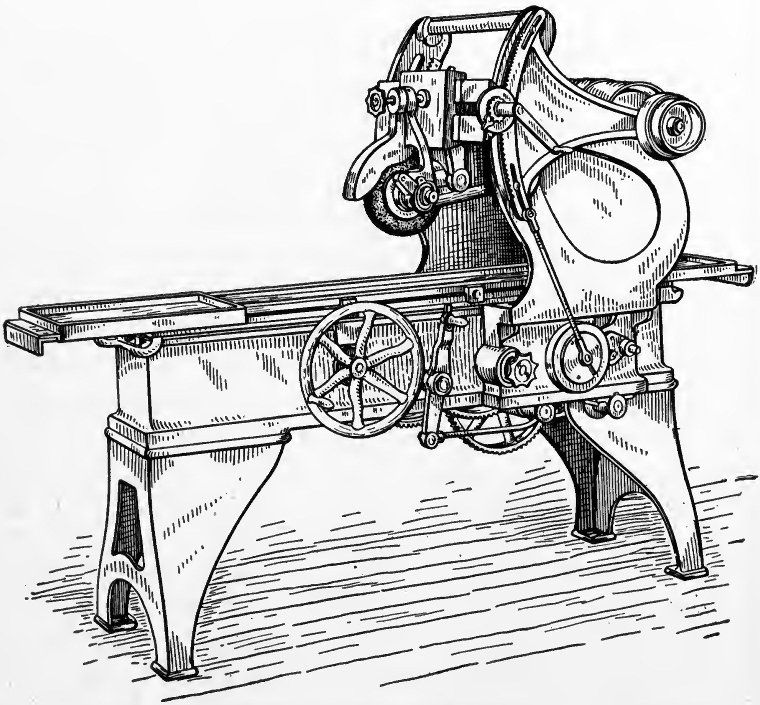


Fig. 248. Surface-Grinding Machine

to and fro in a manner similar to that of a planer, and carries adjustable reversing dogs which may be set to limit the extent or position of the travel. The grinding wheel mechanism is supported upon a cross-rail similar to that in a planer and capable of vertical adjustment on the arc of a circle whose center is the driving shaft supplying power to drive the grinding wheel. The wheel mechanism carrying the grinding wheel has a transverse, automatic feed the entire width of the work table.

In using this machine, the work is clamped directly to the table or held in any convenient fixture, as a milling machine or planer chuck or vise. In strapping work to the table, it must be rigidly held in place; but it is not necessary to clamp it down as tightly as on the milling machine or planer table, and great care should be used to avoid springing, warping, or other distortion, as grinding work is expected to be very true and accurate; in fact, this is its chief claim as a method of finishing surfaces.

To avoid distortion from overheating, comparatively thin wheels are generally used, particularly if the piece being ground is thin and light, as a thin casting of complicated form.

Selecting the Grinding Wheel. Grinding wheels are made with abrasives as coarse as No. 46, and as fine as No. 150. There is a great difference in the degree of hardness of a wheel due to the kind of bond, or adhesive material, with which the abrasive is mixed in forming the mass of which the wheel is composed. As to the fineness of the abrasive, that as coarse as No. 46 is suited for work on rough castings, as in the cleaning room of a foundry. For general work in shop grinding, the roughing-off will be best done with a wheel of about No. 60; and ordinary finishing, with about No. 90. For very fine finishing, the wheel may be much finer.

As to the degree of hardness of a wheel, it may be generally said that the harder the material to be ground the softer should be the wheel. There are several degrees of hardness made by the manufacturers, the simplest classification being Hard, Medium, and Soft, designated by the letters H, M, and S, respectively. All letters standing before M in the alphabet, refer to wheels harder than medium; and all letters after M refer to wheels softer than medium.

A coarse wheel grinds faster than a fine one, but leaves deep scratches in the work. A soft wheel may be made of a much finer grade than a hard one.

A soft wheel grinds faster than a hard one, but it is apt to glaze over, or fill up with particles, if used on a soft material.

Lubrication. To increase the cutting capacity of an abrasive wheel, to prevent it from glazing over, and to carry off the heat generated by the friction of the wheel on the work, a stream of water is frequently used, arrangements being made in most machines—particularly in those for grinding tools and for cylindrical grinding—

TABLE IX

Speed of Grinding Wheels

Diameter of Wheel (in.)	Maximum Revolutions per Minute	Diameter of Wheel (in.)	Maximum Revolutions per Minute	Diameter of Wheel (in.)	Maximum Revolutions per Minute
1	19,000	5	4,400	14	1,580
$1\frac{1}{2}$	12,500	6	3,700	16	1,380
2	19,000	7	3,160	18	1,230
$2\frac{1}{2}$	8,800	8	2,770	20	1,100
3	7,400	9	2,460	22	1,000
$3\frac{1}{2}$	6,300	10	2,210	24	920
4	5,500	12	1,850	26	850

for forcing the stream upon the wheel at the point of contact with the work by means of a small pump. For grinding milling cutters, reamers, taps, and similar tools, water is not used.

Table IX gives the maximum speeds of carborundum wheels of various diameters.

The accuracy of grinding renders the use of fine measuring tools a necessity. The micrometer caliper, especially with the vernier graduation, is best suited for this work.

While grinding is the only method of finishing some materials, such as hardened tool steel, and the most accurate way of finishing any kind of stock, its value as an economical method has only lately been recognized. The general method of finishing lathe work has been to take a roughing cut with about $\frac{1}{16}$ inch feed, then a finishing cut with about $\frac{1}{100}$ inch feed, and then file to remove the tool marks. In the majority of cases it is more economical, as well as more accurate, to take a roughing cut with $\frac{1}{6}$ inch feed to within $\frac{1}{32}$ inch of the size, and then finish by grinding.

In some cases it is possible to get excellent results by grinding to size directly from the bar without previous turning. (See Part V.)

Lapping. *Lapping Holes.* Lapping is a term applied to a particular method employed in the grinding out of holes. The lap consists of a cylinder of soft metal run rapidly inside the hole to be lapped, and covered with emery and oil at the same time. The surface of the lap should invariably be of soft metal. It may be made of copper, or it may be an iron bar with a covering of lead or tin. It should be turned slightly tapering at each end, so that it will enter the hole. At the middle, it should be a snug fit.

The end of the bar is run through the hole and set on the lathe centers with a dog to drive it like an ordinary mandrel. It is covered with oil and sprinkled with emery. The lathe is then run at a high speed, and the work moved to and fro over the lap. Light pieces may be held in the hand. When this is done, care should be taken to turn the piece so that the grinding may be even over the whole circumference. The tendency, when holding work in the hand, is to allow it to rest upon the top of the lap; this causes the grinding to be done on one side of the hole unless the piece is frequently turned. Laps may be used for grinding holes true and parallel. For this purpose the work should be accurately centered with the lap, and firmly bolted to the lathe carriage. The lap is then run at a high speed, and the work moved to and fro over it.

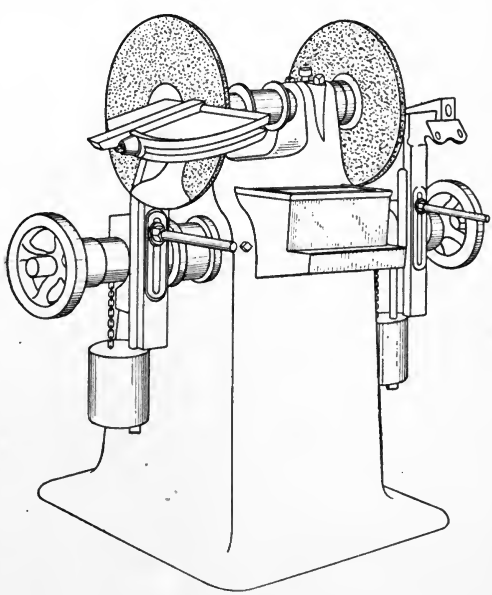


Fig. 249. Disc Grinder

Lapping Flat Surfaces. Laps are sometimes used for grinding flat surfaces. In such cases they are in the form of discs. They are put on the lathe spindle in the place of the faceplate. The work is then pressed against the disc. As the outer edge of the disc has a higher speed in feet traveled per minute than those portions nearer the center, the grinding is more rapid at the edges. The work must, therefore, be constantly turned if it is held in the hand. The best way is to clamp it firmly on the lathe carriage, and press it against the lap by means of the hand feed.

Disc Grinder for Flat Top Work. Laps for flat surfaces have grown in favor so rapidly that special machines called disc grinders have been made to do this work. The construction of the disc grinder can be so readily seen from the illustration, Fig. 249, that a detailed description is not necessary. For finishing small flat surfaces, especially those which have been hardened, this machine has become an important factor in the modern shop.

This machine is arranged for using ordinary emery wheels; and the grinding is done on the side of the wheel, instead of on its periphery; hence its name. The table rest upon which the work is held is normally horizontal, but is adapted to be set at any required angle when the work is of such a form as to require this adjustment.

The usual difficulty experienced in this method of using an emery wheel is the liability of the disc to glaze over, and, as a result, require frequent turning off to present a good cutting surface. Many attempts were made to replace the solid emery wheel with a cast-iron disc covered with emery cloth; but the same difficulty was found in its use. The experiment was tried, of cutting slight grooves in various directions, generally concentric or radial, in the face of the cast-iron disc. Its usefulness was improved; but the problem was not solved until a single spiral groove was cut, starting near the center and running gradually outward. By this means the tendency to glaze is broken up in a continually progressive manner that effectually prevents this trouble.

Machines similar to the one shown in Fig. 249 are built with double heads so that two discs are placed facing each other, one of them being capable of adjustment so that flat pieces of work can be ground on both sides simultaneously. Machines of this kind are adapted to a considerable range of very useful work.

LAYING OUT WORK

Laying out work is one of the most important details of machine shop practice. Ordinarily all work is laid out. The exceptions are where certain pieces are worked from templets, and in these cases the templet is laid out from certain points on the casting, forging, punching, or whatever is used for the work in hand.

Centering Round Bars. The simplest form of laying out work is to be found in the centering of round bars that are to be turned in the lathe. In this case the end of the piece is chalked. Use a pair of hermaphrodite calipers; set the points *A* and *B* so that their distance apart is a little more than the radius of the piece. Place the caliper leg at three points on the circumference, *A*, *B*, and *C*,

Fig. 250; and describe from each the arcs of circles $A' A'$, $B' B'$, and $C' C'$, respectively. Then, with the prickpunch, mark the point indicated by the small circle in the center. This will be the center. To test its accuracy, place the divider leg in the prickpunch mark, and see if the caliper leg will just touch the bar over its whole surface.

Before drilling, the center should be emphasized with a center punch.

The center square may be used for the operation of locating centers in round stock, as the center can be easily located at the intersection of two diameters drawn nearly at right angles. In some cases it is better to lay the shaft in V-blocks on a plate and use the surface gage, drawing at least two lines through the center of the piece.

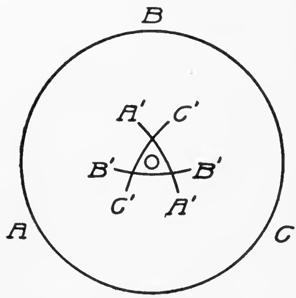


Fig. 250. Centering Round Bar to be Turned in Lathe

It is often necessary to cover the surface of the work where lines must be visible, with chalk, white lead, or copperas, before any laying out can be done; but in cases of this kind it is usual to mark directly upon the end of the bar. Before drilling, the center should be emphasized with a center punch.

The locations for holes should be at the intersection of lines in order to be plain. After marking the center with a prickpunch, take a pair of dividers and describe a circle on the prepared surface concentric with the center already located. This circle should be about the diameter of the hole to be drilled; and in many good shops, it is the custom to draw another circle concentric with the first and about $\frac{1}{16}$ inch larger in diameter. This outer circle is called the reference circle, and is for the benefit of the inspector when it becomes necessary to place the responsibility for a misplaced hole. These circles may be marked with at least four prickpunch marks, as shown in Fig. 178, Part II, in order to indicate the position of the circle in case of the obliteration of the line. The center is then deepened by the center punch, and the hole drilled. In laying out centers upon rough castings, the first thing to do is to snag the work—that is, remove the ridges of the casting caused by the pattern being made in two or more parts. For small castings a coarse file is generally used, while for large work the cold chisel is used. In many shops the cold chisel is operated by compressed air.

Layout for Planer and Milling Machine. In laying out the work for the planer and milling machine, great care must be exercised. It is necessary that there should be a base line to which the lines may be referred. It depends on the character of the work as to how this should be done.

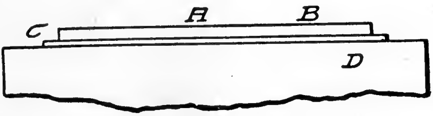


Fig. 251. Laying Out Valve Seats

Sometimes it is quite sufficient to lay off the base line parallel to one side of the casting or forging. If the side thus used is to be finished, then the base line should be located at the proper distance from it to allow for the finishing. The amount required varies with the character of the casting or forging; this has been fully explained. Usually there is some outline of the rough piece that will serve as a guide.

As an example of the laying-out of work, take the valve and steam-chest seats shown in Figs. 251 and 252. The work is to be machined on a planer. The cylinder has probably been bored. It is then placed on the planer, and so set that the center line through the cylinder is parallel to the platen of the planer. The first machine work to be done is the taking-off of the roughing cut from the face *A*. This face is to be planed down to a certain height above the cylinder center; this height may be marked on the edge of the valve-seat by the prickpunch mark *B*. If the surface *C* is to be planed at the same time, its height is indicated by the prickpunch mark *D*. These points may be located by means of the surface gage. Set the

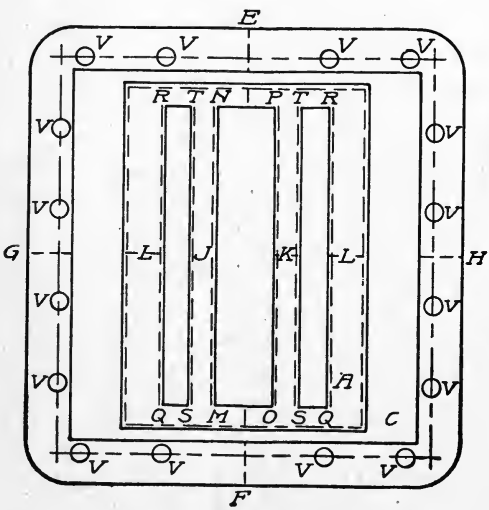


Fig. 252. Layout of Steam Ports

gage on the platen, and elevate the point to the proper height. Move it so that it will touch the side of the casting at the proper point, and make the marks *B* and *D* accordingly. When the surfaces *A* and *C* have received the roughing cut, the plan may be laid off as in Fig. 252. With a square having a suitable length of blade, locate the points *G* and *H* directly over the center of the cylinder. Cover the surfaces *A* and *C* with chalk where lines are to be drawn. Draw the lines *I*, *J*, *K*, and *L* on the surface *A*, between *G* and *H*. Through the center of the side of the exhaust port, draw the lines *E* and *F* at right angles to *GH*. This is done with a scriber. Lay off half the width of the exhaust port on either side of *E* and *F*, and draw the lines *MN* and *OP* parallel to *E* and *F*. In like manner, draw the lines *QR* and *ST* for the limits of the steam ports. All of these lines are to be emphasized by the use of prickpunch marks as indicated.

If the sides of the valve-seat are to be finished, the line to which the metal is to be cut is indicated in the same manner. Finally, the holes *VVV*, etc., for the holding-down studs of the steam chest, are to be laid out. The center lines are first drawn; then the centers of the holes are marked, after which the circles for the holes are drawn as already described.

Layout for Lathe. Work is rarely laid out for the lathe. It is not necessary that it should always be done for the planer. Laying out is employed where accuracy is essential, and where it is possible to secure the proper dimensions, with the piece to be operated upon in position on the machine.

The man who has charge of the work of laying out should have some knowledge of the elementary principles of geometry; he should also have some knowledge of drawing, and should, of course, be able to read drawings.

General Suggestions. A few general suggestions may be given regarding work to be finished in the vise on either the planer, shaper, or milling machine, where several faces are to be finished at right angles to one another. Referring to the rectangular block of Fig. 253, the block is first placed in the vise with the face *MNOP* down, and the face *MADP* against the fixed jaw. The face *ABCD* is then machined, and the work turned so that *ABCD* is against the fixed jaw, and *MADP* down. With the block in this position, *NBCO* is worked, making *NBCO* at right angles to *ABCD*. With *ABCD* still against the fixed jaw, and *NBCO* down, surface *MADP* is next worked. This brings two edges at right angles to the same side and parallel to each other. Then, placing *ABCD* down and either *MADP* or *NBCO* against the fixed jaw, surface *MNOP* is generated parallel to *ABCD*. This leaves the ends to be finished. The vise is swung so that the fixed jaw is at right angles to the line of motion of the tool; and on the planer and shaper they are finished by using the vertical feed. In the two last-named tools, the tool holder is swung so that the tool will clear the work easily on the return stroke.

In working cast iron it is well to chamfer the edges with a file. If this is not done, the metal will break off when the tool reaches the end of the cut, leaving a ragged edge. The depth of the chamfer depends on the amount of metal to be removed.

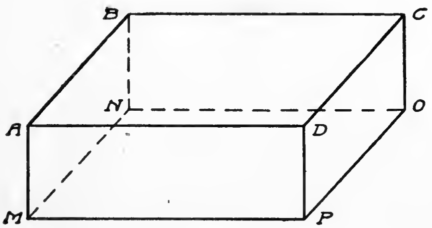


Fig. 253. Block to be Finished

Fitting. Fitting is the term generally applied to the hand work necessary in assembling machinery after all the machine work has been done. Filing, either in the vise or lathe, and scraping, are the operations usually required, although the hammer and chisel are sometimes used. As hand work costs much more than machine work, the machining is done as closely as possible to make the hand work a very small item.

SHOP SUGGESTIONS

In the regular work of any shop, occasions are constantly arising for the determination of the best method of doing work. The success with which the desired end is attained depends upon the skill and judgment of the man in charge. While it is impossible in a limited space to give instructions regarding every possible emergency that may arise, a few suggestions regarding shop practice will be valuable.

Peening. Peening consists in stretching the metal on one side of a piece of work in order to alter its shape. There is a wide difference between peening and bending. For example, suppose the curved or warped piece in Fig. 254 is to be straightened. If it were to be bent until it were straight, it would be placed on the block *A* with the concave surface down, as shown by the dotted lines. It could then be struck by the hammer and driven down past the line of support, and strained so that it would remain approximately straight. Such a method of straightening could not be applied to a piece of complicated outlines. It would remain wavy. In peening to trueness such a piece as shown in Fig. 254, it is laid on an anvil with the convex surface down. It is then struck with the peen of the hammer on the concave side. The blow must be quick and sharp. The result is that the metal is stretched at the point where the blow is struck. By working successively over the whole surface, the concave side is stretched so that it is equal, in its dimensions, to the convex side. The piece then becomes straight, and will so remain. A skilful use of the hammer will straighten almost any piece of thin metal.

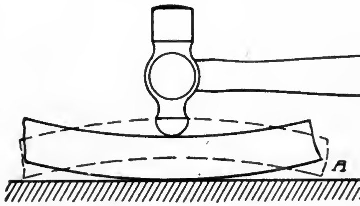


Fig. 254. Peening

Drilling Hard Metals. It is sometimes desirable to drill a hole in very hard metal. To do this the drill must be made very hard; it must be run at a very slow speed; it must be forced against the work as hard as possible without breaking the point; and it must be provided with an abundant supply of oil. For excessive hardening of a drill, it may be heated to a dull red heat, preferably in a charcoal fire, and quenched in mercury instead of water, in order to make the cooling more rapid. It will also assist in the operation, if the surface of the metal to be drilled is nicked with a cold chisel before work is begun. In some cases turpentine, in place of oil, may be used with beneficial results.

Thin chilled cast iron may be softened by placing a small piece of sulphur on the place where a hole is desired, and then heating slowly to a dull red.

Glass may also be drilled. There are two methods: one is to use a flat drill moistened with camphor and turpentine; and the other is to use a copper tube with No. 60 emery or carborundum and oil. In the last method, drill half-way through, reverse, and drill to meet, removing the fin at the center with a round file wet with water or turpentine.

Grinding Valves. This is a kind of grinding that is usually done by hand. It consists in fitting a valve and its seat so that they are in metallic contact. In its results, it is the same as scraping. The process is very simple. The valve is coated with oil, and some fine emery sprinkled over it. It is then put on the seat and worked back and forth or revolved. The emery serves to grind off the high surfaces of both valve and seat. After grinding for a time, remove the valve, and wipe both surfaces clean. The metal on each will show where they have been in contact. When these indications appear over the whole of the surface, or in a continuous ring about the seat of a circular valve, the work is completed.

Generating Surface Plates. In this operation it is necessary to work with three at the same time. For the sake of making the explanation clear, they will be called *A*, *B*, and *C*. After the plates have been planed, a straightedge should be laid on each. A straightedge is merely a piece of flat steel having one or more edges true and straight. Set the straightedge on the plates in all directions. If it touches over its whole length in all positions, then the plates are ready for scraping. If it touches at the edges of the plate and is clear in the center, the former are high and should be filed down. If it touches in the center and rocks to and fro, the plate is convex and the center must be filed down. After the plates have been filed to trueness as far as trueness can be indicated by the straightedge, they are ready for scraping.

Now take plates *A* and *B* and place them face to face. Strike a blow on the upp r one, and it will cause a jarring sound to be heard. This shows that the two are not in perfect contact. Smear the surface of plate *A* with a thin mixture of red lead and oil. Cover the surface evenly and thinly. Then rub the two plates together, and where the red lead comes off onto the surface of plate *B*, the two come in contact. Take the scraper and scrape off a little of the metal from each of the plates where they have been in contact. Wipe off plate *B*; and again smearing plate *A*, proceed as before. Continue this process until the two surfaces are in contact over their whole areas. This does not prove, however, that they are flat. They may be in contact, as required, if *A* is convex and *B* is concave. To test this, the third plate is necessary. Smear plate *B* with red lead, and scrape *C* to fit it. Do not touch *A*. It is evident that *A* and *C* will then be alike. Bring them together. If they are both convex they will roll over each other. If they are concave they will bear at their edges, and not touch in the center. They will appear to be out of true by twice the actual amount. Scrape off the contact points of *A* and *C*. Remove as nearly as possible the same amount of metal from each. When these two plates have been brought so as to be in contact over their whole areas, lay plate aside, and scrape *B* until it fits *C*, but do not touch *A*. Try *A* and *B* together. If they do not touch over their whole areas, treat them as before described for *A* and *C*. Then introduce *C* again. Continue this alternating process until each of the three plates forms a bearing over the whole of the surface of each of the other two.

During the latter part of the process, use alcohol instead of red lead. This will leave clean, bright spots at the points of contact.

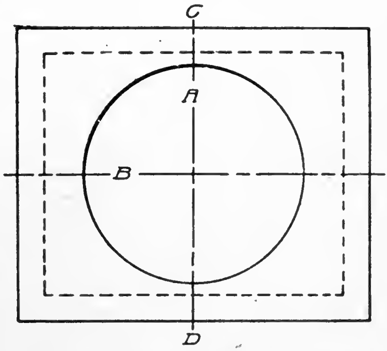


Fig. 255. Connecting-Rod Brasses

Fitting Brasses. This is a piece of work now usually done on a machine, but sometimes done by hand. Brasses which are to be used for connecting rods, and which are made in two pieces, as shown in Fig. 255, have a tendency to warp after the machine work has been done on them. The difficulty arises from their closing along the diameter *A*. Thus, if the brass is finished, and the hole bored out to the proper diameter, and is then cut apart on the line *CD*, it will be found, shortly afterward, that the diameter *A* is less than the diameter *B*. It may therefore be necessary to bore the hole somewhat larger than the working diameter. The kerf made by the saw will usually allow the parts to be drawn together along the diameter *B*, so that it will more than make up the shrinkage at *A*. The hole can then be scraped to fit the pin. The brasses should always be keyed solidly, metal to metal. This avoids a wear of the sides and edges of the metal, due to the thrust of the rod.

Joints. Where a gas or liquid is to be retained in a pipe or other vessel without leakage, a tight joint is necessary. The method of grinding valves to their seats has already been explained. In that case, it was shown that a metallic contact between the valve and its seat is all that is required in order to make it a tight joint. Two surfaces that have been scraped to fit will also accomplish the same purpose. This is frequently too expensive an operation to be performed, especially on rough work. In such places a softer material may be interposed between the two surfaces. Where the joint is to be a permanent one and is not to be taken down, the red lead joint is usually employed. This consists in the use of a mixture of red and white lead between the joints. To ordinary white lead ground in oil, add enough dry red lead to make a paste that can be spread without sticking to the blade with which it is applied. After the mixture has been made, it will be improved by pounding it well with the hammer. It may then be laid between the two pieces of metal forming the sides of the joint, and the latter be drawn together. Red lead joints are extensively used in pipe-fitting. The red lead has a tendency to rust the iron with which it is in contact, and thus forms a very tight connection between the two pieces. Where provision is to be made for taking down the joint at a future time, it is better to use a graphite paste made for the purpose. This does not rust the metal and it forms a perfectly tight joint, which may be taken down without difficulty at any time.

Joints that are subject to occasional disconnecting can be best held by a disc of rubber packing. The latter is cut to fit the flanges between which the joint is to be made, and they are then drawn tightly together.

Joints that are to be frequently taken down are usually packed with a piece of copper wire. Such a place is the joint between the steam chest and cylinder of a locomotive engine. A groove is cut in the two surfaces, and a copper wire is laid therein. This wire should be about $\frac{1}{4}$ inch in diameter. Its size, however, depends upon the joint to be packed. The ends of the wire are soldered together so that no leakage may occur past the ends.

Another form of joint is the rust joint. This is always permanent in character. The making of such a joint consists in rusting the two surfaces together. The following are the proportions by weight of the rusting material: 100 parts of iron turnings, 1 part of sal ammoniac, and $\frac{1}{2}$ part of sulphur. The setting of the joint can be hastened by increasing the amount of sal ammoniac from 15 to

25 per cent. Mix the ingredients thoroughly, and just cover them with water.

Fluting Rollers. Where feed rollers such as those used in woodworking machinery are to be turned and fluted, the turning should always be done first. This insures a continuous surface for the cutting tool. Where old rollers are to be re-turned and fluted, the same rule applies. The fluted surface may be turned to size. The lathe tool will break the edge of the ribs away; but when the fluting is done, these edges are again made smooth. The fluting can be done on a planer, with a round-nosed tool. The roller should be held on centers and clamped so that each groove may be presented to the tool in succession. A planer center, as illustrated in Fig. 190, Part II, affords a convenient method of holding and turning the work.

Scale. Whenever a piece of cast iron is to be turned, the point of the tool should always be made to work beneath the scale. The scale is the hard outer shell that covers all cast iron as it comes from the foundry. It is very hard and brittle. If the edge of the tool is made to work in or against it, that edge will soon be dulled. If it is beneath it, the raising of the chip cracks and removes the scale.

Pickling. Where castings are to be worked, either in the lathe or planer, to dimensions only a little less than those when rough, they should be pickled. This consists in washing them with a solution of sulphuric acid and water. The castings may be either submerged in or swabbed with the solution. The effect of pickling is to cause the scale to drop off in flakes, leaving the metal bare, unprotected, and rusty. The casting should then be washed with a sal soda solution. A good pickling solution for this work is to use 1 part of commercial sulphuric acid in 10 parts of water.

Cold Chisels. It is well to use a coarser grade of steel for cold chisels than for lathe or planer tools. A coarse-grained metal is preferable because the continual hammering in use and redressing will gradually modify the granular structure until it is microscopic in texture. In dressing, it should never be heated above a cherry red, and the temper should be drawn well down so that the soft metal backs up the edge. A capacity to receive a multitude of grindings is not what is wanted. The tool must be able to endure the severe service for which it is intended. It must cut into a distorted mass of metal, where every blow gives it a shock tending to form a new arrangement of its particles. It never receives the steady pressure of the lathe tool; hence its powers of endurance must be greater.

Lining Shafting. In equipping a shop, the first work of the machinist is the erection of the shafting. The main line should be the first laid out; and the engine, together with the jack and counter-shafting, must be located from it. After placing the hangers as nearly as possible in a horizontal line, the shafting should be placed in the boxes and attached to the hangers. For lining the shaft, a level and a fine grass or silk line are indispensable. The line is tightly drawn, horizontally, a short distance from the position the shaft is intended to occupy, and the distance from the surface of the shaft to the line is measured and made equal near each hanger by a stick such as shown in Fig. 256.

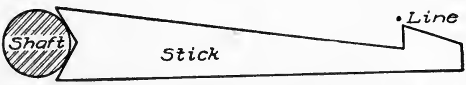


Fig. 256. Gage for Parallel Lining of Shafting

The level is used to make the shaft horizontal; and, if the hangers are adjustable in two planes, the operation is quite rapid.

When other shafting is to be erected parallel to the first, if the distance does not exceed twelve or fifteen feet, a long stick may be used by driving a nail into the end of the stick to allow some adjustment. The level is used as before.

When the distance is great, or obstacles prevent the use of the stick as suggested, a line may be drawn on the floor of the shop by dropping a plumb line from near the ends of the first shaft and connecting the points located. Another line, directly under the desired location, may be drawn by direct measurement, and the second shaft erected by dropping a plumb line to this second floor line near the ends of the second shaft. This method may be employed, with such variations as the case may demand, even though a floor or wall be between the locations.

In leveling up long lines, or around machines, or through walls, the hydrostatic level is a most convenient tool. It consists of two graduated glass tubes set in suitable bases and connected by a rubber tube. When the rubber tube is filled with water, and the glass tubes placed vertically on the shaft, the fluid should stand at the same graduation in each glass. These levels are made with self-acting valves to prevent the escape of the fluid.

When pulleys or hangers make the direct application of a level to the shaft impracticable, leveling hooks, in connection with a wooden straightedge, as shown in Fig. 257, are very convenient. These may be made of wood or metal, and of lengths suitable to the case in hand.

Machine Setting. After the shafting is erected, comes the setting of machines. The countershafts are first erected parallel to the main line, and with due regard to the location of the machine. The machine is then placed, with its driving shaft parallel to the counter, by use of the plumb line; and the platen, table, or other horizontal surface carefully leveled, in two planes, by wedging up

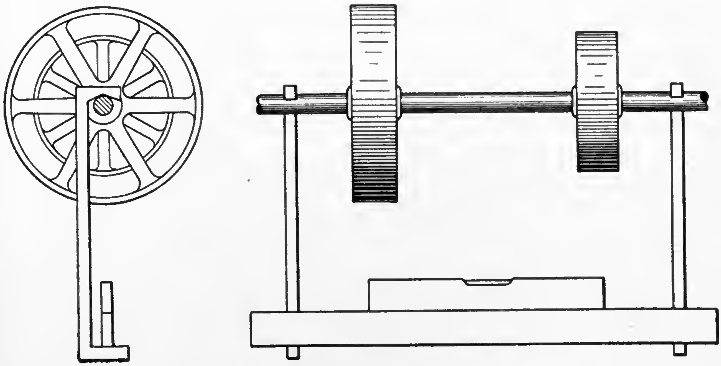


Fig. 257. Method of Using Level for Lining Shafting

the machine with common shingles. The machine is then secured to the floor by lag screws.

When the machines are very heavy, and stone or masonry foundations are necessary, anchor bolts are built into the foundation at suitable points, or holes drilled for expansion bolts. The machine is then lined and leveled as already suggested. The bottom of the machine, however, is usually a rough casting; the top of the stone foundation is still rougher; and, as the wedges are likely to slip out under the jarring of the machine, a permanent support must be provided. This may be done by pouring melted sulphur beneath the bed. To do this, build a dam of clay or sand all around the bed and about 2 inches high. Melt ordinary stick sulphur or brimstone in ladles, and pour in at several points at once. Keep the space flooded until the dam is well filled, and allow it to harden. This will occur very quickly, after which the dam may be removed and the sulphur cut away from the edge of the machine. Care must be taken that the temperature of the sulphur is as high as possible before pouring. Unless this is done, it will cool and set before reaching the inmost recesses beneath the machine. It will then crumble because of insufficient bearing surface to carry the imposed weight. The sulphur having been properly placed and having set, the nuts are then screwed down on the bolts, and the machine is secure.

Belting. The shafting and machines are usually driven by belting. Leather is the material generally used, and the belting may be from single to six-ply in any suitable width. Single belting has a flesh and a grain or hair side, and should be run with the grain side in contact with the pulley. The ends are cut square, and fastened by hooks, coiled wire, or rawhide lacing.

Leather belting is injured by water, steam, oil, and temperature above 110° F. Where such conditions exist, cotton belts faced with thin leather, or rubber belts, may be used. These belts are cheaper than leather, are about as strong, and will transmit power as effectively; but they will not stand mutilation of the edges. This is a point of prime importance, and prohibits their use in many cases.

The power transmitted by a belt is directly proportional to its speed and width. A safe rule is to allow one horsepower for a speed of 1,000 feet per minute, with a single thick belt one inch wide. This is a more liberal allowance in favor of the belt than is usually given, but will increase the life of the belt in far greater proportion than the increase in first cost. Double belts will transmit about one and one-half times as much power as single belts. The above rule applies to belts running over pulleys of equal diameter, or, in other words, to cases where the arc of contact is 180 degrees. For smaller arcs of contact, use the coefficients found in the following tabulation:

Degrees:	90	100	110	120	130	140	150	160	170	180	200
Coefficient:	.65	.70	.75	.79	.83	.87	.91	.94	.97	1.	1.05

To increase the power transmitted, either increase the speed of the belt by using larger pulleys, or use a wider belt.

Example. A 3-inch single belt is running over a 24-inch driving pulley which makes 200 r.p.m. (revolutions per minute). How many h-p. will it transmit?

Solution. The circumference of the pulley in feet is $2 \times 3.1416 = 6.2832$ feet. As the speed of the pulley is 200 r.p m., the speed of the belt will be $200 \times 6.2832 = 1{,}256.64$ feet per minute. For every inch of width, it will transmit $1{,}256.64 \div 1{,}000 = 1.25664$ h-p. Then a 3-inch belt will transmit $3 \times 1.25664 = 3.76992$ h-p.

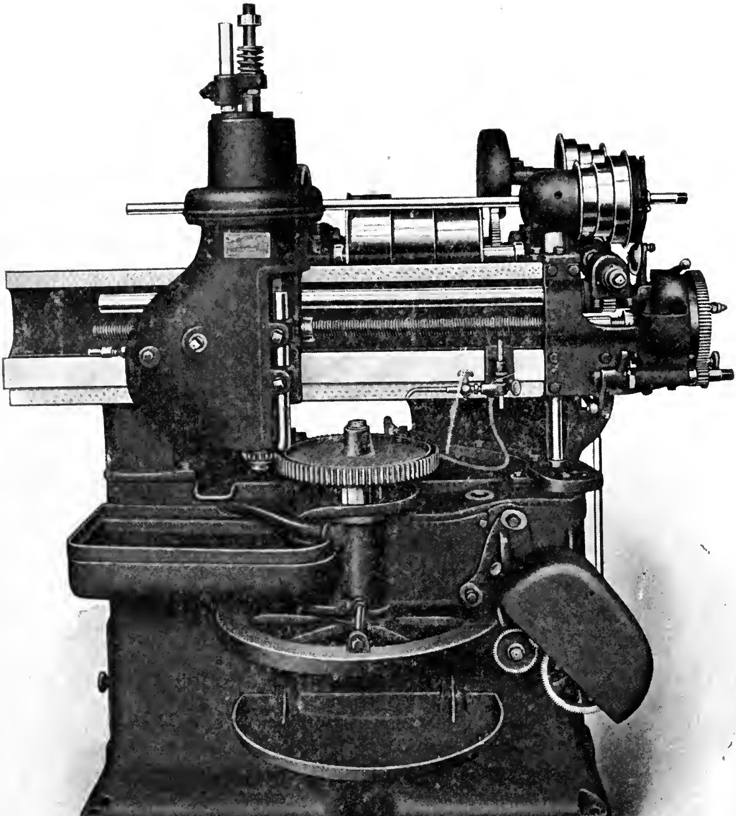
Ans. 3.75 h-p. (approximately)

Example. It is desired to increase the h-p. in the above example to 5 h-p. How may it be done?

Solution. (a) By using a wider belt in the proportion of 3.75 to 5. 3.75 : 5 : : 3 : 4. Ans. By using a 4-inch belt

(b) By using a larger pulley in the same proportion. 3.75 : 5 : : 24 : 32. Ans. By using a 32-inch pulley

(c) By using a double belt. 1 : 1.5 : : 3.75 : 5.63. This would give a little better result than required.



FELLOWS GEAR SHAPER CUTTING SPUR GEAR
Courtesy of Fellows Gear Shaper Company, Springfield, Vermont

MACHINE SHOP WORK

PART IV

GEAR CUTTING

Theory of Toothed Gearing. The fundamental principle of toothed gearing is that of two cylinders or portions of cones with their surfaces in contact, and rolling together in opposite directions.

The first condition, that of cylinders, is shown in Fig. 258, representing the two cylinders *A* and *B*, the axes of both being in the same plane and parallel, and the periphery of the cylinders in contact. It is evident that if the cylinder *A* be rotated in the direction of the arrow, the frictional contact will cause the cylinder *B* to rotate in the opposite direction.

The second condition, that of cones, is shown in Fig. 259, representing the two cones *A* and *B*, the axes of both being in the same plane, but at right angles to each other, and the outer surfaces of the cones in contact. The action is the same as that of Fig. 258.

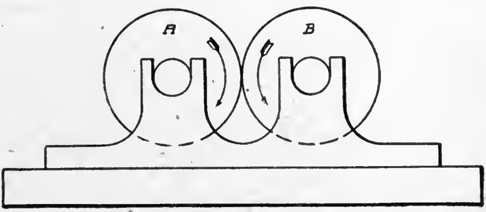


Fig. 258. Two Cylinders in Contact

It will also be evident that if the cylinders in Fig. 258 are of equal diameters, and consequently of equal circumferences, the rotation of *A* through a complete revolution will produce a complete revolution of *B*. If *A* is one-half the diameter of *B*, the latter will make but half a revolution to one complete revolution of *A*; while, if the cylinder *B* is one-half the diameter of *A*, it will make two complete revolutions to one of the cylinder *A*.

This proposition provides for no slipping of the cylinders on each other. For the purpose of transmitting power, the faces of these cylinders are provided with teeth, which are cut parallel to the axes of the cylinder; the teeth of each cylinder interlock with those of the other and effectually prevent any slipping. By this means we produce a pair of spur gears. In the case of the two cones, or a suitable portion of them, if the teeth are formed radiating from the apex of the cone, they become a pair of bevel gears.

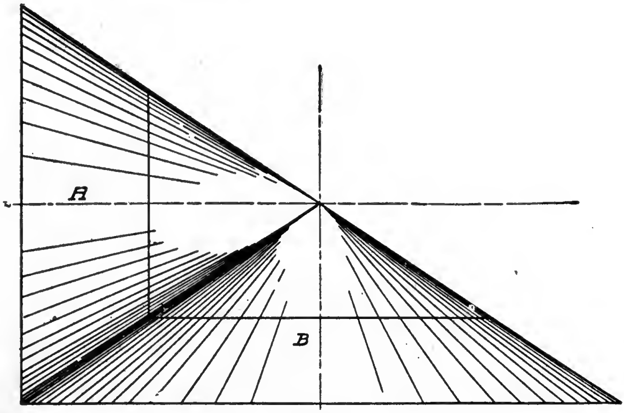


Fig. 259. Two Cones in Contact

The simplest form and the one in most common use, is the spur gear. All other forms are but modifications of it in one way or another, the general principle and the principle upon which the teeth are formed being practically the same in every form of gear in use.

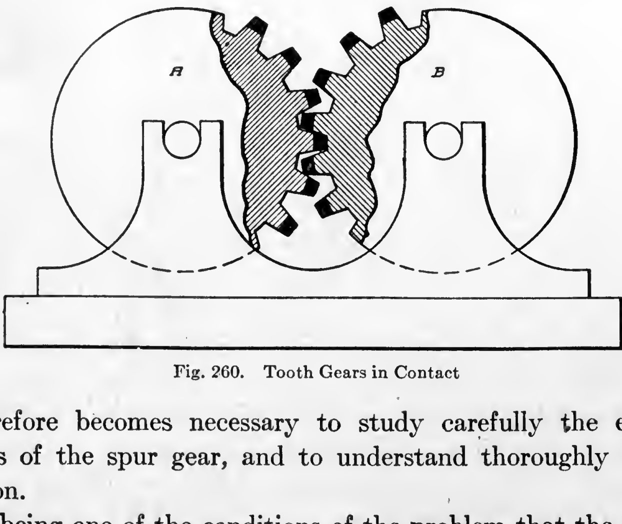


Fig. 260. Tooth Gears in Contact

It therefore becomes necessary to study carefully the essential features of the spur gear, and to understand thoroughly its construction.

It being one of the conditions of the problem that the surfaces of the cylinders shall remain in contact, as shown in Fig. 258, teeth must not be formed in their surfaces by cutting grooves in them, for the reason that, to cause the teeth to interlock, it would be necessary to move their axes closer together, thus overlapping the original surfaces. Teeth cannot be added to the cylinders as this would necessitate moving the cylinders farther apart, thus separating the contact surfaces.

This being the case, the teeth must be formed by a combination of both the above methods, cutting the grooves one-half the depth of the proposed teeth, and adding between the spaces thus formed an equal amount to complete the partially formed teeth. They will then

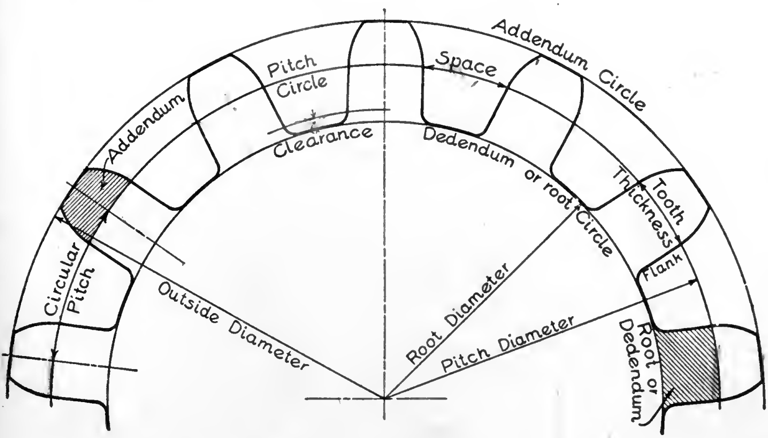


Fig. 261. Names of Tooth Parts

present the forms shown in Fig. 260, the added portions being distinguished by being drawn solid instead of being sectioned. They are called the *addendum*.

The teeth now interlock properly by falling into the spaces, the original surfaces of the cylinders remaining on the contact line; and the diameters of these cylinders still give the base circles for all calculations as to speed, numbers, and dimensions of teeth and similar purposes. These circles are called the *pitch circles*. When a pair of gears vary in diameter by a ratio of 1 to 3, or more, the larger is called the wheel, and the smaller the pinion.

Names of the Tooth Parts. The names of the tooth parts are given in the diagram, Fig. 261, in order that the student may become perfectly familiar with the technical terms used in describing or referring to the teeth of gears, and the methods of calculating, designing, and drawing their various parts.

The *pitch diameter* is the diameter of the *pitch circle.*

The *addendum circle* has the same diameter as the outside diameter—that is, the diameter over the points of the teeth.

The *dedendum circle,* or *root circle,* is the circle at the bottom of the teeth.

The *pitch* is the distance from center to center of the teeth when measured on the pitch circle. When thus measured, it is called the *circular pitch.*

The *face* of the tooth is that portion of the curve outside of the pitch circle.

The *flank* of the tooth is that portion of the curve within the pitch circle.

The *thickness* of the tooth is its width, taken as the chord of an arc of the pitch circle.

The *space* is the distance between adjacent teeth, measured as the chord of an arc of the pitch circle.

DESIGNING GEARS

Fixed Pitch Method. Formerly the teeth of gears were designed on the basis of a fixed distance representing the pitch. This was usually based on the common fractions of an inch or multiples of them, as $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, $\frac{7}{8}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, 2, $2\frac{1}{2}$, 3 inches, etc. The desired number of teeth multiplied by the given pitch gave the circumference; and the distance thus found divided by 3.1416 gave the diameter of the pitch circle.

The pitch was divided into 15 parts, 7 of which represented the thickness of the teeth and 8 the width of the space. To find the length of the teeth, the pitch was divided into 10 parts, of which seven represented the length of the teeth—3 parts being that portion outside of the pitch circle and 4 parts the length inside of it, 1 part being allowed for bottom clearance. Such a method involved many tedious calculations, and in due time mechanical engineers devised a method simpler and more convenient, which has of late years been exclusively used for this purpose.

Diametral Pitch Method. By this system the pitch is designated by a *number* instead of giving the length of the pitch in inches.

This number indicates the *number of teeth for each inch of diameter of the pitch circle.* Therefore, if the diametral pitch is 6, and the diameter of the pitch circle is 10 inches, the gear will have 6×10, or 60 teeth. Thus we know that if the pitch is 6, or, as usually expressed, "6 pitch", and the gear has 60 teeth, the pitch diameter is $60 \div 6$, or 10 inches. And if the gear has 60 teeth, and the diameter of the pitch circle is 10 inches, the pitch is $60 \div 10$, or 6 pitch. We have then the three following simple rules:

(1) *Multiply the diameter of the pitch circle by the diametral pitch to get the number of teeth.*

(2) *Divide the number of teeth by the diameter of the pitch circle to get the diametral pitch.*

(3) *Divide the number of teeth by the diametral pitch to get the diameter of the pitch circle.*

The proportions of tooth parts are determined by methods quite as simple as the question of pitch. They are as follows:

The addendum is equal to one inch divided by the diametral pitch; hence that on a 6-pitch gear will be $\frac{1}{6}$ of an inch.

The dedendum is a like distance increased by the clearance, which is equal to one-tenth of the thickness of the tooth on the pitch circle.

The thickness of the tooth, and the width of the space at the pitch line, are not determined by a rule similar to that given in the former method. In accurately cut gears, the width of the space exceeds the thickness of the tooth by only as much as may be necessary to permit the gear teeth to roll freely together, and need not be over .03 of the circular pitch. In cut gears for ordinary purposes, this amount may be doubled; while in gears having cast teeth, it may need to be as great as 0.10 of the circular pitch depending, of course, upon the accuracy of the casting.

In order to afford a correct impression of the relative dimensions of spur-gear teeth of different diametral pitches, Fig. 262 is given, in which the gear teeth are shown full size. These are the more common pitches. Those larger than here shown are usually 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 pitch.

Development of Gear-Tooth Curves. *Epicycloidal Curve.* This is a matter of considerable importance, and should be thoroughly understood in connection with the work of gear cutting.

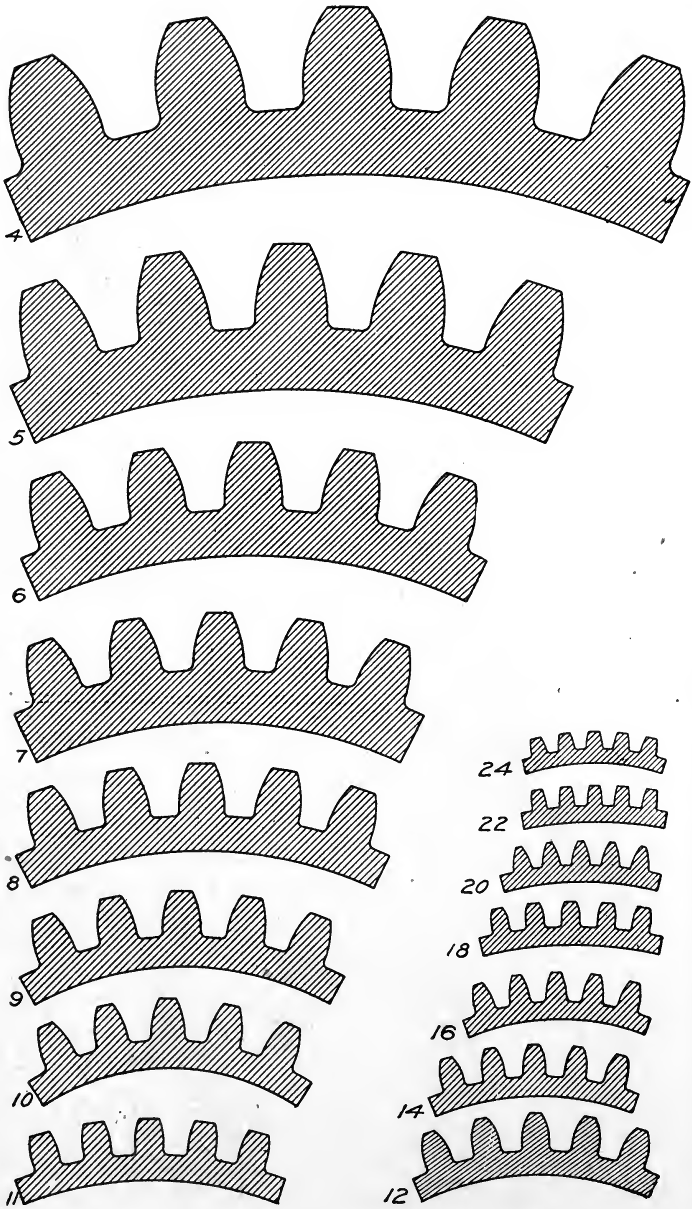


Fig. 262. Proportions of Teeth of Different Diametral Pitches

Formerly the epicycloidal curve was considered to be the most appropriate, since it is traced by a fixed point in the periphery of one cylinder rolling upon another. This is a perfectly correct theory, and many excellent gears are still made with this form of teeth.

There is one serious disadvantage, however, in gears with teeth so formed. In gears of much variation in diameter the teeth are so different from each other in form that they will not run properly with other gears varying much in diameter from the particular gear designed to run with them. The result was a great variety of curves in gears with cast teeth, and of cutters, when the teeth were cut from solid blanks, which often proved very troublesome and expensive; and many efforts were made to produce some more satisfactory method.

Involute Curve. The involute curve was experimented with, and satisfactory results were obtained. It possesses several advantages over the epicycloidal curve, which may be stated as follows:

A single curve is sufficient, while in the epicycloid a compound curve was necessary.

Undercutting the flanks of the teeth is not necessary.

Gears of any number of teeth will run properly with other gears of any number of teeth indiscriminately. This is a very great advantage in many respects.

Cutters properly formed to cut involute teeth may be used for gears of a considerable variation as to numbers of teeth. This fact greatly reduces the number of cutters of each pitch that are required or cutting a complete range of work from pinions of 12 teeth to a rack. Where 8 cutters are required, the ranges of work are as follows:

No. 1 will cut from 135 teeth to a rack
No. 2 will cut from 55 teeth to 134 teeth
No. 3 will cut from 35 teeth to 54 teeth
No. 4 will cut from 26 teeth to 34 teeth
No. 5 will cut from 21 teeth to 25 teeth
No. 6 will cut from 17 teeth to 20 teeth
No. 7 will cut from 14 teeth to 16 teeth
No. 8 will cut from 12 teeth to 15 teeth

The involute curve is generated mechanically by a point at the nd of a cord which is unwound from the surface of a circular disc or a cylinder. The curve is generated as shown in Fig. 263. *A* is an arc representing the cylinder, with its center at *B*. From the vertical line *BC*, and on the arc *A*, are spaced at equal distances the points *1, 2, 3, 4, 5, 6, 7, 8*. Radial lines are drawn from each of those to the center *B*. From each of these points are drawn the lines *a, b, c, d, e, f, g*, which are tangent to the arc *A*. From *2* as a center, and with the distance *1–2*, the portion of the required curve from the arc to the line *a* is traced. From *3* as a center, with the distance *1–3*, the portion of the curve from *a* to *b* is traced. And so on, until the involute curve *D* is traced as far as may be necessary.

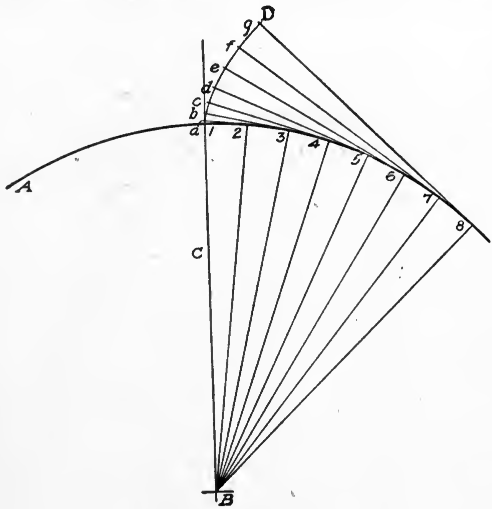


Fig. 263. Generation of Involute

In the practical use of the involute curve thus determined, an arc of such radius, and with its center so located as to approach closely the true curve, is generally used, and forms not only the face but the flank of the tooth. For this purpose, gears are classified according to the number of teeth as follows:

First Class— all gears having over 30 teeth
Second Class—all gears having 19 to 29 teeth, inclusive
Third Class— all gears having 12 to 18 teeth, inclusive

Laying Out Teeth. The method of laying out teeth of the first class is shown in Fig. 264. The pitch circle *A* has its center at *B*, upon the vertical line *BC*. From this center the addendum circle *D* and the dedendum or root circle *E* are drawn. From the vertical line *BC*, and to the right and left on the pitch circle *A*, are laid off the centers of the teeth, and the radial lines *1, 2, 3, 4, 5* drawn. Through *a*, the point of intersection of the vertical line *BC* and the pitch circle *A*, is drawn the arc *F*, of one-half the radius of the pitch circle. Through the point of intersection *b* of this arc with the radial line *4*—equal to the pitch from the vertical line *BC*—the base circle *G* is drawn. To the left of the vertical line *BC* and on the pitch circle *A*, is set off one-half the thickness of the tooth—one-fourth the pitch—to the point *c*. With a radius equal to *bc*, and from *b* as a center, the arc *d* is drawn, representing the face and flank of one side of the center tooth. With the same radius, and with the intersections of the radial lines *1, 2, 3, 4,* and *5* with the base

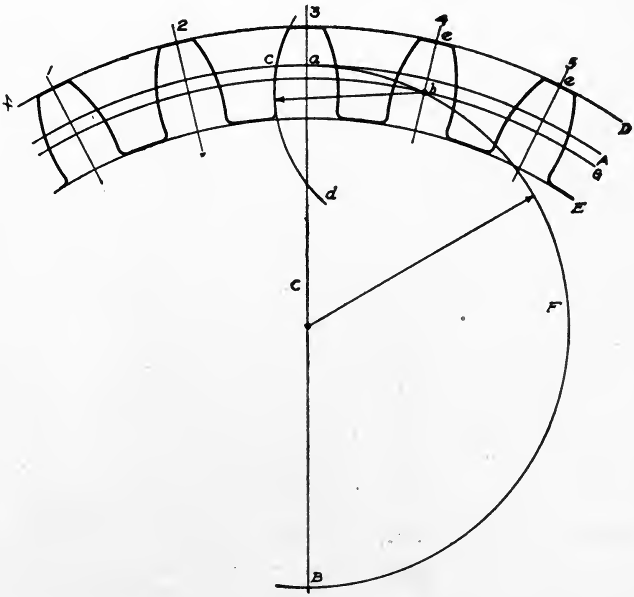


Fig. 264. Laying Out Large Gears

circle *G*, the arcs representing the faces and flanks of the other teeth are drawn. The bottom clearance is equal to one-tenth the thickness of the tooth on the pitch circle; therefore the arcs *d* are brought down to within this distance of the dedendum or root circle *E* and completed with a small arc of a radius equal to the clearance. This method is adapted to the teeth of gears of the first class (30 teeth or over), and will be found applicable to gears cut from solid blanks or those with cast teeth, making proper allowances for clearance in the latter case.

Gears of less than 30 teeth comprise the other two classes. It is readily seen that as the gears are very much reduced in diameter, the angle at which the teeth of one enter the spaces of the other will require a modification in the form of the teeth.

The method of forming the teeth of gears of the second class is shown in Fig. 265, and follows the method shown in Fig. 264, up to

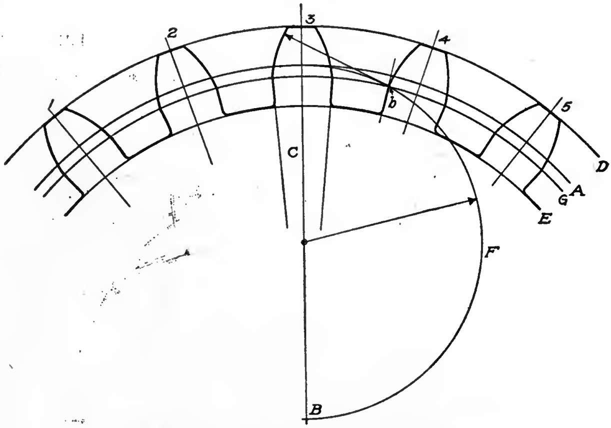


Fig. 265. Laying Out Gears of Second Class

the location of the center for the arc forming the face of the tooth. In this case it is located at the intersection of the tooth curve *d* with the base circle *G;* and the flanks of the tooth are radial instead of parallel lines.

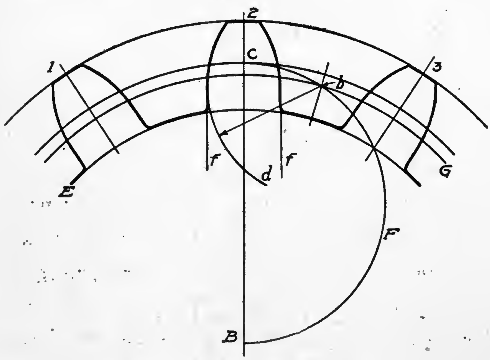


Fig. 266. Laying Out Small Gears

The method of forming the teeth of gears of the third class is shown in Fig. 266. This method proceeds in the same manner as shown in Figs. 264 and 265 as described above, up to the location of the center for the arc forming the face of the tooth. In the first case, this was at the intersection of the arc *F* with a radial line drawn through the center of the adjacent tooth, and for second-class gears it was at the intersection of the arc *F* with the flank of the tooth. In this case it is located at the intersection of the arc *F* with a radial line drawn through the center of the space. The curve *d* is therefore of relatively shorter radius. Instead of prolonging the curve *d* to the clearance arc, the flank of the tooth is formed by straight lines *ff* parallel to the vertical line *BC* and tangent to the curve *d*.

These three methods of describing the forms of involute teeth, for the three classes described, produce curves very closely corre-

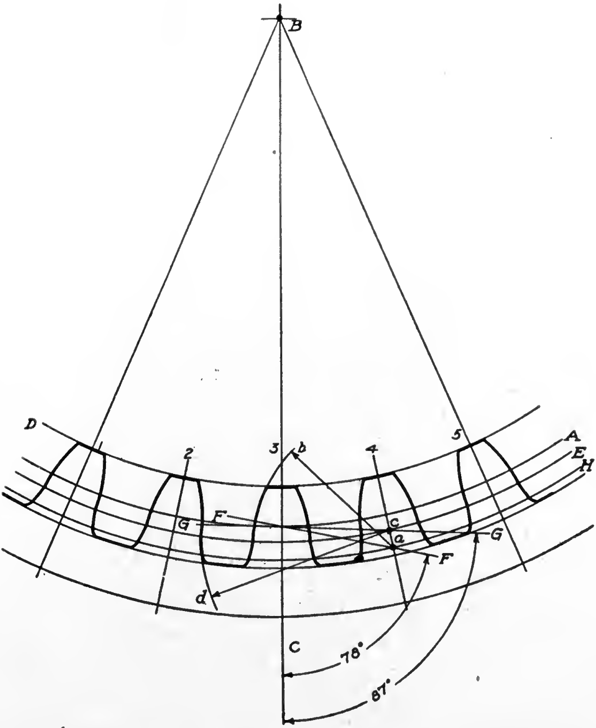


Fig. 267. Laying Out Teeth of Internal Gear

sponding to the theoretically correct involute curves, and quite sufficient for all practical purposes for which gears having teeth cut with circular cutters are intended.

Internal Gears. Internal gears must frequently be used when there is not room for spur gears or when the nature of the work or the design of the machine of which they are a part renders this form necessary or advisable. Thus far we have considered gears represented by cylinders whose outer surfaces rolled together. In the case of the internal gear the outer surface of a smaller cylinder is supposed to roll on the internal surface of a larger cylinder. Therefore, the larger gear will have teeth projecting inwardly or toward its axis.

Theoretically the proper curve for the teeth of an internal gear will be the internal epicycloid, as this is the curve traced by a point

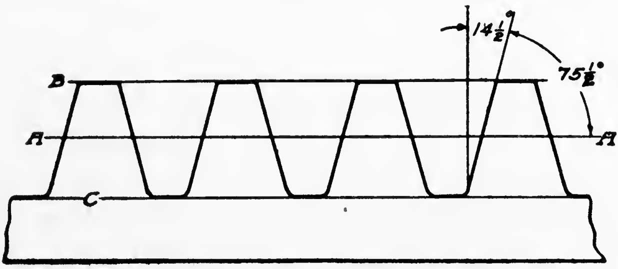


Fig. 268. First Method of Laying Out Teeth of Rack

on the surface of one cylinder rolling inside of another cylinder. The method of laying out the teeth is shown in Fig. 267. The pitch circle *A*, addendum circle *D*, and dedendum circle *E* are drawn as in the previous examples, the vertical line *BC* indicating the center of the work. The pitch is spaced off on the pitch circle *A*, each way from the line *BC*, and the thickness of the teeth and width of the

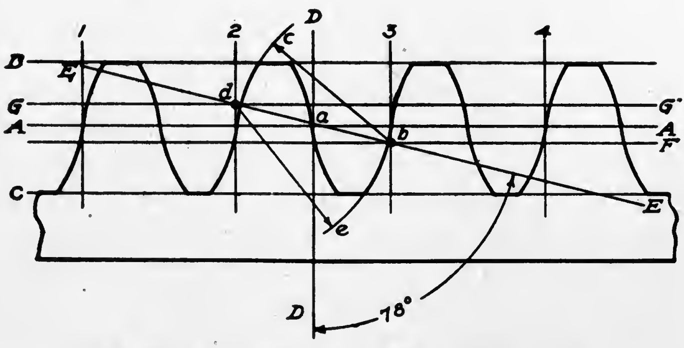


Fig. 269. Accurate Method of Laying Out Teeth of Rack

spaces indicated. At the point of intersection of the vertical line *BC* with the pitch circle *A*, is drawn an inclined line *FF* at an angle of 78 degrees to the vertical line *BC*. Through the point of intersection *a* of this line with the center line *4* of the adjacent tooth, the base circle *H* is drawn, giving the location of the centers for the faces of the teeth, which are described by the arc of the radius *ab*.

In a similar manner the line *GG* is drawn at an angle of 87 degrees with the vertical line *BC;* and through the point of intersection *c* with the radial line *4,* the base circle *J* is drawn, which gives the location of the centers for the flanks of the teeth, which are described by the arc of the radius *cd.* The arc joining the flank curve with the dedendum circle is the same as in previous examples.

Teeth of Racks. Two methods are in use for drawing the form of teeth for racks. The first method is shown in Fig. 268. The pitch line *A,* addendum line *B,* and dedendum line *C* are straight lines located as before described. The teeth and spaces are set off at equal distances on the pitch line *A.* The sides of the teeth, including face and flank, are composed of straight lines *aa* inclined at an angle of $14\frac{1}{2}$ degrees from a vertical line or $75\frac{1}{2}$ degrees from the pitch line *A.* The lower ends of these lines are joined to the dedendum line by small arcs, as previously described. While this form of tooth is not theoretically correct, many racks running with gears having involute teeth are so constructed, and they operate satisfactorily for many kinds of work. However, the second method, Fig. 269, is preferable for accurate work and for carrying heavy loads. The principal lines *A, B,* and *C,* and the spacing of the teeth are the same as in Fig. 268. The vertical line *DD* is erected at the side of one of the teeth. Through the point *a* of the intersection of this line with the pitch line *A* is drawn the inclined line *EE* at an angle of 78 degrees with the vertical line *DD.* Through the point *b* of the intersection of this line with the vertical line *3* of the side of the adjacent tooth is drawn the base line *F,* which locates the centers for the arc with the radius *bc,* forming the face of the tooth. Through the point *d* of the intersection of the line *EE* with the vertical line *2,* at the left of the tooth, the base line *G* is drawn, locating the centers for the arc with the radius *de,* forming the flank of the tooth. The lower ends of these arcs are joined to the dedendum line *C* by small arcs, as previously described.

Table X gives the various dimensions of the parts of gear teeth calculated for involute teeth designed upon the diametral-pitch system. It is useful in comparing the different dimensions of the same pitch with one another, and in comparing similar dimensions used in the same pitch; and it will enable the student to avoid making tedious calculations in each instance.

TABLE X

Involute Gear Tooth Parts

Diametral Pitch	Circular Pitch	Thickness of Tooth	Addendum	Working Depth	Whole Depth
1	3.1416	1.5708	1.0000	2.0000	2.1571
$1\frac{1}{2}$	2.0944	1.0472	.6666	1.3333	1.4381
2	1.5708	.7854	.5000	1.0000	1.0785
$2\frac{1}{2}$	1.2566	.6283	.4000	.8000	.8628
3	1.0472	.5236	.3333	.6666	.7190
4	.7854	.3927	.2500	.5000	.5393
5	.6283	.3142	.2000	.4000	.4314
6	.5236	.2618	.1666	.3333	.3463
7	.4488	.2244	.1429	.2857	.3080
8	.3927	.1963	.1250	.2500	.2696
9	.3491	.1745	.1111	.2222	.2396
10	.3142	.1571	.1000	.2000	.2157
12	.2618	.1309	.0833	.1666	.1796
14	.2244	.1122	.0714	.1429	.1540
16	.1963	.0981	.0625	.1250	.1348
18	.1745	.0871	.0555	.1111	.1198
20	.1571	.0785	.0500	.1000	.1078
24	.1309	.0654	.0416	.0833	.0898

Attention is directed to the following characteristics of these dimensions:

(a) The thickness of the tooth equals one-half the circular pitch.

(b) The addendum equals 1 (one inch), divided by the diametral pitch.

(c) The working depth of the tooth is twice the addendum, as the addendum and dedendum are equal.

(d) The whole depth of the tooth is the working depth plus one-tenth of the thickness of the tooth, which is the clearance. The radius of the clearance arc is one-seventh of the distance between the points of adjacent teeth.

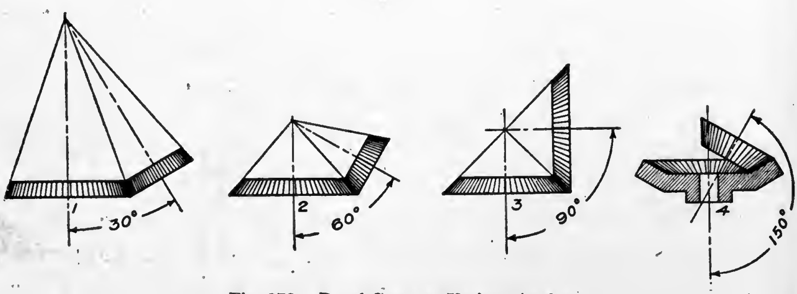


Fig. 270. Bevel Gears at Various Angles

Bevel Gears. In the treatment of spur gears, we have considered them fundamentally as cylinders rolling upon each other (ordinary spur gears) or a cylinder rolling on the inner surface of a larger one (internal gears). We now come to consider cones of various diameters and relative proportions rolling together, as shown in Fig. 259. The surfaces of the cones represent their pitch circles in the same manner as the cylinders. While spur gears must have their shafts always parallel, bevel gears may be designed to run properly at any angle from parallel to 150 degrees. In Fig. 270 are shown several pairs of typical bevel gears with their shafts at different angles. Those of 90 degrees are the more common. The pair shown at *4*

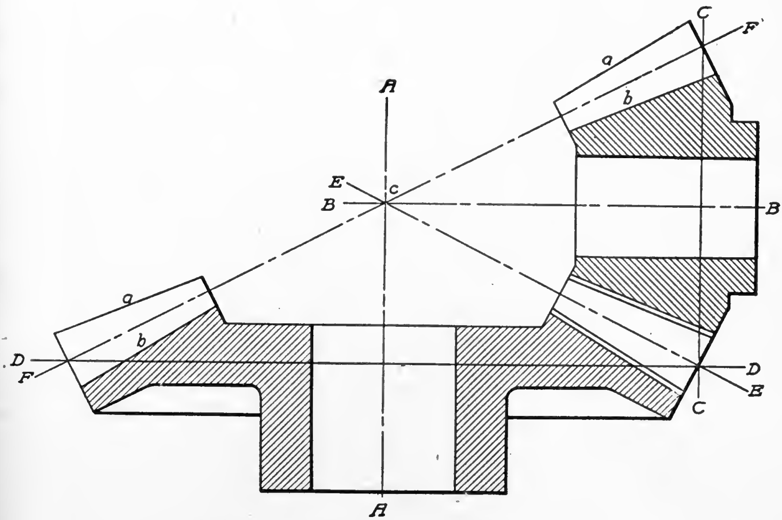


Fig. 271. Cross-Section of Pair of Bevel Gears

are unusual but sometimes necessary, and operate quite as well as the others. In this case the larger gear is an internal bevel gear.

When two bevel gears of the same diameter and number of teeth run together, they are called miter gears, although this term is more likely to be applied to those whose shafts are at an angle of 90 degrees to each other.

Fig. 271 is a cross-section of a pair of bevel gears, and is designed to illustrate the principles applicable to the cutting of gears. The lines *AA* and *BB* are the center lines of the two shafts, their point of intersection being the apex of each of the cones representing the pitch surfaces. The line *CC* is parallel to *AA* and at a distance from it equal to half the pitch diameter of the larger gear. The line *DD* is parallel to the line *BB*, and distant from it one-half the pitch diameter of the smaller gear. Between the points of intersection of the lines *AA* and *BB*, and of *CC* and *DD*, the pitch line *EE* is drawn, giving the line of contact between the two cones. The outline of the cones is completed by the line *FF*. The outer and inner ends of the teeth are lines at right angles to the pitch lines; and upon the outer tooth lines the depths of the teeth above and below the pitch lines are set off; and the lines *a* and *b*, for the top and bottom of the teeth, are drawn radially from the common apex of the cones at *c*. The various dimensions of the teeth are laid off at the large or outer ends of the teeth, and are taken from Table X.

To facilitate the proper cutting of bevel gears, the drawing should give the face angle *a* and the cutting angle *b* for each gear, and the depth of the teeth at the outer end. The angles should be so expressed that a bevel protractor may be set against the hub of the gear, and its arm upon the face angle and cutting angle, to verify their correctness. When the shafts are at right angles, the sum of the edge angles will equal 90 degrees, and the sum of the face angles and edge angles will be equal.

The angles may be determined by this method, for the angle of the pitch line *FF* with the face of the hub (or the line *DD* parallel to it), we may consider as a right-angled triangle *FFD*. Divide the height by the base, and the quotient will be the natural tangent. From the table of tangents we get the angle in degrees and minutes.

Thus, suppose the base is 5 inches, and the height 2.5 inches, then $2.5 \div 5 = 0.5$, which is the tangent. In the table of tangents we find the nearest number is .50004, whose corresponding angle is 26 degrees 34 minutes. The value of any angle expressed in degrees and minutes may be determined in the same manner if the base and height are known.

Worm Gearing. This is a term used to describe the device consisting of a gear similar to a spur gear driven by a worm—that is, a cylinder upon whose surface is a thread fitting into the teeth of the gear. The relative speed of the worm and gear are found by dividing the number of teeth in the gear by the number of threads on the worm. Worms are always understood to be of single thread, unless otherwise specified. The pitch of a single-threaded worm is equal to the circular pitch of the worm gear, and *vice versa.* The shafts of a worm and worm gear are usually (but not necessarily) at right angles to each other.

A simple form of worm gear is shown in Fig. 272, in which the worm *B* has a single thread having an inclination on each side of $14\frac{1}{2}$ degrees, or what is usually called a "29-degree" thread. The teeth of the worm are cut to a similar form, and the pitch circle located the

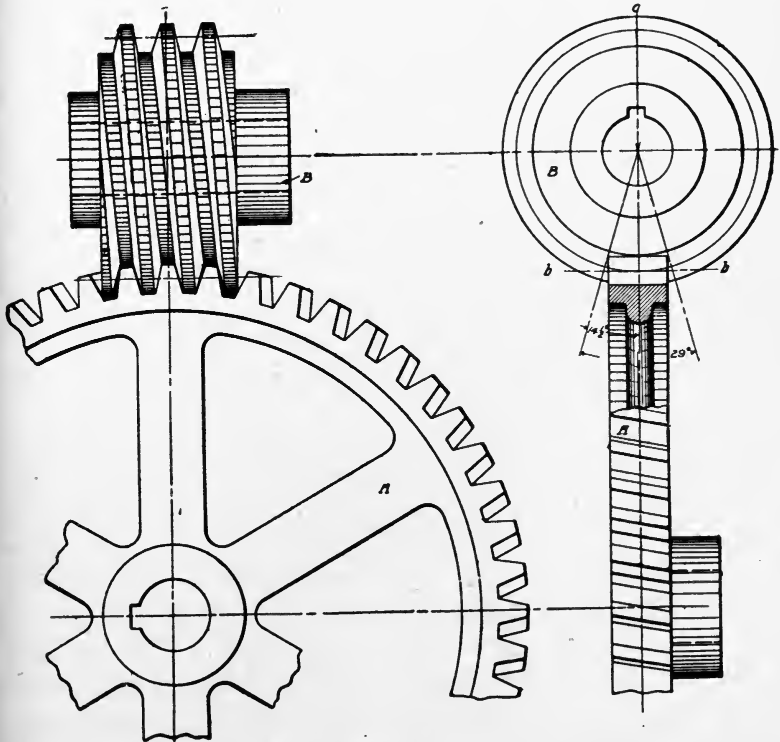


Fig. 272. Simple Worm Gear

same as in a spur gear; but, as the lines of the thread of the worm are not at right angles to the axis, but at an angle due to the pitch of the thread, the teeth of the worm gear must be cut at such an angle as to be tangent to the curved line of the thread, as shown at *a*. The calculations for this worm gear are made the same as for a spur gear. Thus the pitch of the thread, multiplied by the number of teeth, will give the circumference of the pitch circle, which amount, divided by 3.1416, will give its diameter. In consequence of the relatively large diameter of the worm compared with the thickness of the worm gear, enclosing an angle of only 14 degrees on the pitch line, the teeth of the latter may be cut on a line parallel to its axis, as they will conform quite nearly to the curvature of the thread of the worm. This is the simplest form of a worm gear, and one not often used, on account of the small amount of power it is able to transmit.

The usual practice, particularly where considerable power is to be transmitted, is to design the worm wheel as shown in Fig. 273, by which a much greater area of contact is secured, but making a much more complicated form, and one in which some new conditions must be considered. In this case the enclosing angle is 80 degrees, instead of 29 degrees, as in the former example. In the former example, the teeth were cut as in a spur gear, hence the pitch surface *bb*, Fig. 272, was straight, and the diameter of the pitch circle was therefore measured as in a spur gear. In this case the pitch line is considerably curved, being an 80-degree arc on the pitch circle *a* of the worm. It has sometimes

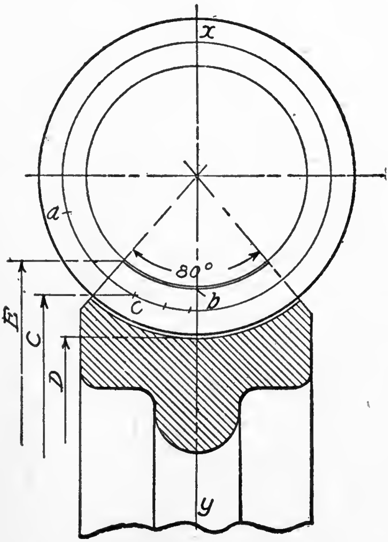


Fig. 273. Worm Gear with Large Enclosing Angle

been the practice to calculate the pitch diameter from the point *b*, usually called the throat of the gear. It is obvious that this is an arbitrary point, that the number of degrees contained in the enclosing angle is not considered, and that, for instance, if the number of degrees were much reduced, so as to materially flatten the arc, this point would vary considerably from its proper place. It has been found in practice that if we divide that portion of the pitch line *a* that lies between the vertical center line *xy* and the enclosing angle into three equal parts as shown, whatever may be the enclosing angle, the point *c* will indicate the correct diameter of the pitch circle. We shall then have the pitch diameter at *C*, the diameter at the bottom of the teeth at *D*, and the outside diameter at *E*.

These relative diameters bear no fixed relation to similar dimensions of a spur gear, or to those of other worm gears of differing proportions.

To find the angle of the thread, we use the right-angled triangle, as shown in Fig. 274, in which the base equals the circumference of the worm, the height equals the pitch of the thread, and the hypothenuse is the development of the thread itself. Mathematically we find the angle of the thread by dividing the pitch (height) by the circumference (base) to get the tangent of the arc, and obtain the angle from a table of natural tangents. Should the worm have a double thread, the height of the triangle will be twice as great.

Spiral Gears. As has heretofore been stated, the spur gear has its teeth cut in a line parallel to the axis. If the teeth are cut at an

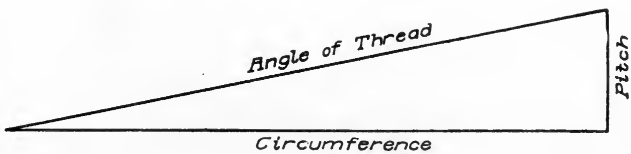


Fig. 274. Diagram for Finding Angle of Worm Thread

angle to the axis, and the cut continued by the gradual rotation of the gear blank as it advances, a spiral gear will be produced. If the cut is prolonged, it will finally make a complete revolution and arrive at the original line parallel to the axis of rotation. The lead of the spiral is the distance from the beginning of the cut to a point where the revolution is completed. The angle of the spiral is found in a manner similar to that described for the diagram, Fig. 274. As applied to this case, the rule will be: divide the number of inches of the circumference of the cylinder on which the spiral is to be cut by the number of inches in the lead, and the quotient will be the tangent of the angle of the spiral, the angle being found from a table of natural tangents. Thus we have the following rule: *Divide the circumference by the tangent of the angle to produce the lead;* or *multiply the tangent by the lead to produce the circumference.*

In making calculations for spiral gears, the pitch diameter, and not the outside diameter, is understood. Spiral gears have several properties that should be remembered in making calculations for them. It is assumed in each case that the gears are engaged, or in mesh, with one another.

(1) Two spiral gears of equal diameter, number of teeth, and angle of teeth, will have the same lead of spiral.

(2) If two spiral gears are of equal diameter, one having twice as many teeth as the other, one will have twice the length of lead of the other.

(3) If two spiral gears are of equal diameter, one having twice as many teeth as the other, the teeth of one will have twice the angle of the other.

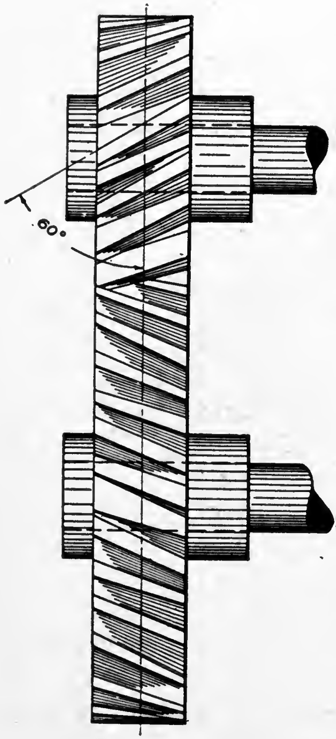


Fig. 275. Simple Form of Spiral Gears

(4) Two spiral gears of equal diameter, on parallel shafts, will have the same angle of teeth on both.

(5) Two right-hand spiral gears must have the angles of their shafts at an angle equal to the sum of the angles of the teeth of both gears.

(6) One right-hand and one left-hand spiral gear must have the angles of their shafts equal to the angle of the teeth of one gear, less the angle of the teeth of the other.

(7) If two spiral gears are of equal diameter, one with twice as many teeth as the other, the gear with the lesser number of teeth will have them at twice the angle of the other.

(8) If one of two spiral gears has teeth at an angle of 45 degrees the other having twice the number of teeth, its lead will be twice as great and its pitch diameter twice that of the other.

(9) Diameters being equal, double the number of teeth indicates one-half the angle and *vice versa*.

(10) If the angles of teeth are equal, either gear may be the driver. If the tooth angle in one gear is twice that in another, it must be the driver.

The lines representing the angles of the teeth of spiral gears must be tangents to the side of the tooth at the pitch line and in the center of the face of the gear. If the pitch is comparatively large in proportion to the diameter of the pitch circle, the angle will be considerably less at the bottom of the tooth than on the pitch line, and considerably greater at the points of the teeth.

The simplest form of spiral gears is shown in Fig. 275, in which the shafts are parallel and the teeth of both gears are cut at an angle of 30 degrees to their axes. This angle is not arbitrary, as any angle that permits the teeth to engage properly is admissible. It should not exceed 45 degrees. The two gears may have relatively any number of teeth, the same as spur gears. Gears of this form are frequently called helical, in consequence of their spiral form of teeth resembling the helix. This is the customary angle for such gears. Their action is similar to that of ordinary spur gears; but in consequence of the progressive engagement of the teeth, they will run with less noise

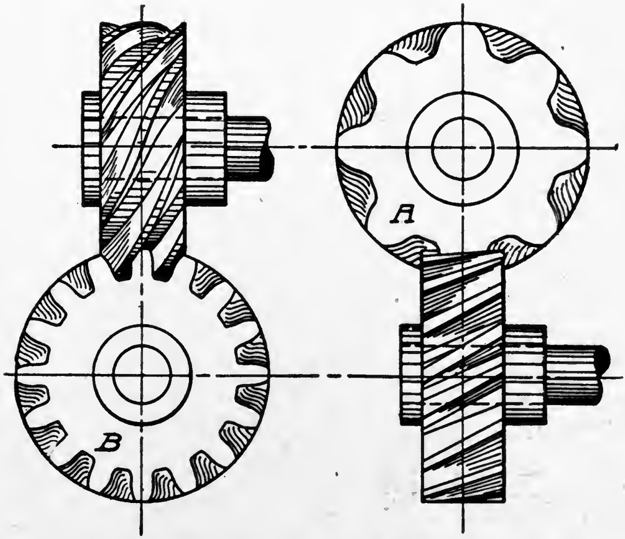


Fig. 276. Spiral Gears Whose Shafts Are at Right Angles

and shock, even when running at high speeds or when transmitting heavy loads.

Fig. 276 represents a pair of spiral gears whose shafts are at right angles to each other, and in which gear *A* has 8 teeth and the gear *B* has 16 teeth. Gear *A* is the driver; and from the fact that it has but one-half the number of teeth of the gear *B*, its speed must be twice as great. The angle of the teeth of gear *A* is 26 degrees 40 minutes. As the shafts stand at an angle of 90 degrees, we subtract the angle of the teeth of the gear *A* from 90 to obtain the angle of the teeth of the gear *B*, giving 63 degrees 20 minutes. The sum of the two angles equals the angle of the two shafts. That spiral gearing and worm gearing are closely allied is evident from this example. In analyzing the action of these devices, this fact should not be forgotten.

The necessary calculations for designing a pair of spiral gears may be illustrated by the following example: The gears are to be 4 and 16 inches diameter of pitch circle, and the shafts are parallel. The larger will have a lead of 96 inches; therefore the smaller will have a lead in the same ratio as the diameters, or 24 inches. Taking the large gear, $16 \times 3.1416 = 50.2656$ circumference, which, divided by the lead (96), gives .5235. Consulting a table of natural tangents, we find that this amount represents an angle of 27 degrees 40 minutes. The angle of the smaller gear will be the same.

If shafts are at other than right angles, this condition will change the angles of the teeth of spiral gears; and when the pitch diameters are alike and the numbers of teeth different, the angles will be different.

It is customary to use racks in connection with spiral gears, the gear being of comparatively short lead. This device is practically the screw and nut, the spiral gear acting as the screw and the rack as the nut. In designing racks for this purpose the teeth may be at right angles to the line of movement or at any angle between this position and 45 degrees. The shaft of the spiral gear used with a rack may be at any angle from parallel to the line of motion to 45 degrees. Angles of 35 degrees or less will produce better results under usual conditions. The pitch of the spiral, the number of teeth, and the angle of the shaft will govern the angle of the teeth of the rack. The teeth of the rack may be of concave form, similar to those of the worm gear if a large area of contact is required for heavy work. Otherwise they are usually cut in a straight line. The form of the teeth should be with straight lines for the side of the teeth, inclined 14½ degrees.

GEAR CUTTING PROCESSES

Two general processes are used for cutting the teeth of gears: *milling* and *planing*. Either of these processes may be used for cutting the teeth of spur gears, bevel gears, internal gears, racks, etc., but they are not equally adapted for spiral gears or worm gears.

Milling Process. The first process, milling with a properly formed revolving cutter, as in ordinary milling machine work, is applicable not only to the work mentioned above, but also to the cutting of spiral gears and a portion of the work upon worm gears. The cutter must be shaped exactly to the form of the space between the teeth of the gear to be cut. It must revolve at a speed suitable to the kind of metal to be cut, and must be supported by a spindle of ample dimensions properly supported in well-fitting journal boxes, set in housings of such dimensions and weight as to insure rigidity and the elimination of vibration. The work to be cut must be properly mounted so as to avoid vibration as much as possible, and be provided with feeding mechanism by which a rate of feed may be produced according to the speed of the cutter and the kind of metal to be cut.

For ordinary uses this process produces satisfactory results upon spur gears, internal gears, and racks. While it is used also for much bevel gear work and answers the requirements of ordinary work, there are conditions in the form of teeth of bevel gears that do not exist in that of spur gears. It has been previously explained that the dimensions of the tooth parts of a bevel gear are measured at the outer end, or at the largest part of the tooth, while the lines of the tooth are radial, meeting at the apex of the cone base, from which the gear takes its form. It may therefore be readily understood that it is quite impossible to form a revolving cutter so as to cut to the correct theoretical dimensions of the tooth through its entire length. It is the practice to form the contour of the cutter so that it is a compromise between the correct forms of the two ends of the teeth, but rather closer to the form at the outer or larger end, the form being practically correct at a point one-third of the face of the tooth from its outer end. As a rule, the width of face of a bevel gear should not be over five times the thickness of the teeth at the outer end. It is usually considerably less. If the face is too wide, the inner ends of the teeth will be cut away too much as the width of the cut is uniform from one end to the other; and this results in thin and useless teeth for a considerable part of their length from the inner end, as there is no contact with or bearing upon the teeth of the engaging gear at this point. For this reason, resort is had to filing the faces of the teeth at the large end, after the gears have been run together so as to show by the marks thus produced.

Planing Process. *First Method.* The second process, that of planing the forms of the teeth, is accomplished by three methods. One is to form a planing tool to the exact contour of the space between the teeth, and by successive strokes of any machine having a reciprocating ram to carry the tool, some fixture for holding the gear blank, and a device for indexing the tooth spaces. This work is frequently done on a shaper and sometimes on a planer. This method produces a cut with parallel sides the same as a revolving cutter, and the depth of the cut may be varied at the two ends so as to be adaptable to bevel gear work although producing work that is no more theoretically correct than that of the revolving cutter. This device may be used upon spur gears, internal gears, racks, etc., with fairly good effect, but is a comparatively slow process. It may, however, be sometimes used where a milling machine or ordinary gear cutter cannot, as in cutting the teeth of internal gears.

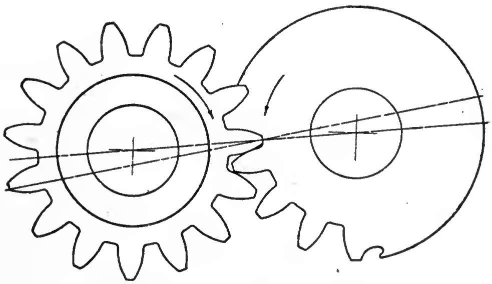


Fig. 277. Planing Gear Teeth

Second Method. The second method, of planing gear teeth—which has proven an important device for forming the teeth of spur gears, internal gears, and racks—operates by means of a circular cutter upon which the teeth are formed similar to the teeth of the gear itself. This is the system used in the Fellows gear shaper. The action of the cutter is shown in Fig. 277. The gear blank is mounted on a proper spindle, and the machine started, the cutter reciprocating on its center line and parallel to its axis. The cutter is then fed toward the blank, and cuts its way to the proper depth. At this point, both the cutter and the blank begin to rotate in the directions indicated by the arrows, the cutter maintaining its reciprocating motion. This rotation of the cutter and the blank is obtained by separate and external mechanism, which insures that the movement shall be the same as though the cutter and the blank were two complete gears in correct mesh. The combined result of rotary and reciprocating motions is that the cutter teeth generate conjugate teeth in the blank, which mesh correctly with the cutter teeth and with one another. Any two gears of the same pitch cut with this cutter will mesh correctly together.

Third Method. A third method of planing gear teeth, and one of very great importance, particularly in forming the teeth of bevel gears, is used by various gear-cutting machine builders. In some cases the tool slide travels upon a carriage whereof one end is pivoted directly under the apex of the base cone, and its opposite or outer end is properly guided to the exact contour of the tooth, which is formed by a tool having a single cutting edge with a narrow and somewhat rounded cutting point. In other cases the tool slide is in a fixed plane, while the arbor upon which the gear blank is mounted is journaled in a portion of the machine so constructed as to give the necessary adjustment and movements to the gear blank. These planing processes will be more particularly noticed later in describing the various types of gear-cutting machines.

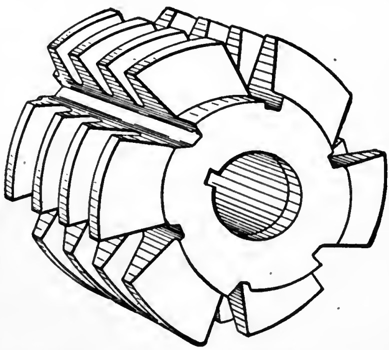


Fig. 278. Hob for Forming Teeth of Worm Gears

Hobbing Gears. In forming the teeth of worm gears, the greater part of the space is cut out by a stocking cutter or roughing cutter, which is adjusted at a proper angle, according to the pitch of the worm which the worm gear is to fit, and gradually sunk into the face of the worm-gear blank so as to form the spaces between the teeth. This revolving cutter will not produce the correct form for the teeth, as they must fit the sides of the worm thread. Recourse is therefore had to a cutter called a hob, which is shown in Fig. 278. This cutter is in effect a worm, across the threads of which are formed deep grooves, thereby producing cutting faces as shown in the engraving. Each of the teeth shown is relieved, or backed off, so that when the faces of the teeth become dulled by use and are ground, the accurate form of the teeth is not changed. This hob is mounted in the exact position that the worm is to take with reference to the worm gear, except that the centers of the spindle carrying the hob, and the arbor carrying the worm gear, are slightly farther apart, and so arranged as to be brought to the exact distance apart, as the hob shapes the teeth of the worm gear. This operation, called hobbing, is performed by the rotation of the hob, which, acting as a screw and producing the rotation of the worm gear, forms the teeth by its cutting action. In some cases the worm gear is positively rotated by suitable gearing. Previous gashing is then unnecessary.

In Fig. 279 is shown the usual form of a rotating cutter for producing the involute form of gear teeth. The teeth of these cutters are relieved, or backed off, so that their form is not changed when ground upon the face after they have become dulled by use.

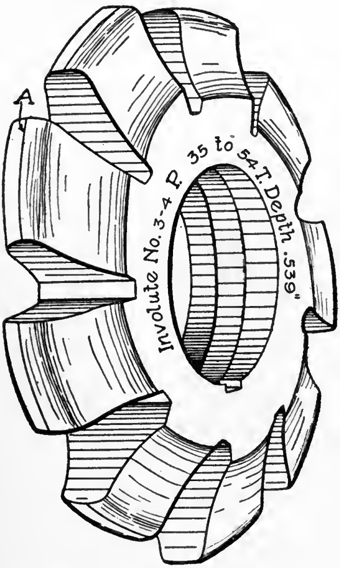


Fig. 279. Rotating Cutter for Involute Teeth

Tools for Testing Gear Teeth. To ascertain if the teeth of a gear are being cut properly, the gear-tooth caliper shown in Fig. 280 is used. This is for measuring the distance from the top of the teeth to the pitch line, and the thickness of the teeth at the pitch line. It will measure all teeth from 2 to 20 diametral pitch, and is provided with vernier scales in both directions so that it can be very accurately adjusted to the required dimensions as given in Table X.

Fixed gages are frequently used instead of the gear-tooth caliper. Thus, for the depth of the teeth, a sheet-metal gage of the form shown in Fig. 281 is provided. A gage for the width of the teeth is shown in Fig. 282. There must be separate gages for each different pitch, each of which is stamped with a figure indicating the pitch for which it is to be used.

General Conditions of Practical Gear Cutting. Before describing the various types of gear-cutting machines and the methods by which each performs its work, attention is directed to some of the general conditions in the practical use of gear-cutting machines of any type.

When rotating cutters are used, they are mounted upon the spindle and secured in place in the same manner as ordinary milling-machine cutters—namely, located in proper position by clamp collars

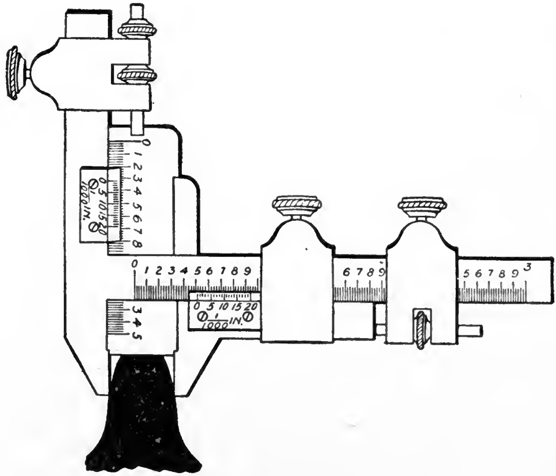


Fig. 280. Gear-Tooth Caliper in Use

on each side, held in place by a nut. Care should be taken to see that they run true. If not, there is liable to be dirt or chips between the collars and shoulders of the arbor or the cutter; and they should be removed, carefully cleaned, and replaced. If still out of true, the arbor may be sprung, and it should be corrected before any work is done. The cutters should be sharp; otherwise much heat and friction will be caused, and poor and inefficient work will result.

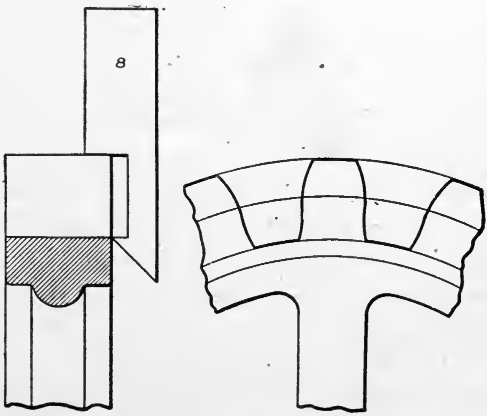


Fig. 281. Sheet-Metal Gage for Measuring Depth of Teeth

The gear blank is usually mounted upon an arbor fitting in a taper-reamed hole in the index spindle, and sometimes reaches entirely through the spindle, being confined in position by a nut in its rear end. These arbors are of different diameters so as to fit all the regular sizes of the bore of the gear blanks. The gear blank is adjusted to its proper place on the arbor by loose collars if necessary, and confined by a nut which must be screwed up very tightly so as to prevent the blank from moving on the arbor during the process of the cutting.

Upon the cutter shown in Fig. 279 is a line *A*, exactly in the center of the tooth. The position of the cutter and the work arbor carrying the gear blank must be so adjusted with relation to each other that this line will exactly coincide with the axis of the arbor. To effect this, in machines in which the work arbor is horizontal, it is brought under the cutter and accurately adjusted; then the arbor and its carriage are moved to the proper position to begin cutting the teeth. On some machines, special provision is made for centering the cutter.

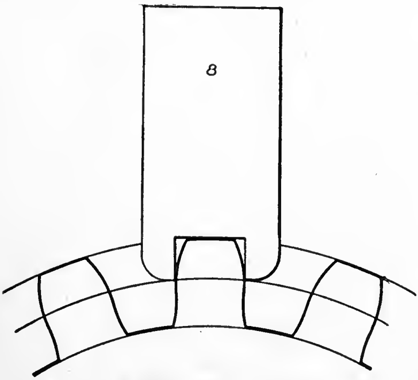


Fig. 282. Sheet-Metal Gage for Measuring Width of Teeth

The proper change gears or such similar devices as the machine is provided with are then arranged for the spacing or indexing of the blank. The design of this device may vary in different machines, but the device usually consists of ordinary change gears, which are selected and applied according to a table furnished with the machine, which table gives the required gears for all the usual numbers of teeth to be cut. The machine is started, and the work brought to the cutter so as to mark it plainly, when it is withdrawn and the machine stopped. The indexing device is now operated, step by step, through one entire revolution of the gear blank, back to the mark made by the cutter. The work is now brought up to the cutter to ascertain if it exactly coincides with the mark made. If so, the cutter may be set to the proper depth by advancing it to a point considerably less than the whole depth, and cutting down slightly past the center of the cutter; then moving the cutter, in the line of its feed, out of the cut, and measuring the depth. The work is now slightly advanced and the cut deepened; and so on, until the proper depth is reached.

On some machines an index is provided on the adjusting screw, enabling the work to be brought up to the cutter so as to barely touch it; and then, by reading the index, the entire depth is adjusted at once and with certainty.

When gears of very coarse pitch—as $2\frac{1}{2}$ pitch and larger made of cast iron, and 5 pitch and larger made of steel—are to be cut, it is customary to use first a roughing or stocking cutter which removes two-thirds or more of the metal, after which the finishing cutter, shown in Fig. 279, is used to finish the work. A roughing cutter usually has inclined, straight, or stepped sides, no attempt being made to follow the contour of the finished tooth.

Speed of Cutters. On gear work the speed of cutters will be slightly less than that of the ordinary milling cutters, as the cutting surface is not only over the points of the cutting teeth, but upon both sides. Hence the speed will more nearly approach the proper speed for the formed cutters of the milling machine. The variations of speed for the different kinds of material will be the same as for milling-machine cutters.

Feed. The proper feed for gear cutting will be the same as for milling-machine cutters (or in some cases slightly less), on the same material, for cast iron usually about $\frac{1}{16}$ inch per revolution.

Cutting Spiral Gears. In cutting spiral gears the universal milling machine is generally used, as it is provided with proper devices for rotating the gear blank at the same time that it is fed toward the cutter. The machine is provided with an indexing mechanism, and also with change gears by which any length of lead of the spiral may be obtained. In all cases of spiral gear cutting, the milling-machine table must be set at an angle, as shown in Fig. 276, the center of the cutter being directly above the point of intersection of the axes of the arbor carrying the gear blank and that upon which the cutter is mounted.

The preliminary cutting or gashing of worm gears is frequently done on a universal milling machine, on account of its adaptability to all kinds of angular work and to making feeds in all directions.

Lubrication of Cutters. In gear cutting, the lubrication of cutters is governed by the same conditions and requirements as in ordinary milling-machine work, and is governed by the material to be cut.

TYPES OF GEAR-CUTTING MACHINES

To familiarize the student with the special features of different types of gear-cutting machines, illustrations and descriptions are given of the machines made by some of the more prominent builders.

Whiton Gear-Cutting Machine. In Fig. 283 is shown the Whiton automatic gear-cutting machine. The cutter is carried by

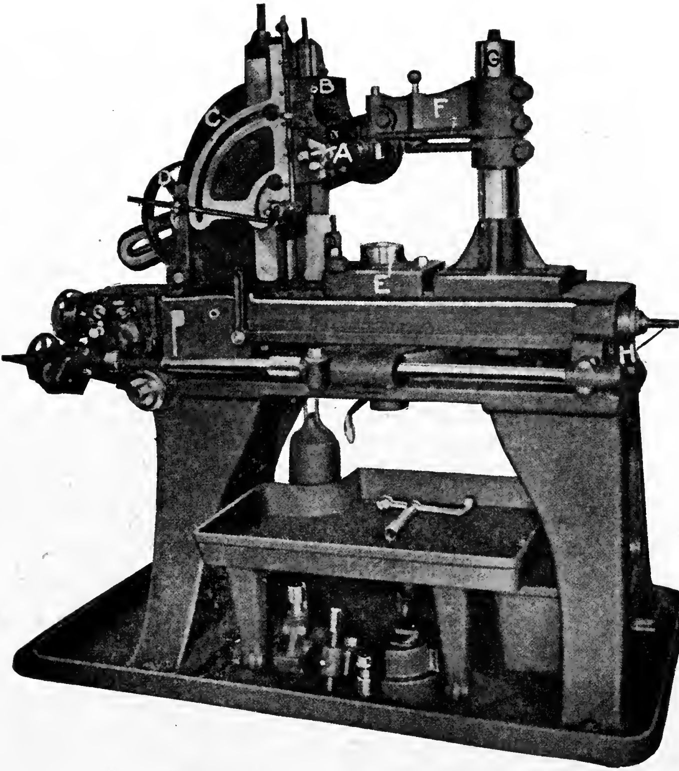


Fig. 283. Automatic Gear-Cutting Machine
Courtesy of D. E. Whiton Machine Company, New London, Connecticut

the spindle A, which is journaled in a saddle B, sliding upon the swinging carriage C and capable of adjustment at any angle necessary to cut bevel gears. The machine is shown arranged for cutting spur gears. The cutter arbor A is driven by the pulley D at the back of the machine, acting through a system of gears not shown. The blank to be cut is held on an arbor fitted into the vertical spindle E, and its upper end supported by a center in the arm, adjustably clamped to the column *G*. The traversing screw *H*, has a graduated dial. A gage is provided for centering the cutter; and graduated stops provide micrometer adjustments for setting over the cutter in bevel gear cutting, and for setting over the blank. At *J* are the change gears of the indexing mechanism.

Brown and Sharpe Gear-Cutting Machine. Fig. 284 represents a Brown and Sharpe gear-cutting machine. The gear blank is

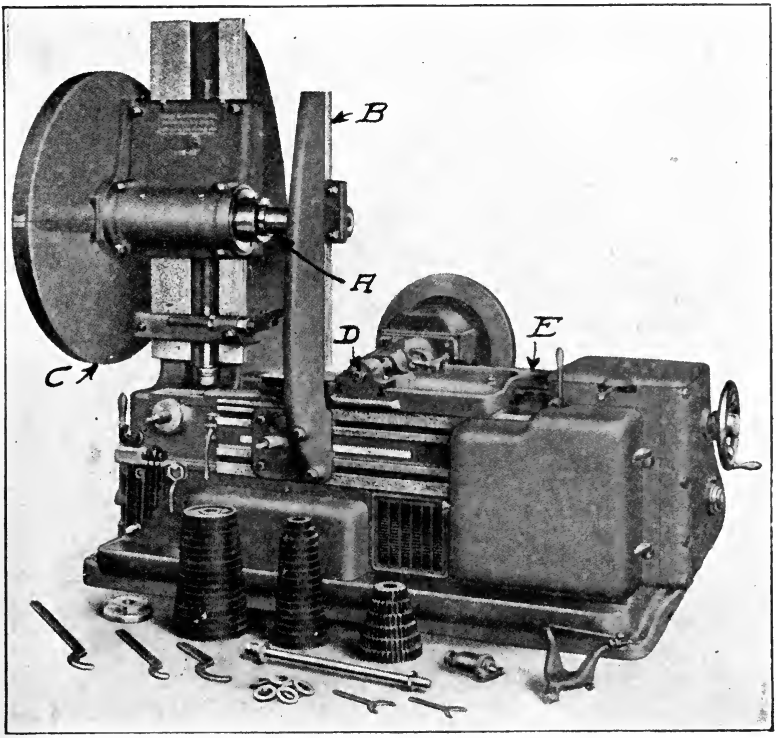


Fig. 284. Number 6 Gear-Cutting Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

carried on an arbor fitted to the horizontal spindle *A*, and supported by the outer supporting bracket *B*. The indexing mechanism is in the rear of the indexing wheel *C*. The cutter is carried by the cutter spindle *D*, mounted in the traveling carriage *E*. In smaller machines the base upon which this carriage slides is pivoted so as to be set at any required angle for cutting bevel gears. The machine is entirely automatic in its action. It has an attachment for cutting internal gears.

Automatic Gear-Cutting Machine. The automatic gear-cutting machine built by Gould and Eberhardt is shown in Fig. 285. It is of the same type as that built by Brown and Sharpe and possesses some excellent features. The gear blank and cutter are mounted in a similar manner, and the adjustments are made at much the same points. It is furnished with attachments for hobbing worm gears

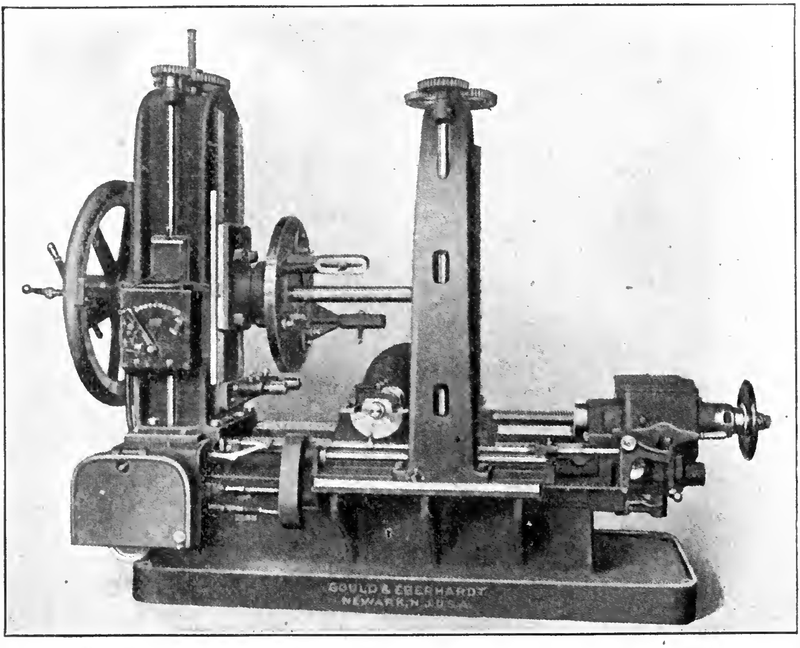


Fig. 285. "New Type" Gear-Cutting Machine Entirely Automatic for Cutting Spur Gears Only
Courtesy of Gould and Eberhardt, Newark, New Jersey

and for cutting racks and internal gears. The one shown is not adapted for cutting bevel gears.

Becker Gear-Cutting Machine. The Becker Milling Company gear-cutting machine, shown in Fig. 286 is of the milling-machine type, designed by Amos H. Brainard, a builder of milling machines. The gear blank is mounted upon an arbor fitting a taper hole in the work spindle *A* or fixed upon an arbor and mounted on centers. The cutter is mounted upon a cutter arbor *B*, journaled in a sliding saddle *C* whose support *D* is pivoted to the machine knee so as to be adjustable to any angle required for cutting bevel gears as well as spur gears. The machine is entirely automatic in its action.

Bench Gear-Cutting Machine. Fig. 287 shows a bench gear-cutting machine built by the Sloan and Chase Manufacturing Company. It is intended for small gears only, and will not cut a gear larger than 3½ inches in diameter. The same company build large machines, some of the Brainard type. The machine shown carries the

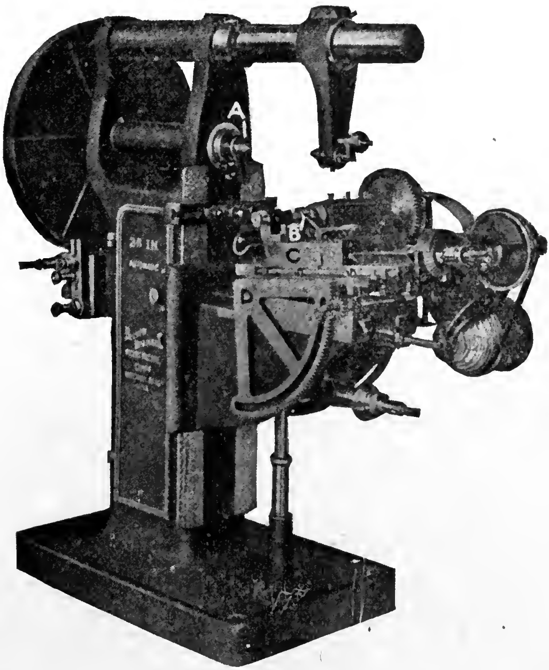


Fig. 286. Gear Cutter
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

gear blank on the spindle A, and the cutter on the spindle B. The indexing mechanism is at C, and the machine is entirely automatic.

Fellows Gear Shaper. The Fellows gear shaper, shown in Fig. 288, is a distinct type in construction and action, the peculiar form of cutter used being shown in Fig. 277. The gear blank is mounted on the vertical work spindle A, which has on its lower end and within the casing B an indexing worm gear operated by the change gears at C. These are driven from the cone pulley D by means of the vertical shaft E, by a very gradual but continuous motion as the vertically reciprocating cutter *F* forms the teeth on the blank, gradually rotating in unison with the rotation of the blank. The reciprocating movement of the ram carrying the cutter is produced by suitable mechanism within the casing *H* operated by the shaft *G*. The machine is automatic in its action, and cuts spur gears and internal gears. A modified form machine is adapted to cutting the teeth of racks. The cutting action is that of planing.

Gleason Gear Planer. In Fig. 289 is shown the Gleason gear planer which is an excellently designed machine for planing gear

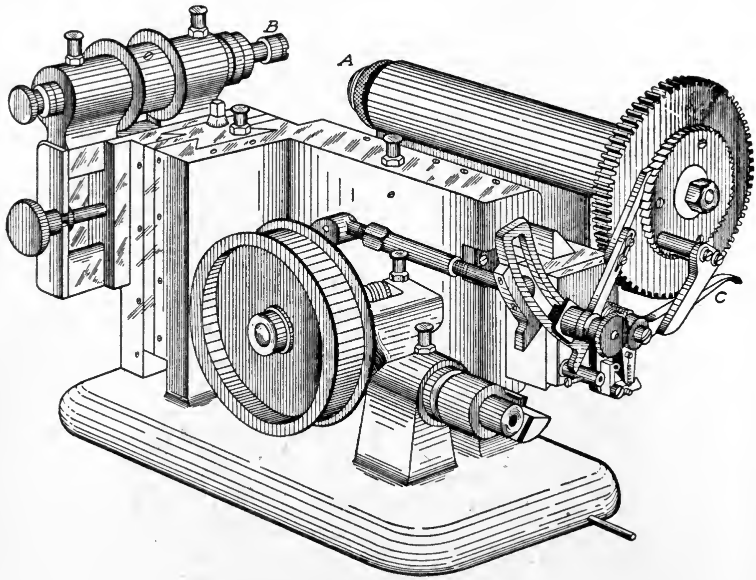


Fig. 287. Bench Gear Cutter
Courtesy of Sloan and Chase Manufacturing Company

teeth with a single tool having a narrow, rounded cutting point. The gear blank *A* is mounted on a horizontal spindle having at its rear end suitable automatic indexing mechanism *B*. The tool *C* is carried in a reciprocating tool block *D*, which travels upon a swinging carriage pivoted at *E* directly under the apex of the base cone of the gear blank. The exact curve and direction of its feed are controlled by one of the formers *F*, *G*, *H*, mounted upon the triangular former carrier *J*, which may be rotated so as to bring either former up to its operative position, forming a rest and guide for the friction roller *K* on the outer end of the swinging carriage. Of the three formers, F is used for a roughing cut, and the other two for the upper and under sides of the tooth. Being placed at a considerable distance from the pivot upon which the carriage swings, they are made many times larger than the tooth, and great accuracy of form is thereby secured. The roughing cut is frequently made with a rotating cutter

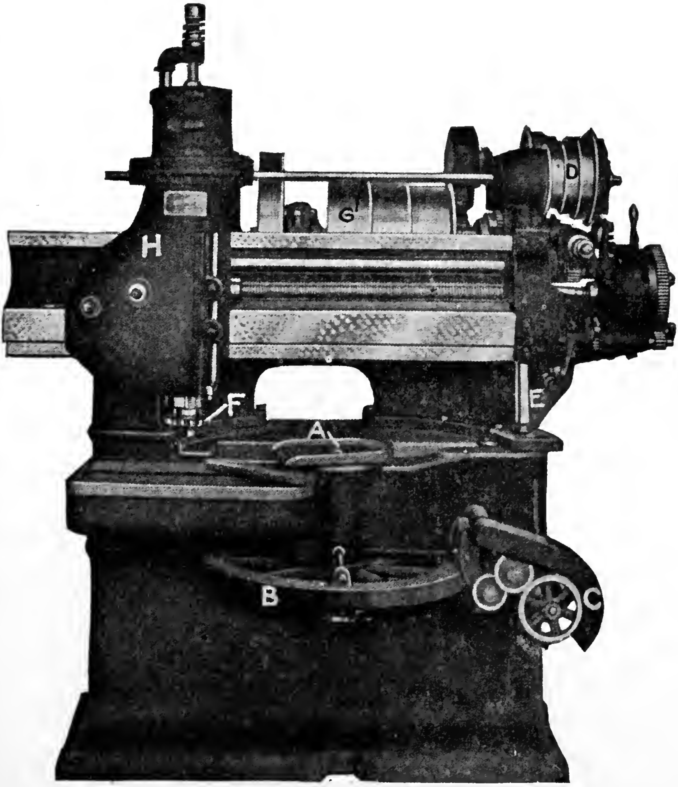


Fig. 288. Gear Shaper
Courtesy of Fellows Gear Shaper Company, Springfield, Vermont

on an ordinary gear cutting machine. Modifications of this machine are built specially for cutting spur gears upon the same principle.

Bilgram Gear-Planing Machine. The Bilgram gear-planing machine, shown in Fig. 290, operates upon a principle similar to that of the machine just described, but with this important difference. In the Gleason machine the tool is caused to move so as to trace the exact contour of the side of the gear tooth, in addition to its reciprocating movement for cutting. In the Bilgram machine, on the other hand, the tool has only a reciprocating motion, while the gear blank

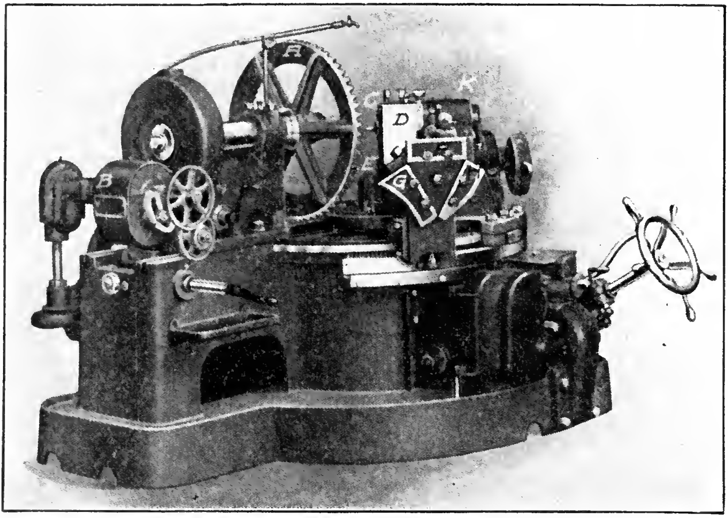


Fig. 289. Gear Planer
Courtesy of Gleason Tool Company, Rochester, New York

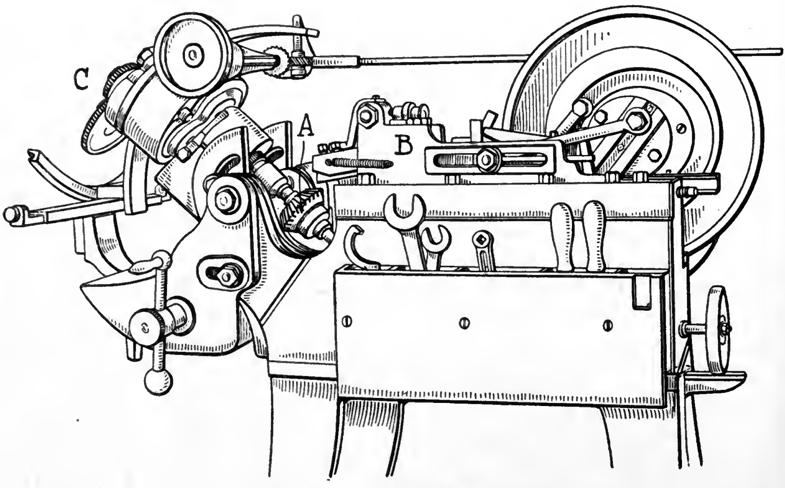


Fig. 290. Gear-Planing Machine

and its supporting mechanism are given the rolling motion similar to that imparted by one rotating gear to another, or that of a rolling cone. To accomplish this, the axis must in the first place be moved in the manner of a conical pendulum. Therefore the bearing of the arbor which carries the blank is secured in an inclined position between two uprights to a semicircular horizontal plate, which can be oscillated on a vertical axis passing through the apex of the base cone of the blank. To complete the rolling action, the arbor must in the second place receive simultaneously the proper rotation; and this effect is produced in the machine by having a portion of a cone (corresponding with the pitch cone of the blank) attached to the arbor, and held by two flexible steel bands stretched in opposite directions, one end being attached to the cone and the other to a fixed part of the mechanism, thus preventing this cone from making any but a rolling motion when the arbor receives the conical swinging motion. In the engraving *A* is the blank to be cut; *B* the ram carrying the cutting tool; and *C* the indexing and rolling mechanism.

TURRET LATHES

The turret lathe, as we know it today, is a comparatively modern machine, and was developed from an ordinary engine lathe by the addition of revolving tool-holding devices called turrets.

The turret was at first made of circular form, and rotated upon a vertical pivot which had a binding nut whereby it could be held in any desired position. The circumference of the circular turret was drilled and reamed for four tools projecting horizontally from it at angles of 90 degrees with each other. Later the number of tool holes was increased to six, and the turret was frequently made of hexagonal form.

The turret was at first located upon a lathe carriage in place of the tool block, and properly set in line with the lathe center by means of the cross-feed screw. The lateral feed, upon which the device depends for its action, was obtained by the operation of the feeding mechanism in the apron attached to the carriage.

The object sought to be accomplished by the addition of this device to the lathe was that of carrying various drilling, reaming, counterboring, and similar tools by which several operations could be performed upon a piece of work without removing it from the chuck, or without any further change of tools than that of revolving the turret. The tools, when once adjusted, required no further alteration as the several pieces of work were completed and removed from the chuck, and other pieces substituted for a like series of operations. By this means the work could be performed much more rapidly, the producing value of the machine being correspondingly increased.

Fig. 291 shows the original form of the turret *A*, supported upon the sliding block *B*. The turret is pivoted upon the vertical stud *C*, and secured in any desired position by the nut. A later development provided means for locating it positively in as many positions as

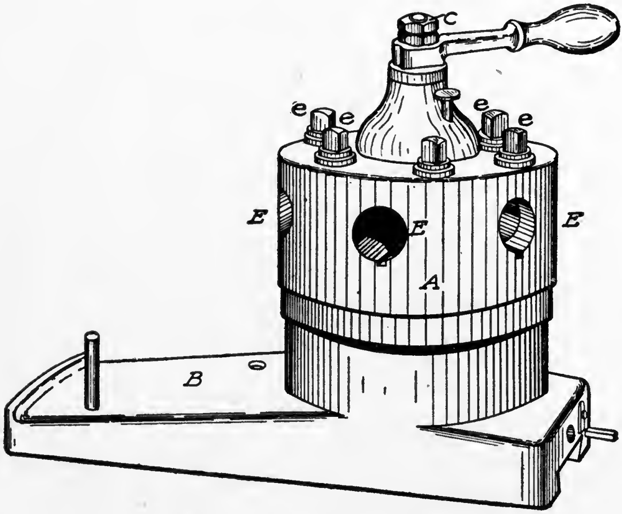


Fig. 291. Original Form of Turret

there were holes for tools. This turret is drilled for four tools, three of which are shown at *EEE* secured by the set screws *eee*.

As the value of the turret mechanism came to be generally appreciated, it was still further developed by the addition to the number of tools that it would carry; by a ratchet arrangement for revolving it; by an index plate for holding it in any desired position; and by various other improvements that will presently be referred to.

These developments soon carried it beyond the scope of the engine lathe, and special lathes were designed in which the improved turret was the principal feature. These are the turret lathes proper, as we find them built today.

Classification of Turret Lathes. To obtain a comprehensive view of the various forms of turret lathes, including engine lathes so modified as to adapt them to turret-lathe work, they may be divided into five classes as follows:

(1) Engine lathes adapted to serve as turret lathes by having a hand-revolved turret mounted upon the carriage in place of the usual tool-block or compound rest.

(2) Engine lathes adapted to serve as turret lathes by having a hand-revolved turret mounted upon a laterally moving slide, supported upon a shoe or saddle fitting the V's of the bed.

(3) The turret lathe proper, specially designed and built as such, with a turret revolved and fed by hand, supported by and pivoted upon a slide, which is in turn supported by a shoe or saddle fitted to the V's of the bed.

(4) A turret lathe designed and built in a similar manner to that last described, and in which there is a power feed for the cuts. It is so arranged that the turret is revolved automatically. This lathe is frequently called a semi-automatic turret lathe.

(5) A complete automatic turret lathe having a power feed for the cuts; a quick return of the turret slide, operated by power; with the turret automatically revolved at the end of its run.

The lathes described in the third, fourth, and fifth classes are usually provided with a carriage called a cross-slide, carrying one cutting tool in front and frequently another tool at the back, inverted so as to cut without reversing the direction of revolution of the work.

A very useful modification of the type described in the third class is called the monitor lathe, probably from the fancied resemblance of its turret to the turret of the type of warship called a "monitor". In this lathe the slide upon which the turret is supported and pivoted is moved back and forth by means of a horizontal hand lever, and is therefore very rapid in its operation. From the fact that this constitutes a rapid hand feed for the turret, this type is adapted for light work or work upon soft metals. For this class of work it is a very rapid and efficient machine. Fig. 292 shows one of these machines. The lever *A* is for operating the turret slide *B*, carrying the turret *C*, which was first revolved by hand but later by a ratchet device located in its base and actuated by a pawl during the latter portion of the movement of the slide in withdrawing the cutting tools from the work. The lever *D* is for operating the cross-slide *E*, carrying a cutting-off tool and frequently a forming tool also.

In a general way it may be said that the turret lathe is one of the most useful and efficient machines in the shop for the production of parts in large (and often in moderate) quantities usually known as repetition work, which can be finished by the operations of turning, facing, boring, reaming, counterboring, or any similar circular work, the machine being equipped with suitable tools for the work undertaken.

This machine is practically identical with that frequently known as a hand screw machine, which has the wire-feed attachment for feeding bars of stock through the main spindle. It is used for making not only screws, but many small cylindrical parts, particularly

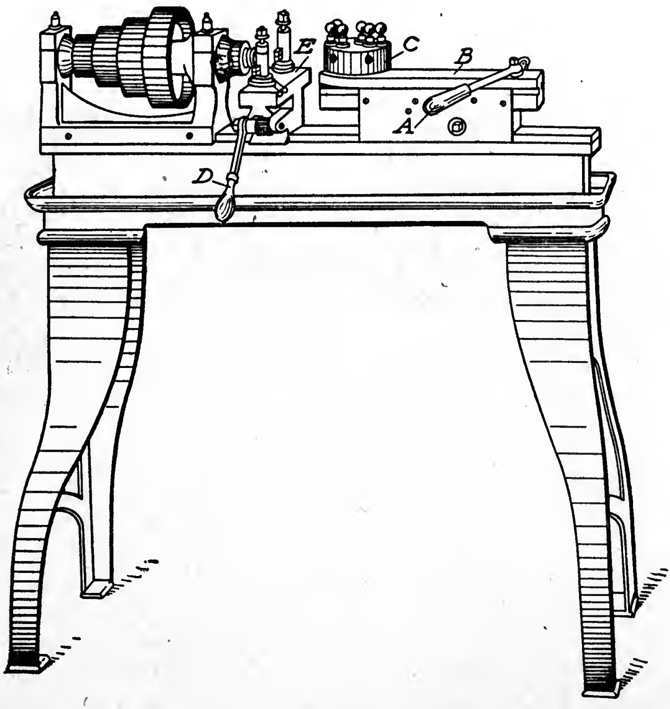


Fig. 292. Form of Monitor Lathe

when the quantities of one kind are not of sufficient number to make it economical to set up the automatic screw machine for their manufacture. The other machine which is the only successful rival of the turret lathe and the hand machine, is of the same family, but known as the "automatic screw machine", which will be illustrated and described later on.

An engine lathe equipped as described in class 1 is shown in Fig. 293. In this particular machine, the turret is of hexagonal form. In the earlier machines it was usually cylindrical. It is arranged to be revolved by hand, and is released or held in place as desired by a plunger operated by the lever *A* and engaging in slots in the periphery of a circular plate attached to the base of the turret. The transverse position of the turret is adjusted by the cross-feed screw *B;* and the lateral movement or cutting feed is by the crank *C*, or by the power lateral feed of the lathe. The turret is pivoted to the shoe *D*, which is quite similar to the one shown in Fig. 291, and fits on the dovetail of the lathe carriage after the removal of the

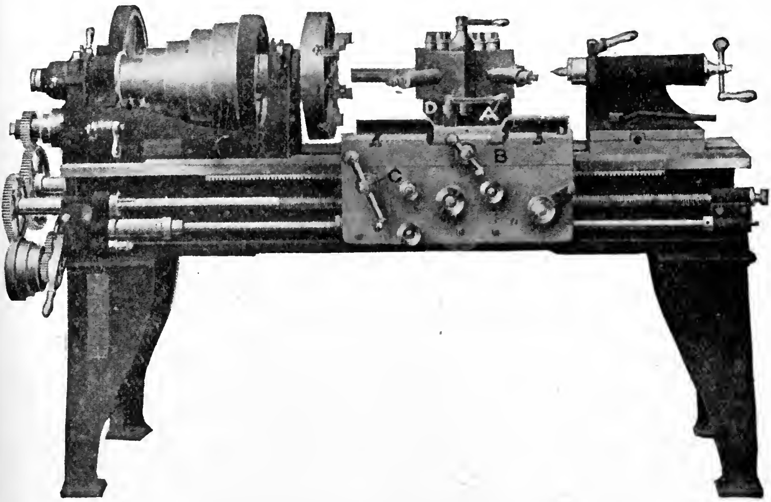


Fig. 293. Engine Lathe with Hand-Revolved Turret on Carriage in Place of Tool-Block

regular compound rest or tool-block. In all other respects this machine is a regular engine lathe.

Fig. 294 shows the machine referred to in class 2. In this case the tailstock of the engine lathe is removed, and replaced by a base *A* similarly attached, which supports the turret slide *B*, upon which is pivoted the turret *C*. The base *A* is fixed at any desired point on the lathe bed. The turret slide *B* is operated by the pilot wheel *D*, and limited in its forward movement by the adjusting screw *E*. Frequently there are several of these screws in a sliding, swinging, or rotating stop-holder, by which device an adjustable stop may be provided for each tool in the turret. The regular compound rest *F* is retained in its place, and may be used to carry forming or cutting-off

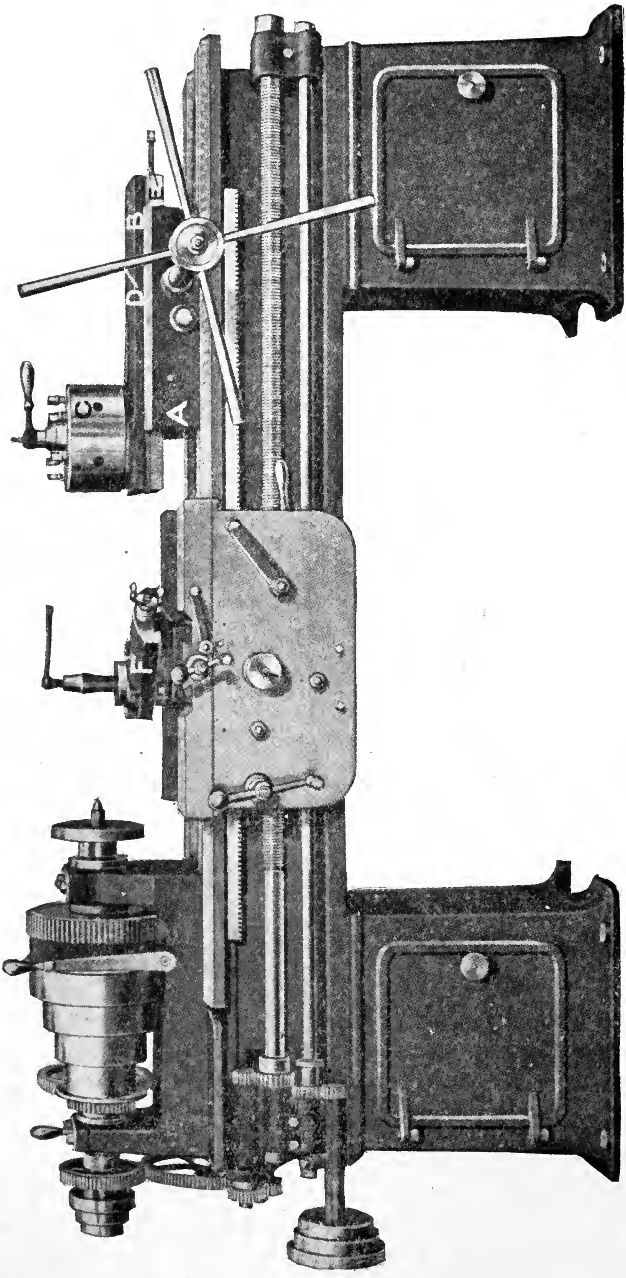


Fig. 294. Engine Lathe with Hand-Revolved Turret Mounted on Latterally Moving Slide

tools. The lathe proper may be any form of an engine lathe. Nearly all manufacturers of engine lathes now furnish turrets to fit either upon the carriage or upon the V's of the bed, for the purpose of doing these classes of work.

The machine specified in class 3 is shown in Fig. 295. It is designed and built as a turret lathe. The base *A*, turret slide *B*, turret *C*, and pilot wheel *D* are constructed and operate as in the last example. The turret slide *A* is provided with an adjustable multiple-stop screw *E*, by which the length of cut of each individual tool in the

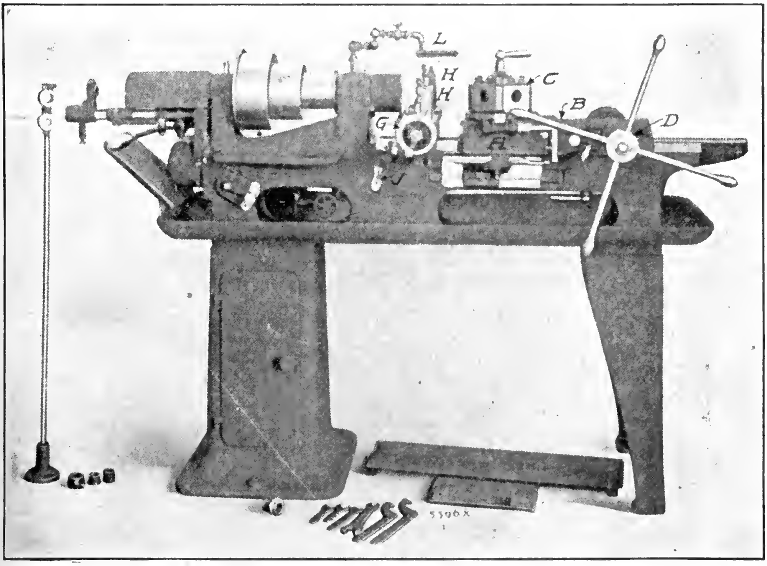


Fig. 295. Turret Lathe, Hand-Revolved and Hand-Fed
Courtesy of Pratt and Whitney Company, Hartford, Connecticut

turret is limited. A simple form of cross-slide takes the place of the carriage on the engine lathe. It is adjustable to any point on the bed. It carries two tool-blocks which may be adjusted in relation to each other by the hand-wheel *G*. The entire top slide carrying the two tool-posts *H H* is operated transversely by means of the lever *J*. By this device, a cutting-off tool may be carried in one tool-post, and a forming tool in the other. This machine is built in various sizes. It is equipped with chucks for taking round and hexagonal rods of different diameters; and with much larger chucks for holding castings and drop forgings which are to be bored, reamed, turned, faced, or formed. It is also provided with what is called a wire feed, by means of which long bars are automatically passed entirely through the main spindle and chuck. This device will be shown and explained in connection with Screw Machines. Provision is made for lubricating the tools by a stream of oil or other lubricant, contained in the tank *K* beneath the machine, whence it is drawn by a small rotary pump (not shown in the engraving) and forced up through the piping *L*, from which it falls upon the cutting tools.

In Fig. 296 is shown a turret lathe fulfilling the requirements stated in class 4. The turret is mounted in substantially the same manner as in the last example, and is automatically revolved at the

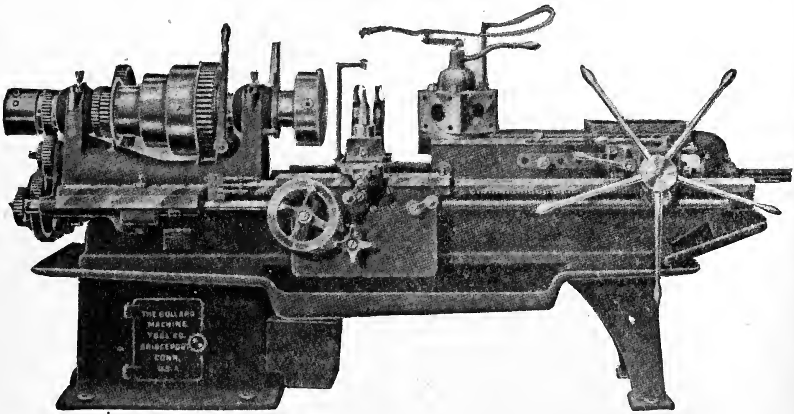


Fig. 296. Semi-Automatic Turret Lathe. Turret is Automatically Revolved at End of Each Stroke
Courtesy of Bullard Machine Tool Company, Bridgeport, Connecticut

end of the return stroke. It is hexagonal in form, and the six faces are not only drilled and reamed for holding tools, but the faces are accurately surfaced, and are drilled and tapped so that large tools and special devices may be bolted to them when necessary or desirable. An elaborate and useful system of adjustable stops controls and limits the travel of individual turret tools. The cross-slide is designed more upon the lines of an engine lathe carriage, and has attached to it an apron which carries the necessary gearing for feeding purposes. The carriage carries tool-posts for one front and two back tools. The movement of the carriage on the cuts is limited by pivoted, adjustable stops for each of the three tools. There is a system of piping for the lubrication of the turret tools, and another for the three carriage tools. The headstock is triple-geared so as to give various gear as well as belt speeds and a powerful drive for heavy work. These changes of the gear speeds are made by levers, without stopping the machine. The main spindle is hollow so as to

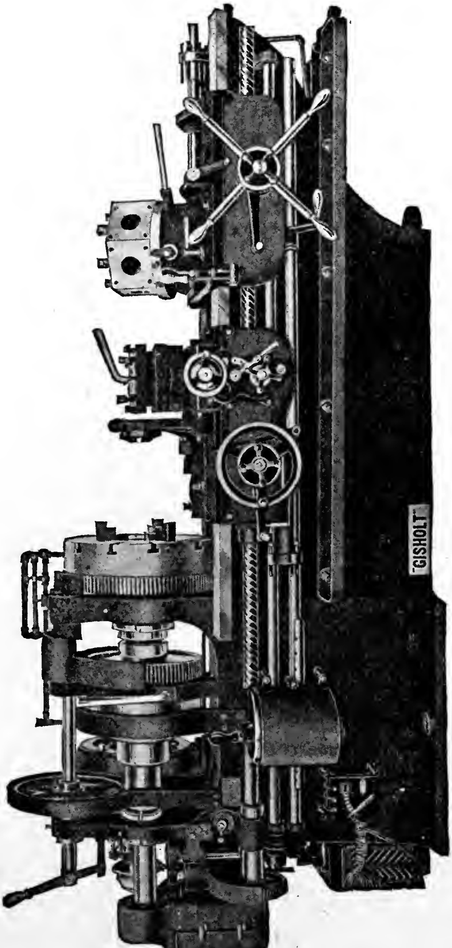


Fig. 297. "I" 24-Inch Turret Lathe with Motor Drive
Courtesy of Gisholt Machine Company, Madison, Wisconsin

take bars through it, and the chucks are adapted to take round, hexagonal, or square bars. There is a taper attachment at the back of the carriage, by means of which tapered as well as straight work can be turned by the carriage tools.

A very complete turret lathe is shown in Fig. 297, as an example of class 5. The turret is mounted upon a carriage fitted to the V's of the bed, and provided with an apron carrying the feeding mechanism. The turret is not set upon a horizontal support and pivoted on a vertical stud, as in the former examples, but it is inclined toward the back of the machine for the purpose of elevating the long turret tools out of the way of the operator. The turret is hexagonal, and the faces drilled and reamed for holding cylindrical shanked tools, and also accurately faced, drilled, and tapped for bolting on large and heavy special tools and devices. The turret is revolved automatically, and the cutting movement is controlled and limited by individual adjustable stops for each turret tool. The lateral movement

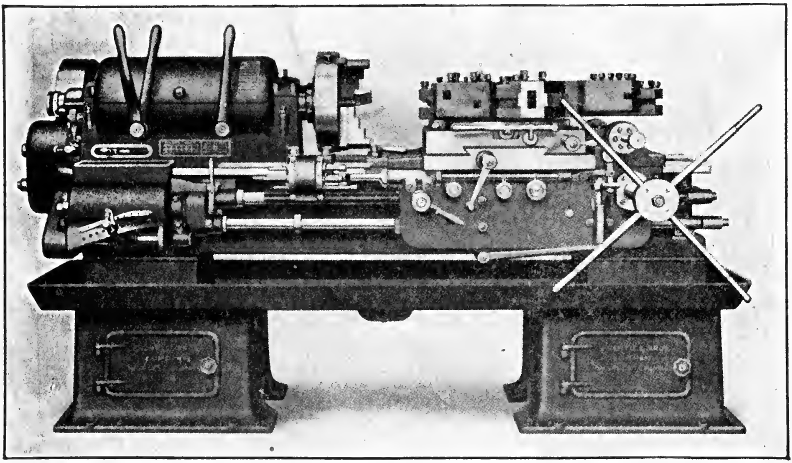


Fig. 298. "Prentice" High-Speed Turret Lathe
Courtesy of Reed-Prentice Company, Worcester, Massachusetts

of the turret is produced by a lead screw of very sharp pitch, so that the return stroke is not only automatic but rapid. Upon a heavy carriage, designed upon the lines of a heavy engine lathe carriage, is mounted a revolving tool-post adapted to carry four tools for cutting-off, forming, turning, etc. A taper-turning attachment is located at the rear of the carriage, whereby tapered work may be as readily turned as straight work. The lateral movement of the carriage is controlled and limited by four adjustable stops at the left, thus providing individual stops for the tool-post tools. Stops are also provided for their transverse cuts. A system of piping is provided, whereby all tools may be lubricated by oil or other lubricant, under pressure from a rotary oil-pump. This form of lathe is built very substantially, and is intended for the machining of large and heavy castings. For this purpose the turret as well as the carriage is equipped with long and heavy tools, some of which will be illustrated and described later on. The headstock of this lathe is very large and substantially built, and is triple-geared so as to give it great driving power for heavy work. It is driven by an electric motor, the rheostat for which is seen at the extreme left of the engraving, near the floor. In Fig. 298 is shown an automatic turret lathe built by the Reed-Prentice Company of Worcester, Massachusetts.

Fig. 299 shows what is known as the flat turret lathe, so called from the design of the turret. In this case the tools are not placed

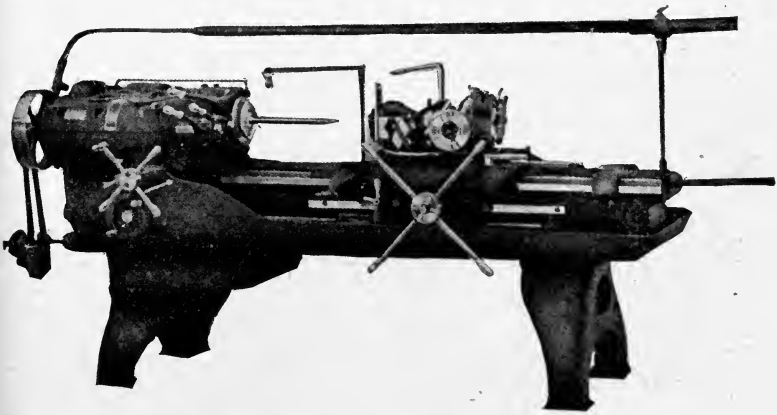


Fig. 299. Flat Turret Lathe, with Special Tools Bolted to Top of Flat Plate
Courtesy of Jones and Lamson, Springfield, Vermont

in tool holes in the outside of the turret nor bolted to the faces of it. On the contrary, they are bolted down to the upper surface of a horizontal, circular plate. It is a radical and most successful innovation in the designing of a turret lathe, and requires tools and fixtures specially designed for its use.

In other examples we have what is called the hollow hexagonal turret, which, instead of being made solid as in Fig. 293 and numerous other examples, consists of walls of sufficient thickness to properly support the tool-holders and the tools bolted to it.

Turret-Lathe Tools. A great variety of tools are used in the turret lathe, for an indefinite number of uses, as the different forms of pieces to be machined are of a never-ending variety of shapes which almost defies any attempt at analysis or classification. It is possible, however, in a general way, to separate these tools according to the work which they are designed to do, as follows:

(1) For the Turret: Centering tools, drills, reamers, counterbores. For the Cross-Slide: Cutting-off tools and plain forming tools, as for finishing the end of the bar after a machined piece is cut off, cutting a groove in the work before it is cut off, etc.

(2) For the Turret: Plain box tools containing a turning tool and a back rest, both adjustable to different diameters; taps and threading dies and holders for the same; forming tools that may be run on the end of a cylindrical piece of work. For the Cross-Slide: In addition to the cutting-tools, horizontally moving and vertically moving forming tools. (Occasionally these tools may be so made as to move in an inclined direction.)

(3) For the Turret: Box tools carrying several turning or forming tools, or both, with the necessary back rests, bushings, etc. For the Cross-Slide: Facing tools; multiple tool-holders, carrying, turning, cutting-off, and forming tools, and special tool-posts.

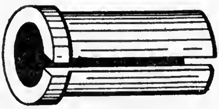


Fig. 300. Split Collet

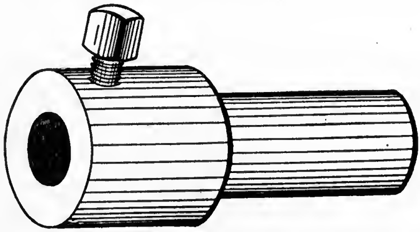


Fig. 301. Plain Drill Holder

(4) This class includes a large number of special tools and fixtures for use in both the turret and cross-slide, by which a great variety of work of all sizes and forms is successfully machined.

Tools for the Turret. Drills, reamers, boring bars, counterbores, etc., may have shanks formed upon them, or may fit in collets fitted to the tool-holes in the turret, or in plain drill-holders. A split collet is shown in Fig. 300; and a plain drill-holder, in Fig. 301.

Taps and dies may be held in the releasing holder shown in Fig. 302. The shell *A* is fitted to the tool-hole in the turret, through which the shank of the holder *B* passes and is permitted to revolve freely, except when the two are locked together by the pins *CC* when pressure is applied against the face of the die-holder, or by the pin *D* when pressure is exerted in the opposite direction. In the medium position, both pins are inoperative. This permits right- and left-hand dies to be used, the machine being reversed at the proper moment.

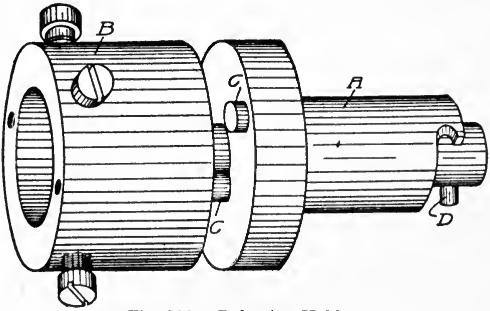


Fig. 302. Releasing Holder

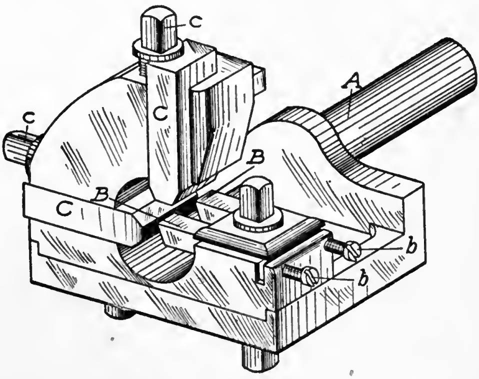


Fig. 303. Simple Box Tool

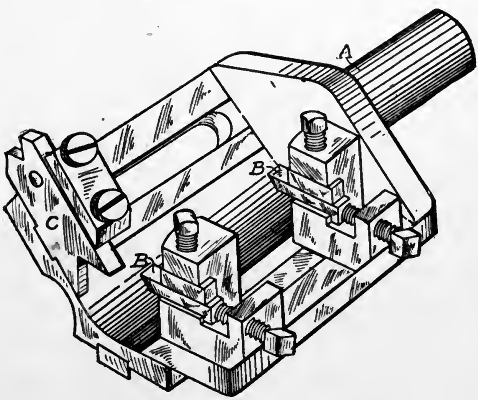


Fig. 304. Double Box Tool

Fig. 303 shows a simple form of box tool, in which *A* is the shank entering the tool-hole in the turret; *BB* are the cutting tools, adjusted by the screws *bb;* and *CC* are the jaws of the back-rest device adjusted to the diameter of the turned portion of the work by the screws *cc.* Of the two tools, the leading one is for roughing, and the other for finishing.

In the box tool shown in Fig. 304, the two tools *BB* are adjustable with relation to each other; hence two shoulders may be turned upon a piece of work simultaneously, at a required distance apart. One box tool may make the roughing cuts, and in the next tool-hole may be a similar box tool with its tools set to make the finishing cuts. The back-rest jaw *C* is also adjustable, so as to keep it directly back of the leading tool. If the box tool is so constructed as to have the tools *BB* at a considerable distance apart, two back-rest jaws may be necessary, being set in the slots shown.

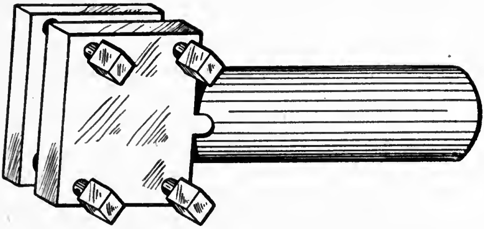


Fig. 305. Simple Tool Clamp

Fig. 305 shows a simple form of tool clamp in which a variety of tools having square or rectangular shanks, such as inside boring tools, may be clamped, thus enabling the operator to use ordinary lathe tools for many simple jobs.

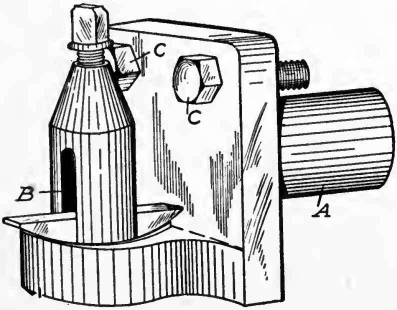


Fig. 306. Turret Holder for Tool-Post

Fig. 306 shows a turret-holder for a tool-post *B*, adapted to tools similar in form and purpose to those of Fig. 304, but with greater rigidity, as the shank *A* is secured in the tool-hole, and the cap screws *CC* hold it rigidly to the face of the turret.

Fig. 307 shows a well-designed box-tool device, providing for two tools and four back-rest jaws, all adjustable in any direction that may be necessary. At

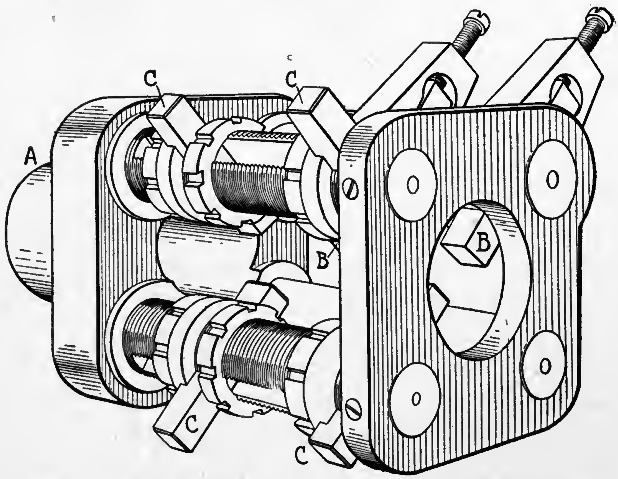


Fig. 307. Box Tool Holder for Two Tools and Four Back-Rest Jaws

A is the shank to be entered in the tool hole in the turret; *BB* are the two tools; and *CCCC* are the four back-rest jaws.

The large tools that are bolted to the faces of the turret will be shown in the engravings illustrating turret-lathe operations.

In Fig. 308 is shown a well-designed form of cross-slide, carrying two tools very rigidly secured and capable of adjustment in all directions horizontally; the tools may also be inclined. The base *A* supports the two tool-blocks carrying the tools *BB*. The base *A* may be moved transversely across the lathe-bed by means of the hand-wheel *C*, which is a very steady and well-controlled movement suitable for broad-faced forming tools or for facing tools; for narrow

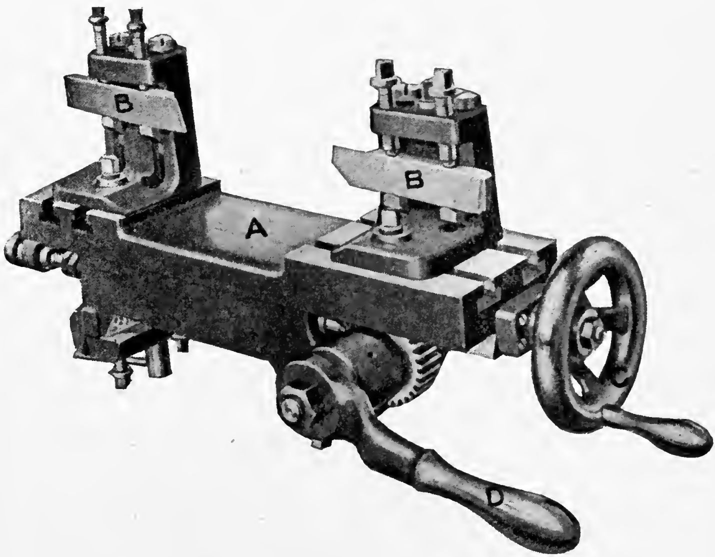


Fig. 308. Cross-Slide Carrying Two Tools

or cutting-off tools, recourse is had to the rack-and-pinion device operated much more rapidly by the lever *D*.

The tools held in the tool-holders (commonly called box tools), in tool-posts, or in the various styles of tool-holders for the cross-slide, and in many of the special tool-holders of fixtures, are usually short pieces cut from a square or rectangular bar of tool steel of suitable dimensions for the work and the holding fixture. They are roughly shaped at the cutting point, hardened, and then ground to the form desired. In using what is commonly known as high-speed steel for these tools, short pieces are broken from the bar; and the proper forms for the cutting point or edge are obtained by grinding, no forging operation being necessary. While the forms usually used in lathe tools are also used in this class of cutting tools, there are many others, the particular form of work to be done determining their shape.

Turret-Lathe Operations. The particular sphere of the turret lathe, and the use of the various tools and tool-holding devices, can be best explained by illustrating and describing some of the more important operations in the machining of castings of the usual forms.

Some of the practical observations applicable to the handling of the work and the tools are given, and their importance should be fully realized by the novice in attempting turret-lathe work.

Great care should be used to have all tools, tool-holders, attachments, fixtures, etc., securely clamped in place, so that there will be no danger of their working loose, and vibration will be eliminated as far as possible.

The tools should be ground to the correct shape, and the finishing tools should be carefully stoned with a fine-grained oil-stone so that their cutting edges will be smooth and keen. They will then do much smoother work, and the cutting edges will last much longer.

Generally there must be a roughing and a finishing cut, the same as in an ordinary lathe. In the turret lathe the two cuts are made by different tools, so as to avoid constant changes of adjustment.

Stop-gages should be carefully set so that correct dimensions may be produced when the turret slide or cross-slide, as the case may be, is run firmly against the stop, but so that there is no straining or forcing of it. Unless care is used in this respect, correct dimensions cannot be maintained.

Proper speeds must be used, according to the material to be machined and the diameter of the work. The same speeds will be used as for engine lathes. When tapping or threading dies are used, the speed, on the cut, must be very materially reduced.

In chucking comparatively thin cylindrical work, it should be held by the outside, as there is much less danger of breaking it than if it is held by the inside.

In machining heavy-rimmed balance wheels, they are frequently held by the inside of the rim so as to leave the outside and face clear for the tools.

Pulleys and similar light wheels are frequently held by the arms, which rest against suitable supports so as to avoid distortion and to leave the rims and hub free for machining operations.

In boring operations, particularly deep holes, the tool should be made with a long guiding end or pilot, which may enter a bushing in the main spindle of the machine before the tool commences to cut. This will reduce vibration and chatter, insure a true hole, and prolong the life of the tool.

When the piece of work is comparatively long—that is, projects to a considerable distance from the chuck—the outer end should be

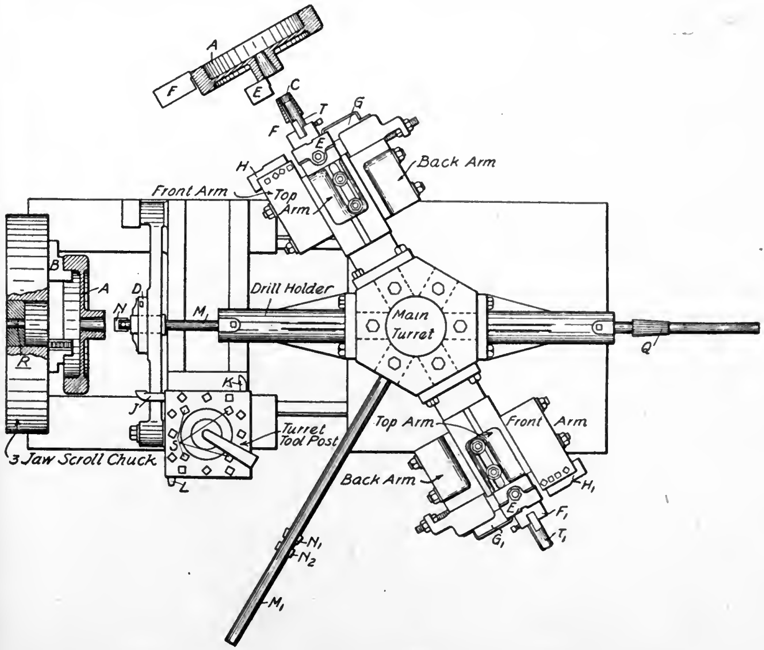


Fig. 309. Turret Lathe Arranged to Machine Webbed Balance Wheel

run in a center rest similar to that on an engine lathe, to hold it true and rigid, and to insure true and accurate work.

Fig. 309 is a plan of the chucking arrangement; the turret and its tools; and the cross-slide tool-block of a turret lathe arranged to machine a webbed balance-wheel. It is to be finished all over, and must therefore require two operations.

First Operation. The wheel is chucked as shown at *A* on the inside of the rim, by the chuck-jaws *B*. This leaves the outside of the rim clear for the turning tools. The cored hole is first rough-bored with the cutter N in the end of a boring bar M, which is held in a steady rest or drill-support D. The hole having been rough-bored, the boring bar M is withdrawn, and the steady rest D thrown back out of the way. The turret is rotated so as to bring the boring bar M_1 into position. The forward end of this bar is supported by a bushing H in the main spindle. The two cutters N_1 and N_2 are for roughing out the hole preparatory to using the taper reamer Q on another face of the turret. While boring with the bar M_1, the scale is broken on the web and hub by the tool-post tools shown at

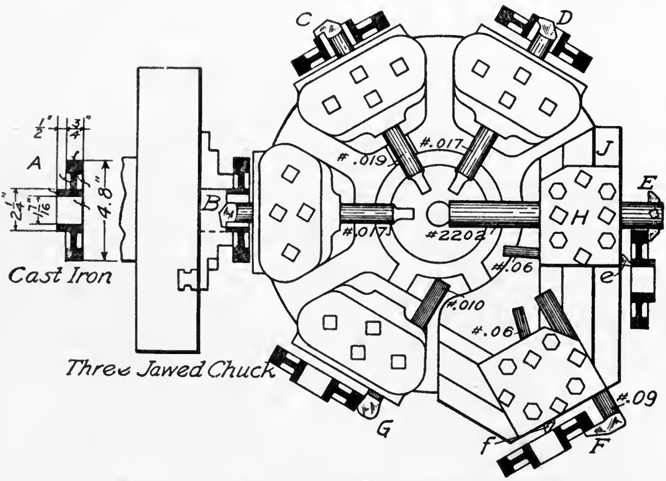


Fig. 310. Arrangement for Machining Spur-Gear Blank

J and K. The scale on the periphery is broken by the tool J. The turret is revolved so as to bring the taper reamer Q into position, and the end of its bar enters a bushing in the main spindle. A taper bushing C is inserted in the taper hole for receiving the supporting arbor or pilot T in the facing head, as shown at the top of the engraving. The balance-wheel is rough-faced, and the outer surface of the rim turned with the cutters E, G, H, and F in the facing head. This brings the piece approximately to size. For finishing these surfaces, the cutters G_1, E_1, H_1, and F_1, in the finishing head are used, this head being supported in the taper bushing C_1. The finishing cuts are very light.

Second Operation. These cuts being completed, the balance-wheel is removed from the chuck, reversed, and again placed in the chuck, which has in the meantime been equipped with slip jaws of soft metal, bored out so as to exactly fit the curvature of the wheel. The piece is still further supported by a tapered arbor projecting from the hole in the main spindle and accurately fitting the taper-reamed hole. The turret is equipped with tools similar in form and purpose to those described. The scale is broken by tools in the rotating tool-posts, as in the first operation. The first set of tools rough off the face of the rim and hub, and face the web. The second set finishes these surfaces completely, and the operation is completed.

The operations for machining a spur-gear blank are well shown in Fig. 310. In this case a flat turret is used on the machine shown in

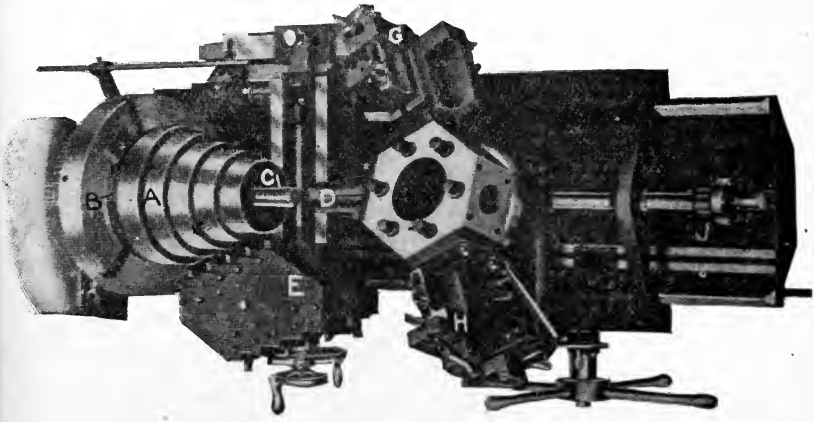


Fig. 311. Turret Lathe Arranged to Machine Outside of Cone Pulley

Fig. 299. At *A* is shown a section of the finished piece of work, giving the actual dimensions. The casting is chucked by the hub, as shown at *B*. At each of the other five faces the piece of work is represented as mounted, with the tool arranged in proper relation to it to make the required cut. The rough boring having been completed, the turret is revolved to the next face, and the hook tool *C* faces the back of the hub. Upon the next turn of the turret, the boring tool *D* makes a finishing cut in the bore, bringing it to an exact diameter. Another turn of the turret, and the bar *E*, with its inside facing cutter, faces the rear side of the rim, while a facing cutter *e* faces the front of the hub. It will be noticed that the tool-holder *H* travels along the slide *J*, thus providing for the necessary feed for both the tools *E* and *e*. The next movement of the turret brings into

action the finishing tools F and f, which finish the rear face of the rim and the front face of the hub, operating in a similar manner to the tools E and e. A final turn of the turret brings the round-nosed turning tool G into position, and turns the outside diameter of the gear blank, completing the operation. Upon this machine, provided with the tools shown and operated as described, an iron casting of the dimensions given can be completely machined by an expert operator in from eight to ten minutes. The same work done upon an engine lathe would require four or five times as long.

A much more complicated series of operations is presented in Figs. 311 and 312. In Fig. 312 is shown the first of the series of

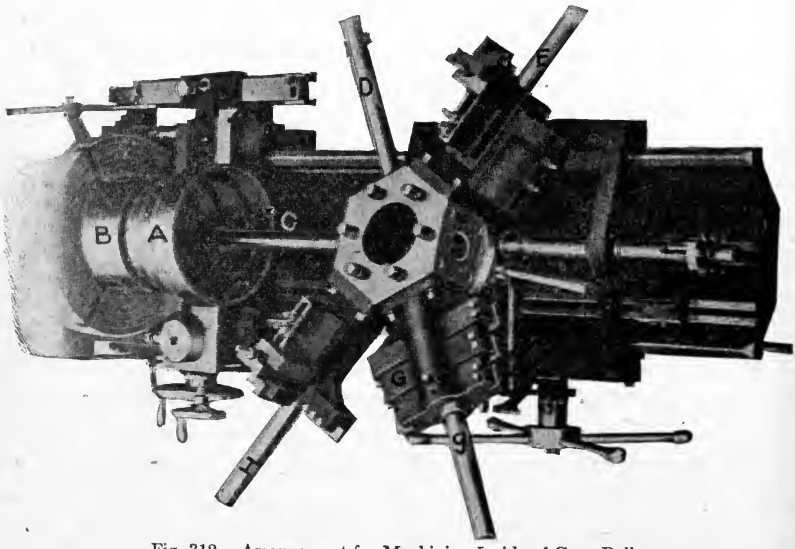


Fig. 312. Arrangement for Machining Inside of Cone Pulley

operations, comprising the machining of the inside of the cone. In Fig. 311 the series of operations necessary to finish the outside are shown. Referring to Fig. 312, it will be seen that the cone-pulley casting A is supported upon the second step from the small end by the cylindrical base B. Within this the three jaws of the chuck grasp the smallest step of the cone, holding it very rigidly and securely in place. The boring bar C carries the cutters for rough-boring the cored hole. Its inner end is supported by a bushing in the main spindle, as shown in Fig. 309. The next turn of the turret brings the boring bar D into action, which finishes the hole to the proper diameter. The next tool *E* faces the edge of the rim on the largest step of the cone. The face *F* of the turret carries no tool. Tool *G* is a very important, compound tool whose work is to finish the inside of the larger three steps, and also to face the annular surfaces between the steps. It consists of a massive casting, bolted to the turret face and divided into three double-ended arms, each of these ends carrying a tool of proper form for the inside turning and facing, making six tools in all. Through the center of this tool-holder is an arbor or steadying bar *g*, which passes through the bushing in the main spindle and holds the tool-carrier steady and in its proper central position. The tool *H* serves to finish the inside of the largest step, for a short distance from the face, to the accurate diameter for fitting the flange that supports this end and furnishes a hub through which its shaft or spindle passes.

The second series of operations is shown in Fig. 311. These operations consist of machining the outside of the cone-pulley casting *A*, that portion of the inside of the larger end finished by the tool *H* in the first series of operations fitting over a circular disc *B*, through slots in which the chuck jaws are forced outwardly against the cone casting. In fixing the casting in position, an arbor *C* projects from the bored hole, and is entered in a reamed hole of the same diameter in the centering fixture *D* attached to the turret, whereby the outer end of the cone-pulley casting is quickly and accurately centered. This fixture also serves as an excellent support for the outer end of the cone during the process of turning and facing the outer surfaces. The special revolving tool-block *E* carries on one side five tools for turning the outside of the cone steps, as shown in the illustrations, and, on the opposite side, five facing tools for facing the annular surfaces between the steps. In the operation of turning the outer surfaces, it is necessary to crown them—that is, to make the center of each step of slightly larger diameter than at the two edges, as in ordinary pulleys. To accomplish this, the taper attachment *F* is brought into use, being set to give the larger diameter on the side toward the chuck and turning half the width of the outer surface; the setting is then reversed for turning the other half. As all five surfaces are turned or faced simultaneously, the operation is very rapid when compared with the work of an engine lathe. The inside of the small end of the cone is finished with the tools *G* and *H* in the usual manner. In all turret operations, the lateral travel of the turret is controlled and limited by the revolving multiple-stop device at *J*.

There are many devices and adjunct fixtures in use upon the turret lathe; and their number, as well as the ingenuity of their design and the extent of their usefulness, is constantly increasing. So numerous are they that no attempt is here made to show and describe them. The same, in a lesser degree, may be said of the turret-lathe tools. At the same time, there is a very large range of work constantly done on turret lathes with the most ordinary equipment. It was formerly assumed that the turret lathe could be used with economy only when at least a hundred pieces were to be machined. It is ordinary practice at the present day to use the turret lathe when as few as a dozen pieces (and sometimes less) are required. As the value of the turret lathe and its efficiency come to be better understood, its usefulness is better realized and appreciated.

AUTOMATIC SCREW MACHINES

The automatic screw machine, in its design and method of operation, is a highly developed type of turret lathe, its cutting tools being carried in some form of turret. By the term turret, as used in this connection, is understood a revolving, multiple tool-holder, whether rotating on a vertical or on a horizontal axis; and whether consisting of a single casting having the necessary tool-carrying appendages, or of a cylindrical form carrying a series of sliding, tool-carrying spindles. The principles upon which it is designed and constructed, and upon which it operates, are the same.

The automatic screw machine, as originally designed, was intended principally for making small screws and studs; hence it was called a screw machine. The flexibility of its plan, and its adaptability to a large range of operations, encouraged its development along other lines of work. Normally it was adapted to making screws, studs, and similar work from a bar, which was passed through its hollow spindle from the back of the machine, and was pressed forward against a stop carried in one of the tool-holes in the turret whenever the chuck was opened sufficiently to release the bar of stock. The device which fed the bar through was operated by a weight, and was called a wire feed, originally from the fact that screws were made from pieces of straightened wire. The same device, built of sufficient weight and strength, is capable of feeding quite large bars of stock through a machine of many times the capacity thought possible in the early years of the development of this machine. This wire feed device operated automatically, it only being required to introduce a new bar when that in the machine was used up.

The predominant feature in the design of the automatic screw machine, after the use of the turret, is the employment of drum cams, upon which are fixed a series of removable cam members suitable to the piece of work to be made, and by which the automatic movements of the different operative parts of the machine are produced. It is because of the action of these cams that the machine is classed as automatic.

By automatic, we mean a machine in which all of the movements are mechanically made, including the bringing of a new length of work through the chuck, upon which the various operations are made in succession so that the operator has only to keep the cutting tools sharp and to put in another bar of stock when one has been entirely used up. By semi-automatic, we mean a machine in which the rough piece of work is placed in the chuck by the operator, and on which all the various operations—such as drilling, boring, reaming, forming, facing, etc.—are mechanically performed, as well as the rotation of the turret. Thus the machine operating on bar work can readily be made automatic in a strict definition of the term; while if the pieces are small and separate castings, drop forgings, and the like, they must be placed in the chuck by the operator, and the chuck closed, before the automatic work of the machine commences.

There are built, however, machines of this class, in which the castings or drop forgings are placed in a sort of magazine or hopper, whence they pass to the chuck, in which they are gripped ready for the subsequent machining operations, this work being entirely automatic and the only attention required from the operator being that of keeping the magazine full of pieces and the tools sharp and properly adjusted.

Types of Automatic Screw Machines. *Manufacturing Automatic Chucking and Turning Machine.* Fig. 313 shows a Potter and Johnson machine, called by them a manufacturing automatic chucking and turning machine. It is a good example of a semi-automatic machine which has nearly all the features of the typical automatic screw machine, and at least one feature that is not adaptable to a machine making the pieces of work from a bar run through the hollow spindle and carrying cutters by which the back of a piece of work held in the chuck is automatically faced. This is accomplished through the lever *C*, rod *D*, and cam *E*.

The headstock is triple-geared so as to provide for ample power for heavy work, this gearing being changed to the desired speeds by a simple lever mechanism. The turret is mounted in the same manner as in a turret lathe, upon a laterally moving slide. This, however, is actuated by suitable connections to the drum cam *A*, the cam

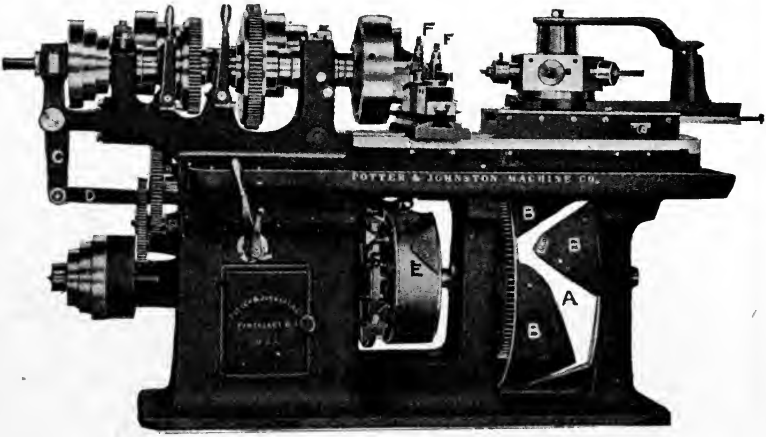


Fig. 313. Automatic Chucking and Turning Machine
Courtesy of Potter and Johnston Machine Company, Pawtucket, Rhode Island

tracks of which are composed of removable plates *BB* fitting the surface and attached by screws. The turret has five faces; consequently there are five sets of these plates, which may be so shaped and arranged as to give any length of stroke desired. Usually a full stroke is given to the turret slide, the act of cutting being confined to the latter part of the stroke. The cross-slide is equipped with two tool-posts *FF;* and the tools can be arranged to work at the same time that the turret tools are cutting—or separately, as the nature of the work may require. The cross-slide may also be provided with tool-blocks for carrying blades or forming tools for special work. It is operated through a rack-and-pinion device from a cam *G*, and the triangular actuating blocks upon this cam can be adjusted in any required positions around the circle that may be necessary to produce the required movements. The cams A, G, and E are fixed to the same shaft, which makes but one revolution during the cycle of movements necessary to complete one piece of work. This feature is the same in all the different types of this class of machines.

While the machine shown was designed for handling separate pieces of work, as castings, drop forgings, etc., the removal of the back facing bar, and the substitution of a wire or rod feed with an automatically operated chuck, would convert it into a machine adapted to machine pieces automatically from the bar.

The latest type of Potter and Johnston chucking and turning machine is shown in Fig. 314.

Cleveland Automatic Machine. Fig. 315 shows a Cleveland automatic machine, of which several variations of the same style

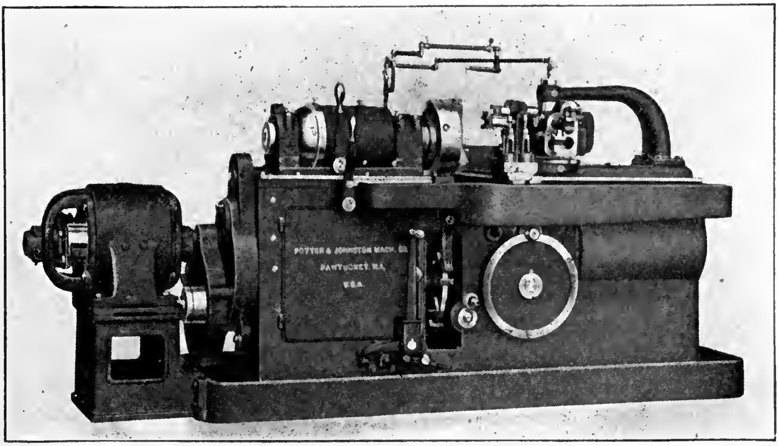


Fig. 314. Latest Type of Automatic Chucking and Turning Machine
Courtesy of Potter and Johnston Machine Company, Pawtucket, Rhode Island

are built. The main spindle A is driven from the system of pulleys B, the belt being controlled by the automatically operated shifter C. At D is shown the device for opening and closing by hand the chuck in the head E of the main spindle A when setting the machine. The mechanism by which the bar of stock is forced forward through the chuck, is at F.

The turret mechanism is at G, and consists of a cylindrical device with its axis in a horizontal position and journaled in the housings at H H, sliding in the left-hand housing in making the cut. This form of turret is exceedingly rigid. The tool-holes are bored in the end of

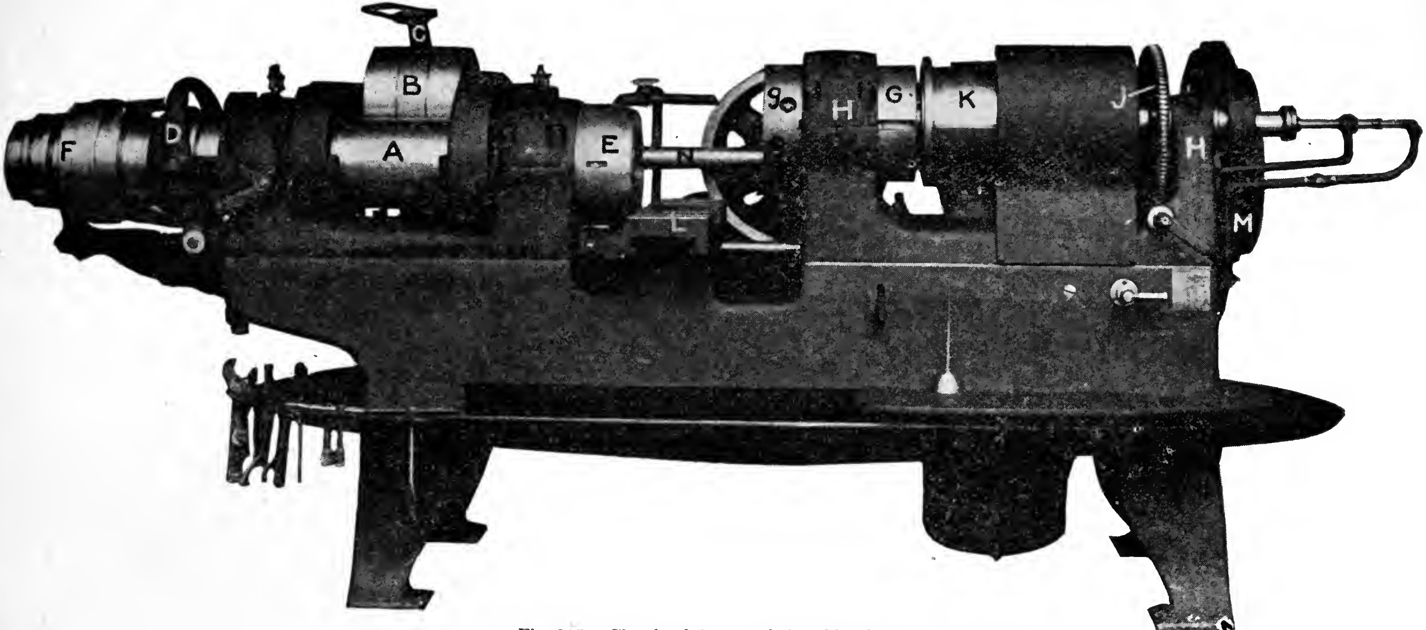


Fig. 315. Cleveland Automatic Machine Shown for Analysis

the cylindrical portion *g*, and the tools secured by set screws, as shown. The turret is moved forward and back by a mechanism oper-

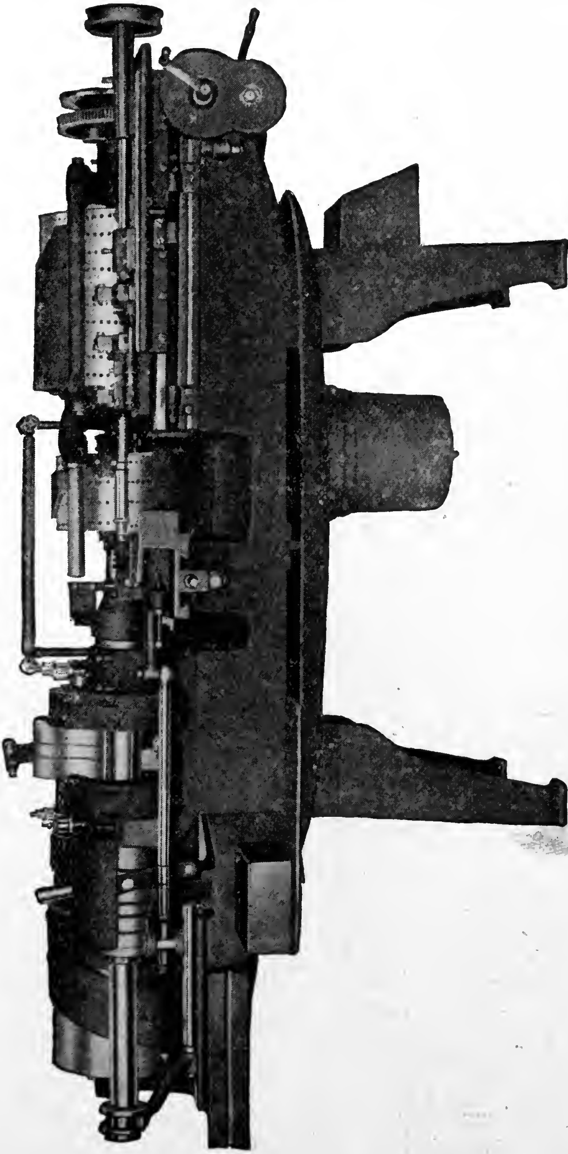


Fig. 316. Latest Type of Cleveland Automatic Machine
Courtesy of Cleveland Automatic Machine Company, Cleveland, Ohio

ated by the shaft *N;* and is revolved on the back stroke by suitable helical cams, a portion of which is shown at *K.* In setting the machine, the turret is operated by the crank *M*, upon whose shaft is a worm engaging the worm wheel *J*.

The cross-slide *L* is arranged for two tool-posts, and is operated by a suitable mechanism in the rear. It is adapted for carrying forming tools as well as the usual cutting-off tools.

There are a number of interesting and valuable attachments furnished with these machines, among which is one for slotting screw-heads, and for slabbing or milling at a time, two sides of square or hexagonal heads by a straddle mill. There is also a third spindle

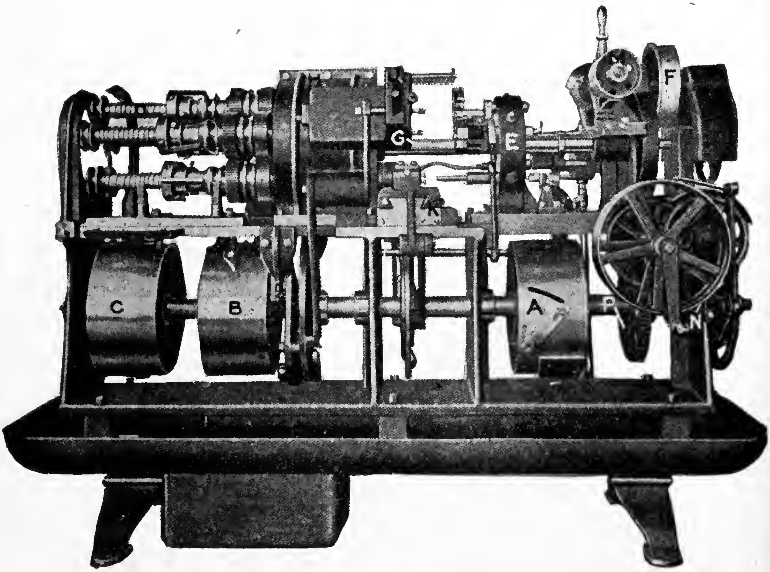


Fig. 317. Universal Multiple-Spindle Automatic Screw Machine

speed attachment, in which the center pulley *B*, usually an idler, is utilized as a driver; and by the addition of a set of differential gears, the spindle speed is reduced in a ratio of three to one, giving a slow speed for threading large work. By this means the spindle speed can be as rapid as is possible for the use of high-speed steel tools, and still have a slow speed available for large tapping or threading.

In case solid dies are used and the threading done with the belt on the pulley *B* (now a driver), the belt is thrown to one of the other pulleys, and the fast reverse speed used to run the die off the work. A magazine attachment is also made for automatically feeding castings or drop forgings down to the chuck, so as to dispense with the services of the operator on this class of work, except to see that the magazine is kept supplied with work.

In Fig. 316 is shown the latest type of Cleveland "automatic".

Universal Multiple-Spindle Automatic Screw Machine. This machine, Fig. 317, is of a type distinctively different from either of the previous examples. The operative parts are operated mostly by the usual drum cams, three of which, *A*, *B*, and *C*, are used. The peculiarity of the design of this machine is that the work is carried in five revolving spindles at *D*, while axially opposite them are five tools. The revolving spindles carry five bars of stock, upon all of which work is being done simultaneously. The results secured by this arrangement are that the work necessary for completely finishing a piece is no longer than that required for performing the longest single operation, regardless of the number of operations required on the piece.

The machine is driven by a single belt upon the pulley *F*, the power being transmitted by spur gearing to the center shaft *G*, which runs through the spindle head *H*, at the left of which it is connected by spur gears with the five spindles at *D*. There are three cross-slides *J*, *K*, and *L*, the tools of which act at the same time as the box tools or other tools usually carried in a turret. The cam shaft carrying the cams *A*, *B*, and *C* is driven by a belt from the pulley *M* to the two pulleys *N*, which, by means of differential gearing, give two speeds to the shaft; on the latter is a worm engaging the worm wheel *P*, thus providing for a rapid speed for indexing, and a quick advance and return of the tools. The belt is shifted automatically to the inner pulley, which drives the shaft slower for the feeding of the tools on the cut. The squared end of the cross-shaft provides for a crank which may be used to rotate the mechanism when setting the machine.

The design of the machine is very ingenious, and its output on small work should be very large in consequence of having five or more tools continuously employed during the time that in the usual type of machine there is one (or, at most, two) in active operation.

Brown and Sharpe Automatic Screw Machine. This machine, shown in Fig. 318, is of a type quite distinct from any of those above described. It will be noticed that the machine is very compact when compared with some of the others previously illustrated. This being the case, it is necessary to show sectional and other views, in order properly to explain the mechanism so that it may be understood.

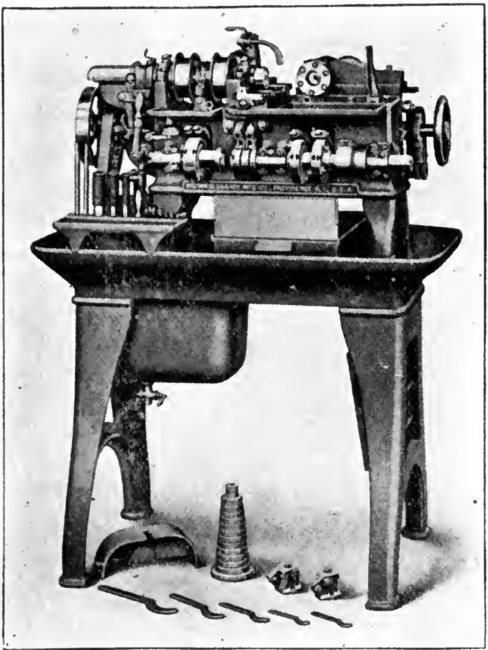


Fig. 318. Brown and Sharpe Automatic Screw Machine, No. 00 Size
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

Fig. 319 is a front elevation showing a section through the spindle, spindle boxes, pulleys, etc. The main spindle runs in phosphor-bronze boxes. The front bearing is adjustable, and is adjusted by nuts *1* and *2*. The thrust is taken by a hardened steel washer *5*, and adjusted by the nut *4*. Friction clutch pulleys *10*, running on ball bearings, drive the spindle.

Fig. 320 is a rear elevation of the machine, and is introduced to illustrate more completely its construction.

The friction clutches are conical; the clutch bodies *11*, Fig. 319, are forced into the pulleys by sliding the sleeve over the levers *12*, which have for one fulcrum

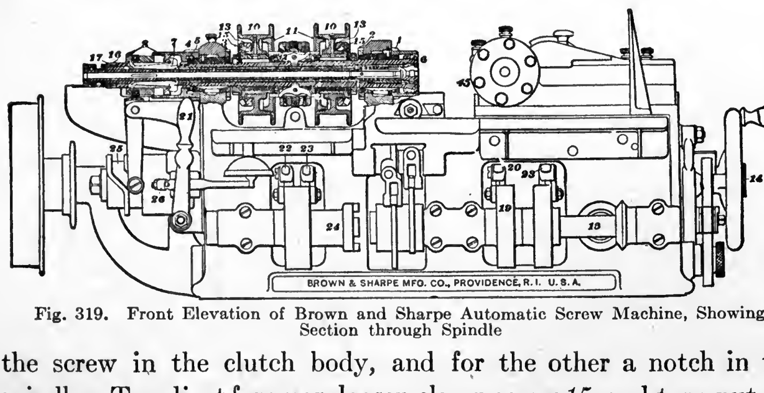


Fig. 319. Front Elevation of Brown and Sharpe Automatic Screw Machine, Showing Section through Spindle

the screw in the clutch body, and for the other a notch in the spindle. To adjust for wear, loosen clamp screw *15*, and turn nut *13*.

The clutch sleeves are set central, to give an equal pressure on both pulleys, by means of the screws *27*. In making this adjustment, there is a slight play allowed in the clutch fork to avoid friction, except at the point of reversal.

The spindle is reversed to run backward by the spring plunger *42*, which, when released, instantly engages the clutch with the pulley nearest the chuck. To run forward, the clutch is reversed by the cam *31*, to engage the other pulley. This cam is operated by the clutch *32*, and at the end of the revolution is drawn out by the lever *23*. At the time of reversing the spindle to run forward, the

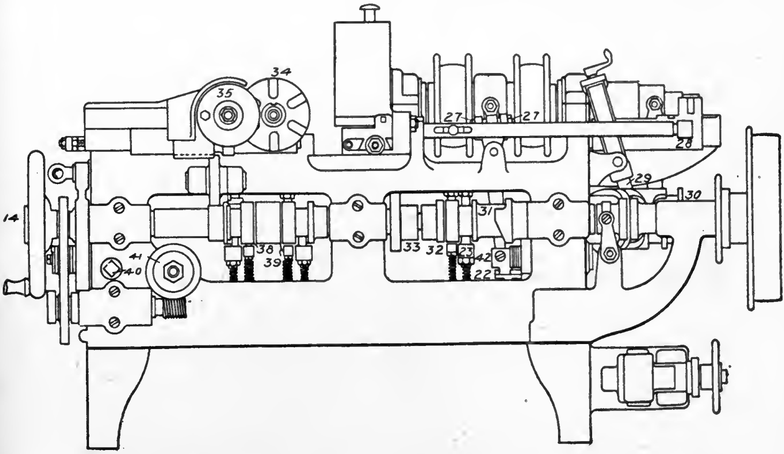


Fig. 320. Rear Elevation of Brown and Sharpe Automatic Screw Machine

action of the cam compresses the plunger spring ready for the next reversal; the plunger is held in place by the wide part of the lever *22*. The levers *22* and *23* are lifted to reverse the spindle at the proper time, by adjustable dogs on the carrier, shown below them in Fig. 319. If the work is to be threaded, this carrier shaft is connected by the positive clutch *24* to the cut-off cam shaft *18*. When changing cut-off cams, the clutch is disengaged and can remain in this position, for work not threaded. Should it be desired to both thread and tap work, or to cut two threads on the same piece, two or more sets of dogs can be used on the carrier.

The spring collet that holds the stock has no end movement, thus providing for the accurate feeding of the stock regardless of slight variations in size. It is closed by means of the sleeve *6*,

Fig. 319, which is tapered inside and slides over the collet. This sleeve is operated by the tube extending through the spindle to the chuck-levers *7*, which in turn are operated by the sleeve *8* through the lever and cam *25*. The chuck mechanism is operated and the chuck fed by the cam *25*, which is driven through spur gears *33*, by the positive clutch *39* on the driving shaft. By depressing the lever underneath the clutch, shown in Fig. 320, the clutch is engaged and makes one revolution; it is then disengaged by the pin in the lever acting upon the cam surface of the clutch, and returns to its original position.

To adjust the chuck, the nut *17* is loosened, and the nut *16* turned until the holding capacity of the chuck is properly regulated; then the nut *17* is tightened, and both nuts are locked by means of the spanner wrenches provided.

The main feed-shaft *14* is driven by the pulley shown at the head of the machine. This pulley is engaged by a positive clutch operated by the starting lever *21*, Fig. 319. Thus the feed is always under complete control. A hand wheel provided with a handle is used for operating the mechanism when setting the machine.

The stock is fed in the usual manner by a feed-tube, the outer end of which is connected by a latch to the slide *28*. This slide has a slot in which is a sliding block connecting it to the lever *29*, which in turn is operated by the cam *25*. The sliding block is adjusted by a screw and crank, as shown in Fig. 320, and, as the lever *29* always moves a fixed distance, the length of feed is regulated by varying the position of the block. A graduated scale is mounted on the slide, and indicates the length of feed.

The feeding fingers are changed by lifting the latch at the rear end of the tube, and withdrawing the feed-tube. These fingers are threaded left-hand.

When it is desired to feed more stock than the usual capacity of the machine, two or more dogs can be used on the left side of carrier *19*, Fig. 319, and the feeding mechanism operated several times.

The turret *45* is mounted vertically on the side of the turret slide, Fig. 319. It has a long taper shank that forms the bearing in the turret slide, and is rotated by a hardened roll in the disc *35*, Fig. 320, which engages the radial grooves in the disc *34* on the rear end of the turret shank. The revolutions of the turret are thus made very rapidly and with no noticeable shock. It is locked in position by a hardened taper pin which is withdrawn by a cam.

The turret slide receives its forward motion for the cutting tools through a bell-crank lever operated by a cam on the shaft *40*, Fig. 320, which is driven through spur gears by the shaft and worm gear *41*.

The quick return and advance of the turret slide, and the revolving of the turret, are controlled independently of the turret-slide feed-cam, by a crank, while the roll on the bell-crank lever is passing from the highest point of the turret-slide feed-cam to the point of starting the next cut. The crank is operated by gears at the rear of the machine, driven by the positive clutch *38*, Fig. 320, on the driving shaft, with lever and other parts for making one revolution, as described in connection with the feeding mechanism. As the crank revolves, it allows a spring to return the turret slide without the rack. The turret is then revolved as described; and when the crank comes to rest after making one complete revolution, the machine is ready for the next operation.

The cross-slides are operated by the cut-off cam shaft *18*, Fig. 319, which is driven through bevel gears by the worm-wheel shaft *41*, Fig. 320.

The front slide has a direct lever or segment of a gear; the back slide has, in addition, an intermediate lever or segment to reverse the motion, thus bringing the cams for operating both slides into a convenient position. The form of that part of the cam controlling the quick movement of the slides is the same for both. The segments mesh into racks that extend beyond the slides. The outer end of these racks is threaded and provided with nuts for adjusting the cuts of the tools. Stop-screws are also provided to insure accuracy in forming.

The cross-slide tools have circular shanks, and are held in place by screws. Eccentric nuts are provided on screws that allow the tools to be easily and quickly adjusted to the proper height. These tools are sharpened on the face without changing the outline, the same as formed milling cutters.

The tools are lubricated by a geared oil-pump of ample capacity, provided with suitable piping. The pump is not stopped with the disengaging of the feed-clutch, thus insuring a large, steady stream of oil as soon as the tools begin to cut.

In Fig. 321 is shown a No. 2 Brown and Sharpe automatic screw machine.

Hollow Mills. For turning the bodies of small screws, the shoulders on studs, and many similar operations, hollow mills are used. A simple form of one of these is shown in Fig. 322, which has three cutting edges. An improved form is shown in Fig. 323, consisting of a collar through which pass three set screws, their points

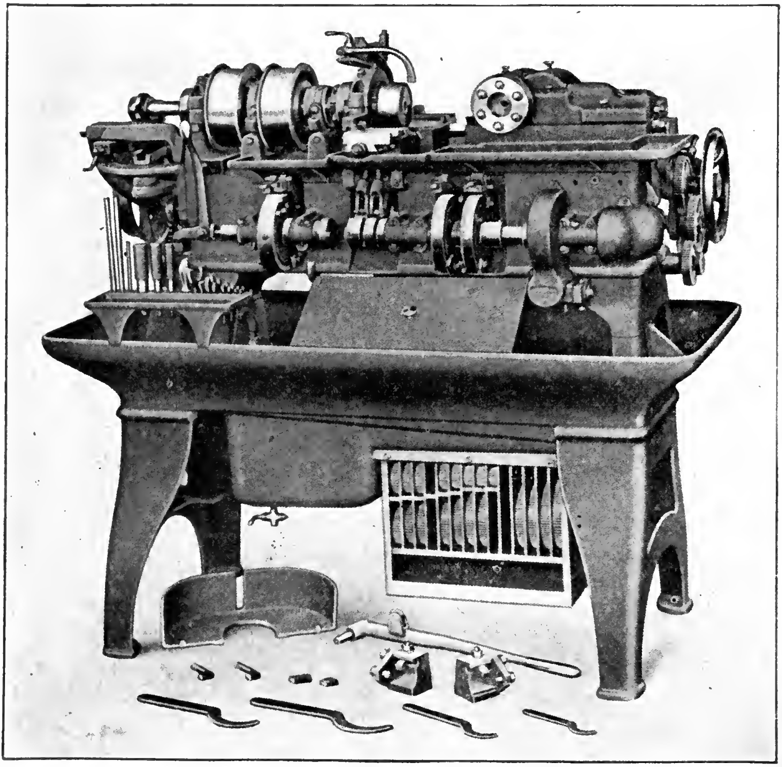


Fig. 321. Number 2 Automatic Screw Machine
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

bearing upon each of the cutting sections, by which means they can be adjusted when so worn that work comes too large. A better form of the hollow mill is shown in Fig. 324, which is constructed with three adjustable blades, whereby the tool may be set for a considerable variation in diameter.

Setting-Up the Machine. A variety of types of automatic screw machines have been shown and described, in order that the reader may familiarize himself with those built by different manufacturers, and so be able to handle whatever kind he may be required to set-up for the job in hand. The great variety of work which the turret lathe and the screw machine are called upon to perform, renders it impossible to describe all the operations necessary for such work; but a few general directions may be given that will nearly always apply:

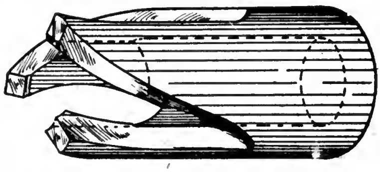


Fig. 322. Hollow Mill with Three Cutting Edges

When making work from the bar, it is first necessary to select and place in the machine the proper chuck, and to arrange at the rear end of the main spindle for the support of that end of the bar. If a rod feed is used, that is next attended to. A stop is now fixed in one of the tool-holes in the turret, against which the end of the bar is forced by the automatic rod-feed. This stop is set so that the bar may be forced out of the chuck only far enough to make the required piece, and to furnish space for the cutting-off tool of the tool-slide to work. The box tools should next be set, and the cutters adjusted to the diameter. The adjustable stops for the travel of the turret for each cut will now be adjusted, the machine started, and each tool brought into action and its adjustment corrected. Supposing that two box tools are used, the stop will be in tool-hole No. 1, and the box tools in Nos. 2 and 3. If the job requires very accurate diameters, a roughing and a finishing box tool will be needed for that portion requiring the delicate work. This will be No. 4. If the smaller diameter is to be threaded, the die will be set in No. 5. If this is a solid die, the belt shifter must be set, by the proper location of the dogs on the shifter cam to produce the reversed motion for

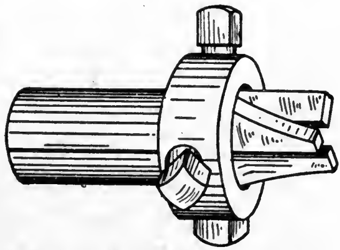


Fig. 323. Improved Hollow Mill

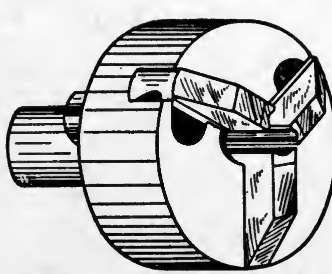
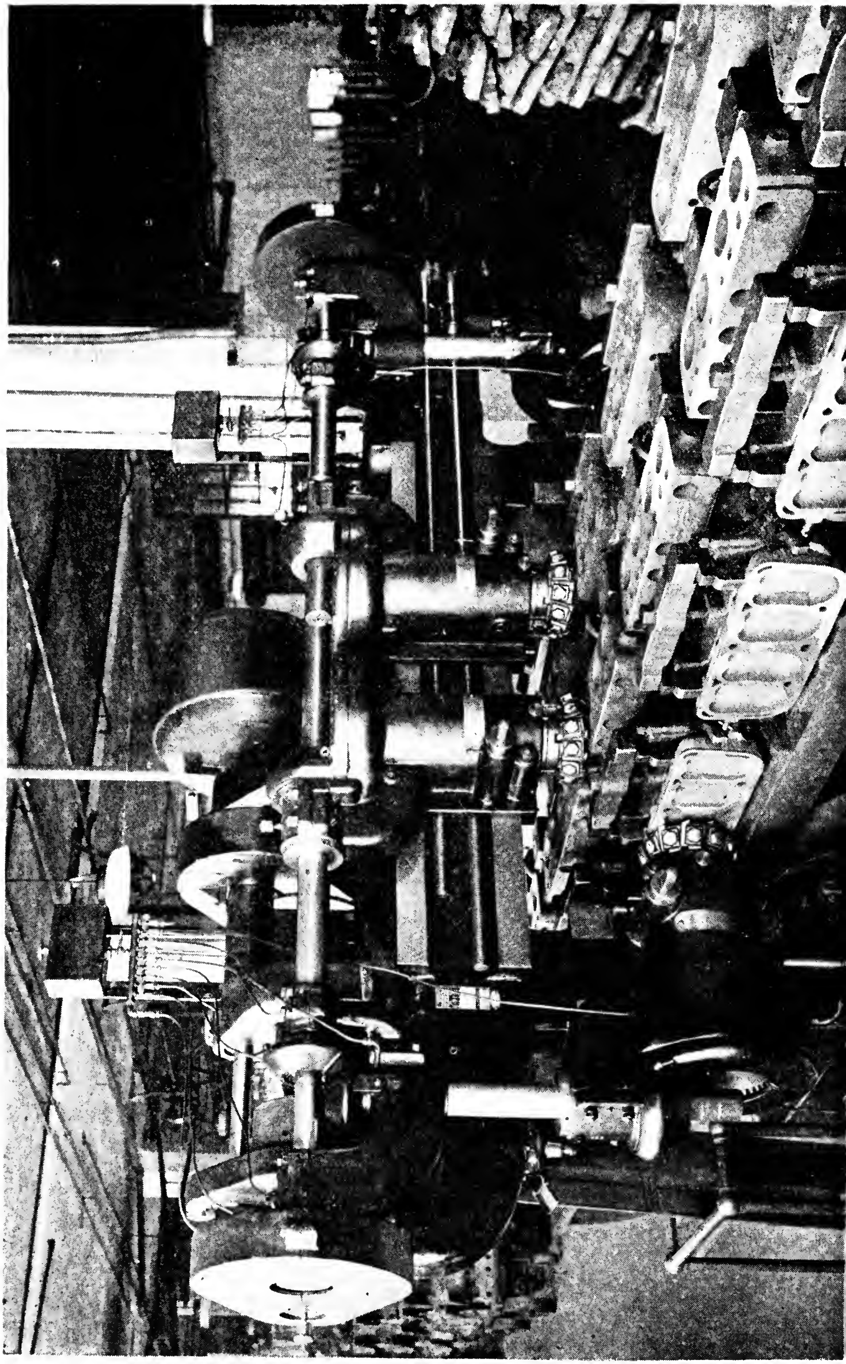


Fig. 324. Hollow Mill with Three Adjustable Blades

backing off the die, and then for the forward motion of the next cut. A pointing tool may be set in No. 6 for finishing the end of the piece after the thread has been cut. The cutting-off tool is now adjusted. In some cases the back tool of the cross-slide is made a forming tool for finishing the end of the piece that is to be cut from the bar, or for rounding or chamfering it; after which the cutting-off tool advances and severs it from the bar. These operations having been provided for, the chuck-operating cam is adjusted to open the chuck at this point, permitting the rod-feed device to force the bar through and against the stop in tool-hole No. 1, after which it should immediately close on the bar, and the cycle of movements be repeated. The drum cam for producing the lateral movement of the turret will not usually need to be changed. The mechanism for revolving the turret will ordinarily be left without readjustment in setting-up the machine for a new job.

If separate pieces, as castings or drop forgings, are to be machined, the first operation is usually boring the hole; then reaming it. If a considerable degree of accuracy is required in the diameter of the hole, there will be a roughing and a sizing cut before using the reamer. The succeeding cuts will depend so much upon the shape and the necessary working surfaces of the piece, that no general sequence of operations can be given.

There is probably no machine in the modern manufacturing plant that requires greater ingenuity and fertility of resources than the selection and setting-up of the automatic machine so as to realize the greatest measure of economy and efficiency.



MACHINE SHOP WORK

PART V

MODERN MANUFACTURING

Machine Building vs. Machine Manufacturing. While machine work in general, and the use of machine tools in particular are much the same in all shops, the methods employed in *machine building* and in *machine manufacturing* are essentially different.

Construction Methods. In machine building only a small number of machines are built in a single lot and it is seldom that they are worked upon in any consecutive order. For example, while several machines of the same kind may be under construction, they may stand in all stages of construction from that of those nearing completion or even completed to some upon which construction has just begun. In some shops, this is so much the fact that machines are constructed only after the order for them has been placed. When manufacturing machines, however, the process is a very different one. Here the work is done in lots of considerable size and each operation on each piece is consecutively performed.

Types of Workmen. The workmen in a shop producing machines by manufacturing methods are differently placed than they are in shops building machines in small lots, perhaps a machine at a time only. In the latter case the workmen may, during the same day, perform lathe work, milling, drilling, bench, and floor work; while in a shop which manufactures machines in considerable lots, the workmen usually works on one machine during the term of employment. This has led to the development of workmen who term themselves lathe hands, planer hands, etc., each workman specializing in the handling of a single machine tool and seeking employment as a specialized machinist. In certain shops, notably those building automobiles, this specializing process has proceeded to such an extent that the workman performs but a single operation on a machine. For example, he may be employed on a lathe to square up the end of crank shafts, which come to him in sufficient quantities to keep him continuously employed during his working day. If the shop is run on a twenty-four hour, three-shift basis, he may in this case be one only, of three workmen, each of whom does the same operation on the same single purpose machine.

PRODUCTION METHODS

Single Purpose Machines. If the reader has carefully followed the above, he will realize somewhat the extent to which modern organization of workmen has proceeded. Another development has been the construction of single purpose machines. For example, Fig. 350, page 294, shows a machine constructed for the single purpose of drilling the clearance holes on solid threading dies. On this machine a single operation only can be performed, but by the use of four spindles and five work-holding chucks, a die is completely finished at one stroke of the table. Single purpose machine tools of any sort can now be bought in the open market, as, for example, single purpose lathes, grinding machines, etc.

In other cases, instead of purchasing single purpose machines, the regular types have been changed by the use made of special attachments, tools, jigs, and fixtures, to perform either a single operation only, or at least a slight range of operation.

Specialized Cutting Steels. Modern investigations have led to the adoption of specialized cutting methods and cutting tools in up-to-date manufacturing. At the very center of these shop efficiency methods stands the newer types of cutting steels. These have so revolutionized metal cutting operations that production has been in many cases more than doubled.

Cutting Lubrication. By means of properly designed machines and pumps, and by experiment in the uses and nature of numerous oils and mixtures, it is now common practice in some lines of cutting to practically submerge the cutting operation with some one of the several cutting lubricants.

Cutting Speeds. These have been increased from the older series of possible cutting speeds to an extent which has led one enthusiast to predict that the time was not far distant when steel and iron would be cut as rapidly as wood.

Cutting Feeds. The great increase in the weights and consequent rigidity and massiveness of the present-day machine tools, as well as the modern work-holding devices, has made possible an increased feeding of the cutting tool little realized by the older machinist.

Automatics. Under this head may be classed those machines which produce the work in a more or less completely finished state with the least attention. While no machine is so constructed that it can be classed as fully automatic, there are many on the market which are so complete in their action that a single attendant will care for and keep in operation as many as a dozen machines.

Automatic Control. Much advance has been made in recent years in devising means of controlling the operation of machines from a central point. Electrical, hydraulic, and pneumatic devices have been and are being introduced which have for their objective the possibility, when once the machine has been adjusted, of controlling its operations by the movement of a lever or the pressing of a button. Such a control is already in certain use upon large planers, boring mills, etc.

Cold Worked Metals. It has been found that certain machine parts, such as screws, shafts, pulleys, etc., can be formed into their proper contours by pressing, rolling, or squeezing processes, in a manner which admits of a lesser first cost, than that of cutting them from the solid in a lathe, milling machine, or other machine tool. As this work is performed without a previous heating of the stock, it is classed as "cold working".

Die Casting Machine Parts. This process consists in casting, in suitable closed dies under pressure, a previously melted alloy. Parts of small and delicate machinery as well as instruments are often produced in this manner so accurate in dimension and perfect in finish that they are assembled without added machine work.

Special Molding Processes. Machine manufacturing is in many cases confined to producing a machine, many of whose parts are made of iron castings in which exact accuracy of fitting is not necessary. The ordinary loom and certain lines of agricultural machinery are notable examples of such machines. By construction of special molding processes, notably that of machine molding, it is possible to produce many machine parts sufficiently accurate to render them directly usable after having been cleaned and common snags removed.

Special Die Forgings. While the ordinary forged piece is seldom suited for use in accurate machine construction without previous machining, several firms are now producing special die forged machine parts of an accuracy in dimensions and perfection of finish that leaves little to be desired.

Heat Treatment. Under this head comes the modern method of giving to many machine parts such as spindles, shafts, gears, cones, clutches, and many others, a special heating and cooling treatment. The production performances of our modern machines are in many cases made possible only because the constructor has learned that certain steel parts when heated and cooled in a predetermined scientific manner are given an added strength to resist wear or breakage.

Ball Bearings. The use in machines of specialized ball bearings has gained rapidly in recent years. While in the case of machine tools their use has been more largely confined to such machines as drillers, their certain use is everywhere self-evident.

Bearing Alloys. Where accuracy of bearing and closeness of fitting is especially desirable, the older type of plain bearing is believed by many machine construction engineers to be the better. To ensure the proper wearing qualities under the varying conditions of service, it has become desirable that the several bearing alloys be carefully studied and their characteristics tabulated.

Bearing Lubrication. Correct proportions of bearing surface to the load, a suitable bearing alloy, and assured bearing lubrication are sought. In studying bearing lubrication, all these must be considered.

Drives. *Belt Drives.* The belt manufacturer has helped to solve this problem by producing belting suited to the machine constructor's needs. Most conditions of temperature, humidity, and pliability have been met by the belt-maker. Many experiments have been made and published by engineers to show what a given belt may be expected to do under varying conditions of heat, cold, and dampness.

Geared Drives. Machines designed for heavy roughing cuts are often provided with a complete geared driving mechanism in which all the speed changes are made through trains of gearing and engaging clutches.

Motor Drives. Instead of driving by means of trains of belting there is an increasing tendency toward the use of direct driving. This is usually done by direct connection of an electric motor to the driving mechanisms. In shops where the machines are fitted with individual motors, it may be so complete that no belting is to be observed.

Jigs and Fixtures. Where strict interchangeability of parts is essential, special work-holding and tool-locating devices are indispensable if a low manufacturing cost is to be attained. These are known as jigs and fixtures.

Time Study. The nearer to a minimum cost a machine can be constructed while maintaining a proper commercial standard, the greater are the chances that the business will be successful. It is, therefore, among other things, extremely important that the lowest possible labor cost shall be ascertained. In modern efficiency work, an exhaustive time study is made of each operation performed in the shop until definite time figures are obtained and recorded in the manager's office.

Motion Study. This term is used to designate that particular line of investigation which has for its objective the elimination of all unnecessary movements in performing a given piece of work. Investigation has shown that an untrained workman when performing even the simplest of operations may, and usually does, make many entirely useless movements to get his results.

Overheads. Under this name are classed all those expenses of manufacture which cannot be as directly charged to production as can labor cost and the cost of materials. They include such items as heat, power, light, insurance, depreciation, taxes, office help, executives, beside others, and are known as the shop burden.

Selling Costs. The cost of selling the manufactured machines may or may not be charged to their cost under the head of "overheads". In any case it must be at least approximated if not exactly known and, of course, charged along with the previous items to the production costs.

PRODUCTION MACHINES

The brief review of modern machine methods given in the preceding pages indicate the trend of the developments being made by the progressive construction engineers. The modern machine constructor makes use of the work of scientists whenever it touches his line of production, and in fact is ever reaching out and searching the world for new production ideas. In the following section will be briefly described and illustrated a few of the more modern special or specialized machine tools used in machine manufacturing.

GRINDING MACHINES

Range of Usefulness. While in many shops the grinding machine is used only as a finishing tool on parts which require a

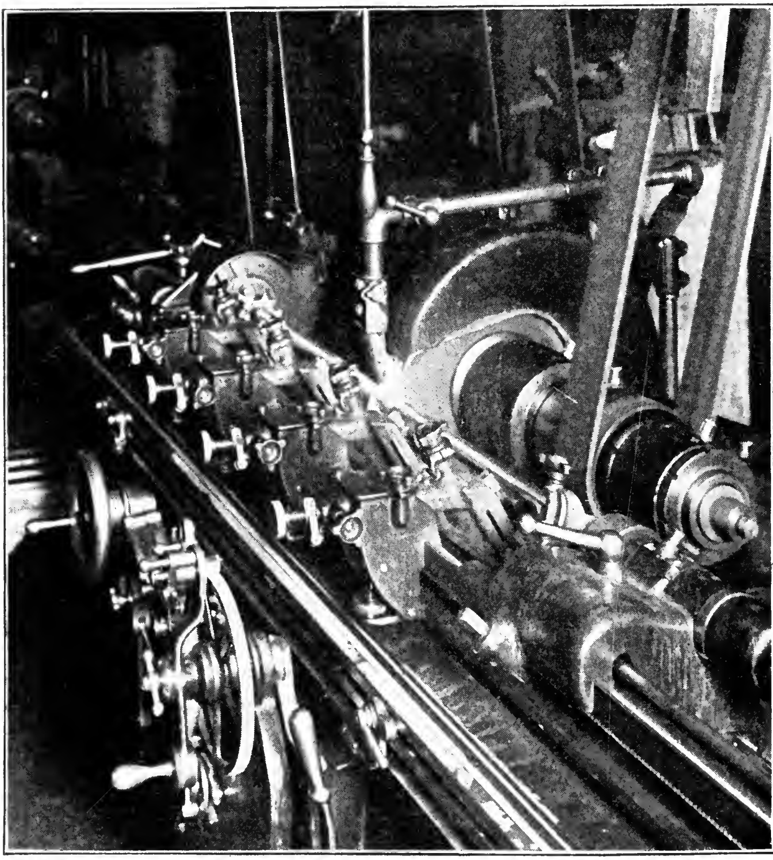


Fig. 325. Example of Steady Rests as Employed by Norton Grinding Company
Courtesy of Norton Grinding Company, Worcester, Massachusetts

special surface, or in which greater accuracy is required than is readily reached by the other machine tools, in modern work shops it is one of the large production factors. The work which comes to the grinding machine has usually been rough turned to an approximate diameter, but in many instances it has been found that the grinding machine will completely finish the piece of work from the rough stock at a lesser labor cost, doing its own roughing and finishing. This is especially true when long slender shafts are produced. Automobile crank shafts, for example, are commonly ground from the rough.

Cylindrical Grinding. Producing cylinders of revolution is one of the more common uses to which grinding machines are put. This is usually accomplished by traversing a rotating abrasive wheel

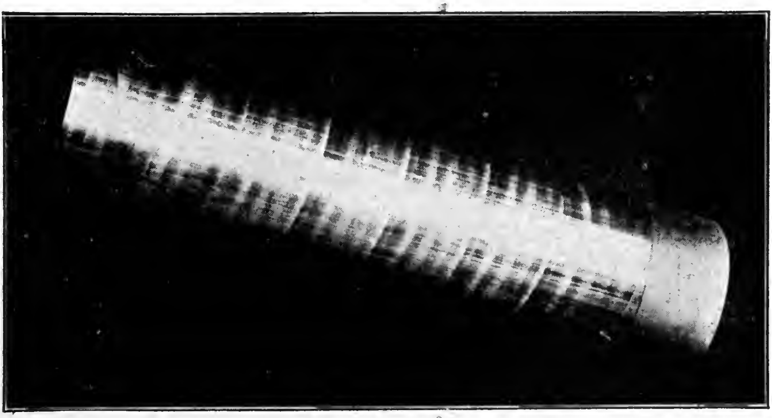


Fig. 326. Traverse Markings on Piece of Ground Work

in contact with the rotating piece of work, as in Fig. 325. In this operation the rotating wheel can be made to feed along the length of the work by giving the work table a traversing motion along the bed of the machine. Some of the things to be noted in this machine are: (a) Its large wheel spindle with generous journals making it possible to use abrasive wheels large in diameter with broad faces; (b) the abrasive wheel bearing stand giving large spindle bearings and great rigidity; (c) a heavy traversing table with large bearing area upon the bed; (d) the work-supporting rests; and (e) the general massiveness of construction.

Wheel Speed. The peripheral or surface speed of the abrasive wheel is usually held pretty closely to 5500 linear feet per minute. While in some cases a wheel speed of 6500 feet per minute or as

TABLE XI

Revolutions per Minute for Various Sizes of Grinding Wheels to Give Peripheral Speed in Feet per Minute

Diameter of Wheel in Inches	4000	4500	5000	5500	6000	6500
1	15,279	17,200	19,099	21,000	22,918	24,850
2	7,639	8,590	9,549	10,500	11,459	12,420
3	5,093	5,725	6,366	7,000	7,639	8,270
4	3,820	4,295	4,775	5,250	5,730	6,205
5	3,056	3,440	3,820	4,200	4,584	4,970
6	2,546	2,865	3,183	3,500	3,820	4,140
7	2,183	2,455	2,728	3,000	3,274	3,550
8	1,910	2,150	2,387	2,635	2,865	3,100
10	1,528	1,720	1,910	2,100	2,292	2,485
12	1,273	1,543	1,592	1,750	1,910	2,070
14	1,091	1,228	1,364	1,500	1,637	1,773
16	955	1,075	1,194	1,314	1,432	1,552
18	849	957	1,061	1,167	1,273	1,380
20	764	860	955	1,050	1,146	1,241
22	694	782	868	952	1,042	1,128
24	637	716	796	876	955	1,035
26	586	661	733	809	879	955
28	546	614	683	749	819	887
30	509	573	637	700	764	827
32	477	537	596	657	716	776
34	449	506	561	618	674	730
36	424	477	531	534	637	689
38	402	453	503	553	603	653
40	382	430	478	525	573	621
42	364	409	455	500	546	591
44	347	391	434	477	521	564
46	332	374	415	456	498	539
48	318	358	397	438	477	517
50	306	344	383	420	459	497
52	294	331	369	404	441	487
54	283	318	354	389	425	459
56	273	307	341	366	410	443
58	264	296	330	354	396	428
60	255	277	319	350	383	414

low as 4500 feet per minute may give good results, wheel speed does not in general practice vary much from the 5500 feet given. Table XI gives wheel speeds used in good practice.

Wheel Traverse. This is taken as the distance the abrasive wheel travels axially during a complete revolution of the work. While experts differ as to what proportion of the face of the wheel this should be, it would appear that where operating conditions will stand it, a traverse of above one-half the wheel face width per work revolution is desirable when rough grinding work. Fig. 326 shows the traverse markings upon a piece of ground work.

Grinding Allowances. When in grinding practice the work has been previously rough turned, it is customary to leave an amount of stock to be removed in the grinding machine dependent upon the size and character of the work and upon the roughing out method employed.

Table XII gives allowances left for grinding as worked out by the Landis Tool Company. If the roughing out is done, using an exceptionally coarse feed, as shown in Fig. 327, the tabulated allow-

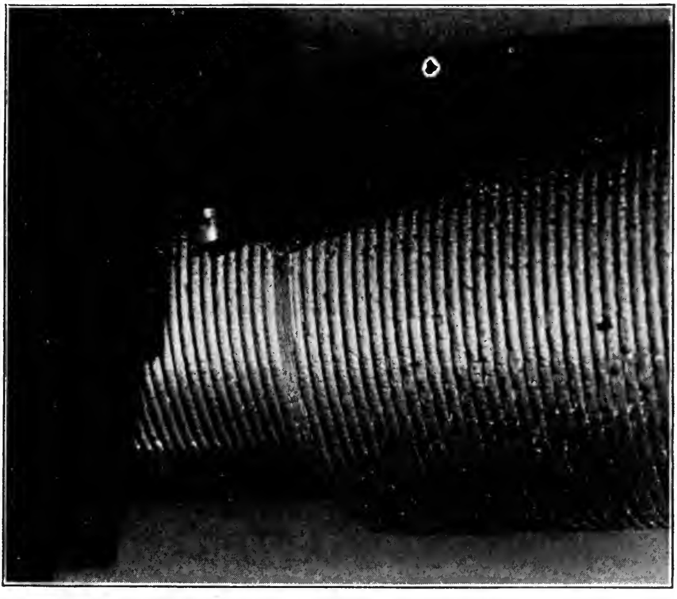


Fig. 327. Roughing-Out for Grinding Showing Heavy Cut

ances will need to be exceeded. It is well to note here that tabulated grinding details in machine construction are useful chiefly as a starting basis.

Abrasive Wheels. Large enterprises are devoted to the production of artificial abrasives. Increased knowledge in the manufacture of the wheels themselves and an added knowledge in wheel selection has materially changed the abrasive wheel industry from that of previous years. The greater portion of modern machine grinding is now done with the manufactured abrasives. These are in most part very efficient in cutting qualities and are sold under a variety of trade names such as *alundum*, *aloxite*, *carborundum*,

TABLE XII

Allowances for Grinding*

Diameter (in.)	Length (in.)										
	3	6	9	12	15	18	24	30	36	42	48
	Allowance (in.)										
½	0.010	0.010	0.010	0.010	0.015	0.015	0.015	0.020	0.020	0.020	0.020
¾	0.010	0.010	0.010	0.010	0.015	0.015	0.015	0.020	0.020	0.020	0.020
1	0.010	0.010	0.010	0.015	0.015	0.015	0.015	0.020	0.020	0.020	0.020
1¼	0.010	0.010	0.015	0.015	0.015	0.015	0.015	0.020	0.020	0.020	0.020
1½	0.010	0.015	0.015	0.015	0.015	0.015	0.020	0.020	0.020	0.020	0.020
2	0.015	0.015	0.015	0.015	0.015	0.020	0.020	0.020	0.020	0.020	0.025
2¼	0.015	0.015	0.015	0.015	0.020	0.020	0.020	0.020	0.020	0.025	0.025
2½	0.015	0.015	0.015	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025
3	0.015	0.015	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025
3½	0.015	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025
4	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030
4½	0.020	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030
5	0.020	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030
6	0.020	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030
7	0.020	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030
8	0.025	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030	0.030
9	0.025	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030	0.030	0.030
10	0.025	0.025	0.025	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
11	0.025	0.025	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
12	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030

crystolon, and several others. Abrasive wheels can be had also in a variety of degrees of hardness, coarseness, and varying bonds, as is seen by consulting Tables XIII and XIV. Degrees of hardness, coarseness, and bonding condition make up what is known as the "grain" and the "grade" of the abrasive wheel.

Grinding Methods. *Skilled Operators.* The larger manufacturers of grinding machines have representatives trained to the highest skill in operating their line of machines. A purchaser of their machines can have one of these highly skilled operators demonstrate the maximum efficiency possibilities of the particular machine.

Grinding Crank Shafts. As a sample of high speed grinding production the finishing of automobile crank shafts may be taken. Fig. 328 shows the methods employed.

Flat Face Grinding. While the work illustrated in Fig. 325 is done by axially traversing a wheel having a face width of about two inches, an increasing amount of work is being done, using the wheel as a broad cutting tool and feeding the wheel directly into the

* From Landis Tool Company, Waynesboro, Pennsylvania.

work until the desired diameter is obtained. By this method there is no axial traversing of the wheel while in its cut. Cup wheels having a width of face as great as nine inches have been used on such machines as shown in Fig. 329. By means of suitable face

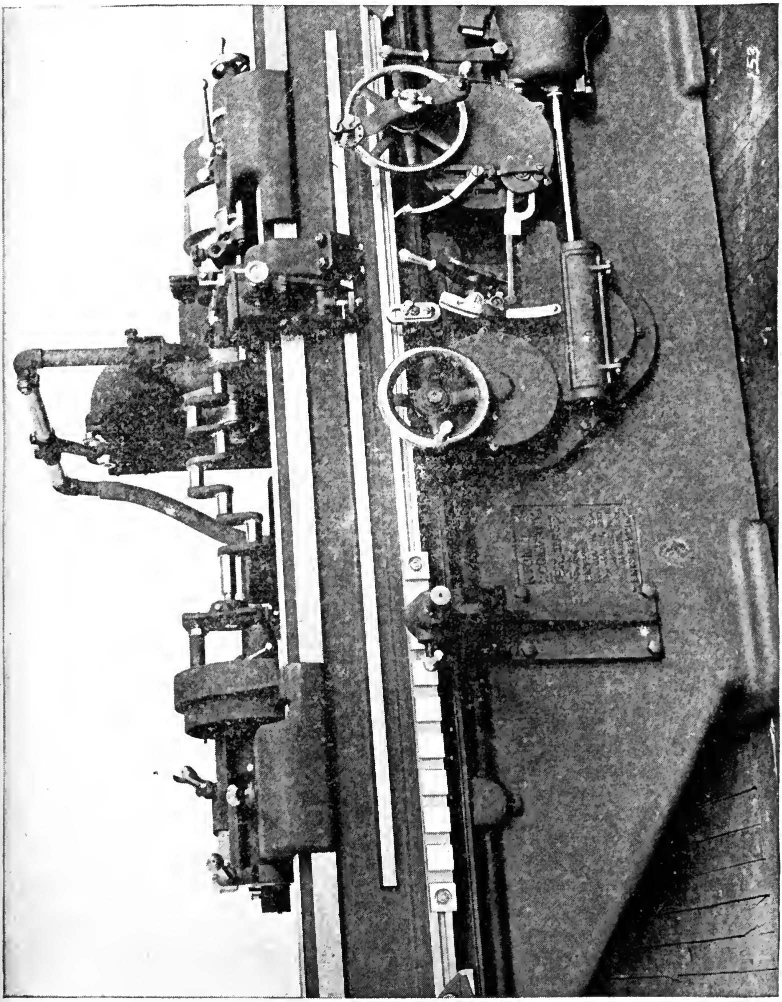


Fig. 328. Norton Grinding Machine Grinding Crank Shaft
Courtesy of Norton Grinding Company, Worcester, Massachusetts

forming attachments, the face of the wheel can be surfaced to a variety of contours. It will therefore be seen that the new method of grinding can be employed not only for straight cylindrical surfaces, but for work having an irregular contour. Fig. 330 shows

TABLE XIII

Norton Grade List

The following grade list is used to designate the degree of hardness of vitrified and silicate wheels, both alundum and crystolon:

	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	

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 correct form of work-supporting rests. Figs. 331, 332, and 333 show how the wheel approaches the work for straight and for contour work.

Internal Cylindrical Grinding. Machine grinding the internal surfaces of gas engine cylinders may be used as a good example of this line of production work. Figs. 334 and 335 show two views of such work. It will be noted that these views illustrate one of several special internal grinding machines particularly designed for this class of work. The prominent feature in its design is that in place of rotating the work against the grinding wheel, the work is rigidly held in a fixed position. By means of a slow revolving

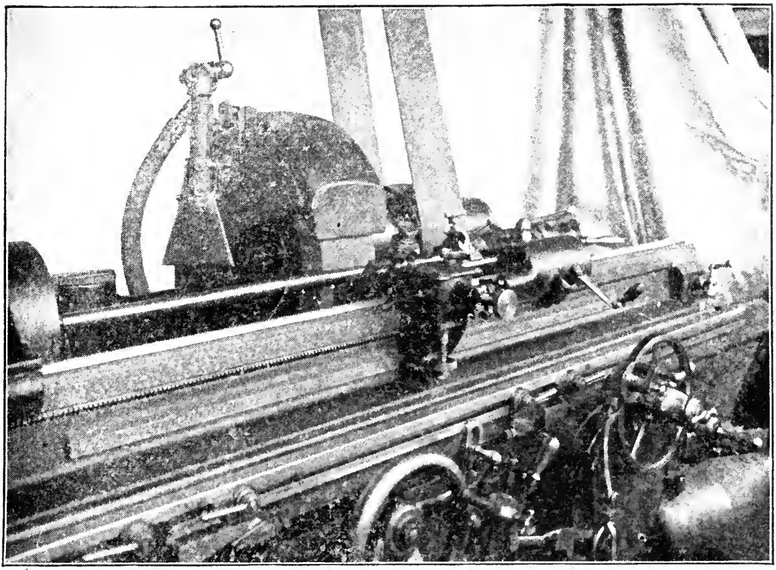


Fig. 329. Norton Grinder with $5\frac{1}{4}$-Inch Face Wheel for Grinding Ford Axles and Drive Shafts

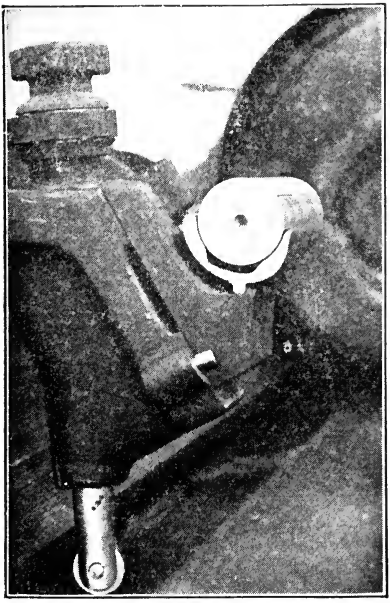
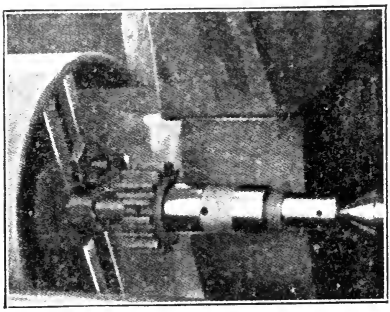
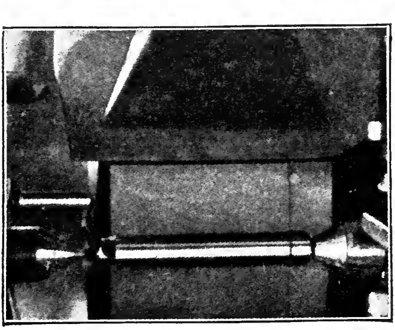


Fig. 330. Work Properly Supported
Courtesy of Norton Grinding Company, Worcester, Massachusetts





Figs 331 and 332. Set-Up for Grinding Straight and Contour Work with Norton Grinder
Courtesy of "Machinery", New York City

TABLE XIV

Selection of Grades

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 Q
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), automatic grinding	30 to 46	J to K	....	....
Knives, leather shaving	60	N to O	....	....
Knives, leather splitting	24 to 30	1 to 2 Elas.	....	....
Knives, molding bits, etc.	46 to 60	3 Elas.	....	....
	46 to 60	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	P Sil.	....	....
	20 to 36	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, molding	....	....	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	....	....
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	....	....

TABLE XIV—(Continued)

Selection of Grades

Class of Work	Alundum		Crystolon	
	Grain	Grade	Grain	Grade
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), finishings	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, finishing	....	....	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.	L to N	....	....
	{46 to 60	L to N	....	....
Steel (soft), surface grinding	24 to 36	H to K	....	....
Steel (hardened), cylindrical grinding	{24 comb.	K	....	....
	{46 to 60	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 grinding	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	....	....

motion given to the spindle carrying frame, the highly speeded rotating wheel carrying spindle is itself carried about in a circle. Provisional adjustments can be made to alter the diameter of this circle to meet changes in the cylinder dimensions. When water jacketed work is being ground, means are provided for circulating water through the jacket, the grinding wheel itself in this case working dry. Suitable wheel speeds and traverse feeds are provided for the range of work the machine is designed to cover. Fig. 336 shows operation of grinding wrist-pin bearing, while Fig. 337 illustrates charging the grinding jig.

Flat Surface Grinding. Under this heading properly comes those machines designed for intensive production. These are of two distinct types. The one shown in Fig. 338 carries a wheel that approaches the work radially, while that shown in Fig. 339 uses the side of a cup-shaped wheel in contact with the work. By means of powerful wheel driving belts and rapid table traverse, these machines produce flat surfaces with an efficiency and accuracy that leaves little to be desired. The work as shown is held upon magnetic chucks and the throw of a simple switch clamps or unclamps it. In use the wheel and the work are flooded with a suitable cutting lubricant. In Fig. 340 are shown a number of gun parts finished

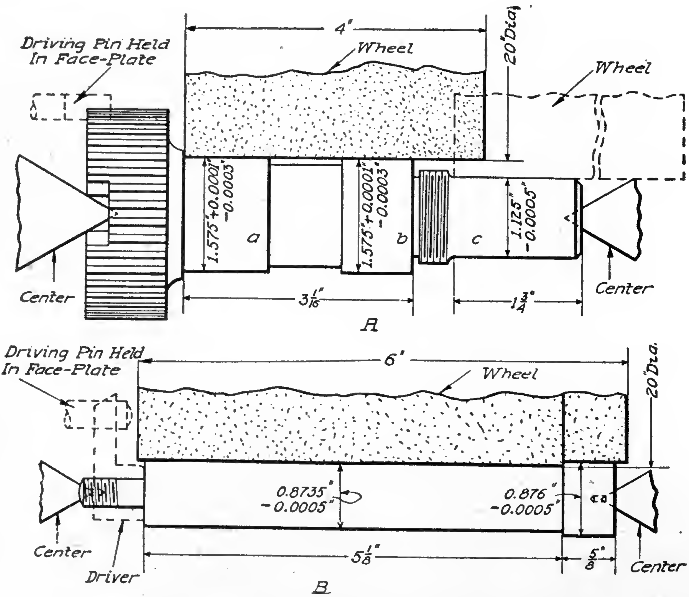


Fig. 333. Diagram of Set-Ups Shown in Figs. 331 and 332
Courtesy of "Machinery", New York City

A

WORK:—Main drive gear, 0.20 per cent carbon alloy steel, carbonized and heat-treated.

OPERATION:—Straight-in grinding external diameter with a Norton (vitrified) alundum combination wheel, grain 38-24, grade L; 20 inches diameter, 4-inch face; speed, 1241 r.p.m.—6500 feet surface speed; work speed, about 100 r.p.m.—41 feet surface speed; amount removed from diameter, 0.010 inch.

REMARKS:—Wide-face wheel is fed straight in on portions (a) and (b), not traversed; small end (c) is also ground in same setting by shifting wheel; production, 265 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

B

WORK:—Idler gear shaft, 0.20 per cent carbon open-hearth steel, carbonized and hardened.

OPERATION:—Straight-in grinding two external diameters with a Norton (vitrified) alundum combination wheel, grain 38-24, grade L; 20 inches diameter, 6-inch face; speed 1241 r.p.m.—6500 feet surface speed; work speed, 100 r.p.m.—24 feet surface speed; amount removed from diameter 0.015 to 0.025 inch.

REMARKS:—Wide-face wheel is fed straight in on work, not traversed; 50 pieces turned out to each truing of wheel; production, 375 pieces in nine hours; machine used, 10 by 36 inch Norton plain grinding machine.

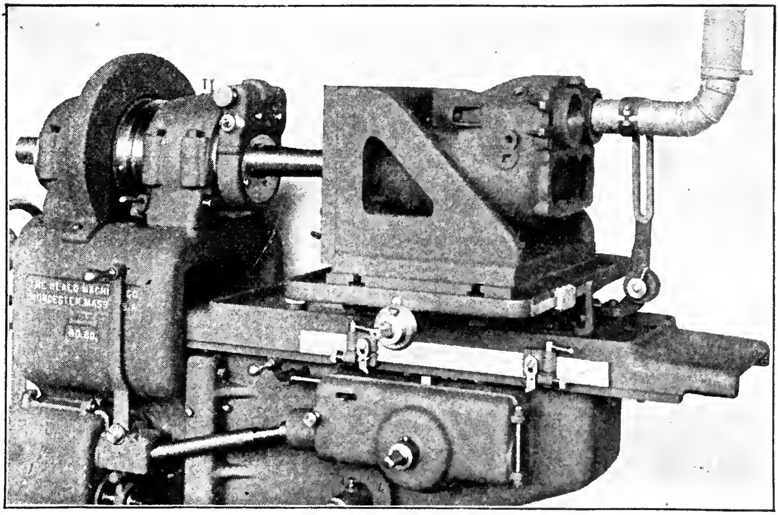


Fig. 334. Grinding Gas Engine Cylinders. View Shows Exhaust for Dust, Jig for Holding Cylinders, and Eccentric Wheel Spindle
Courtesy of Heald Machine Company, Worcester, Massachusetts

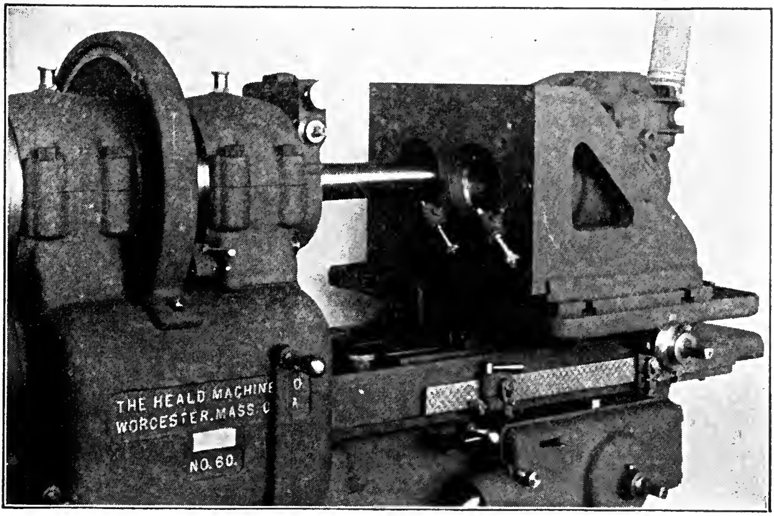


Fig. 335. Grinding Gas Engine Cylinders. Same Set-Up as Fig. 334, Showing Holding Jig and Turning Tool at Mouth of Hole

by a vertical grinder, removing .005 inch to .010 inch of stock. Table XV shows the number of pieces produced per hour.

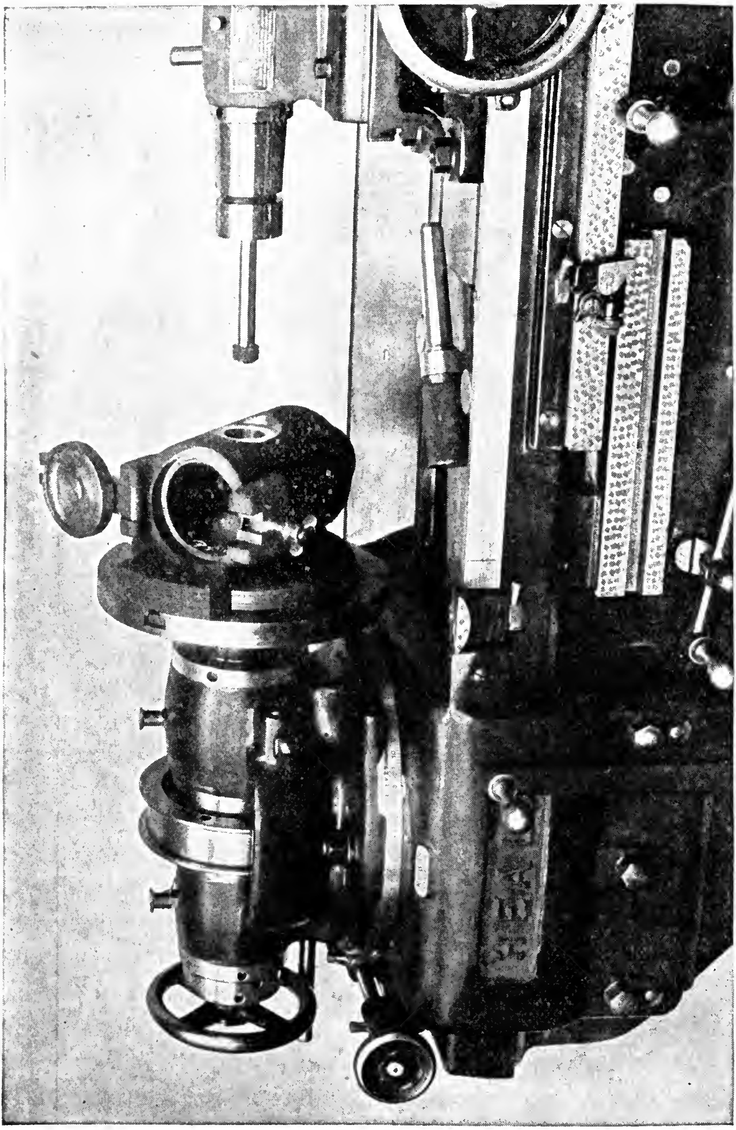


Fig. 336. Set-Up for Grinding Wrist-Pin Bearing; Grinding Time 3 Minutes per Piston
Courtesy of Heald Machine Company, Worcester, Massachusetts

Fig. 337. Charging Grinding Jig Shown in Fig. 336

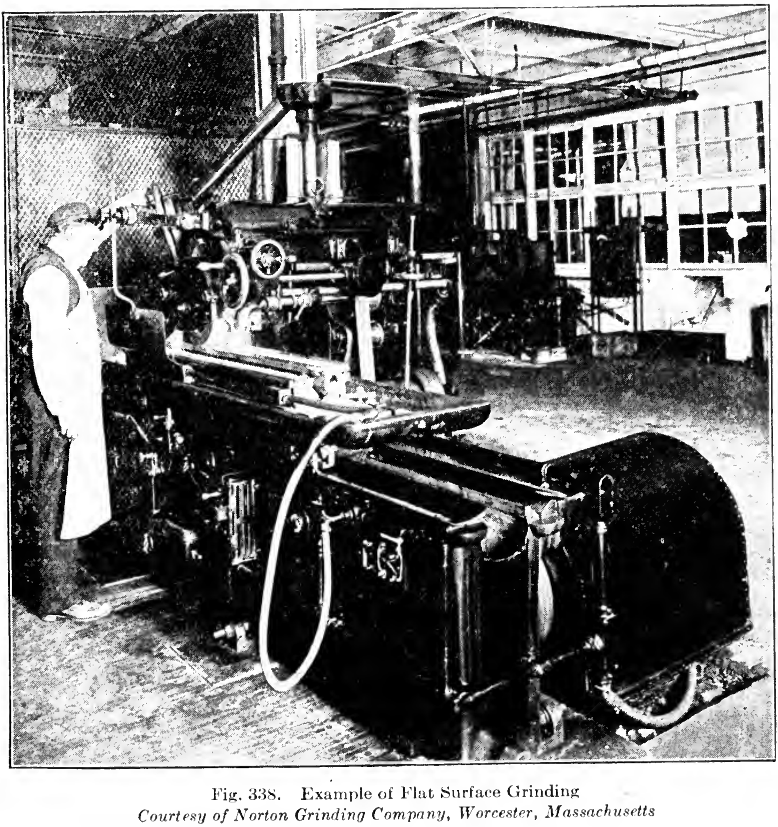


Fig. 338. Example of Flat Surface Grinding
Courtesy of Norton Grinding Company, Worcester, Massachusetts

TABLE XV

Rate of Grinding Gun Parts on Vertical Grinder

No 1 on two sides— 40 to 50 per hour
No. 2 on one side —125 per hour
No. 3 on one side —175 per hour
No. 4 on two sides—100 per hour
No. 5 on one side —150 per hour
No. 6 on two sides—150 per hour
No. 7 on two sides—175 per hour
No. 8 on two sides—200 per hour
No. 9 on two sides—200 per hour
No. 10 on two sides—200 per hour
No. 11 on two sides—250 per hour
No. 12 on two sides—200 per hour
No. 13 on two sides—175 per hour
No. 14 on two sides—200 per hour
No. 15 on two sides—200 per hour
No. 16 on two sides—175 per hour
No. 17 on two sides—100 per hour
No. 18 on two sides—125 per hour
No. 19 on two sides—200 per hour
No. 20 on two sides—150 per hour
No. 21 on two sides—150 per hour
No. 22 on two sides—100 per hour
No. 23 on two sides—150 per hour

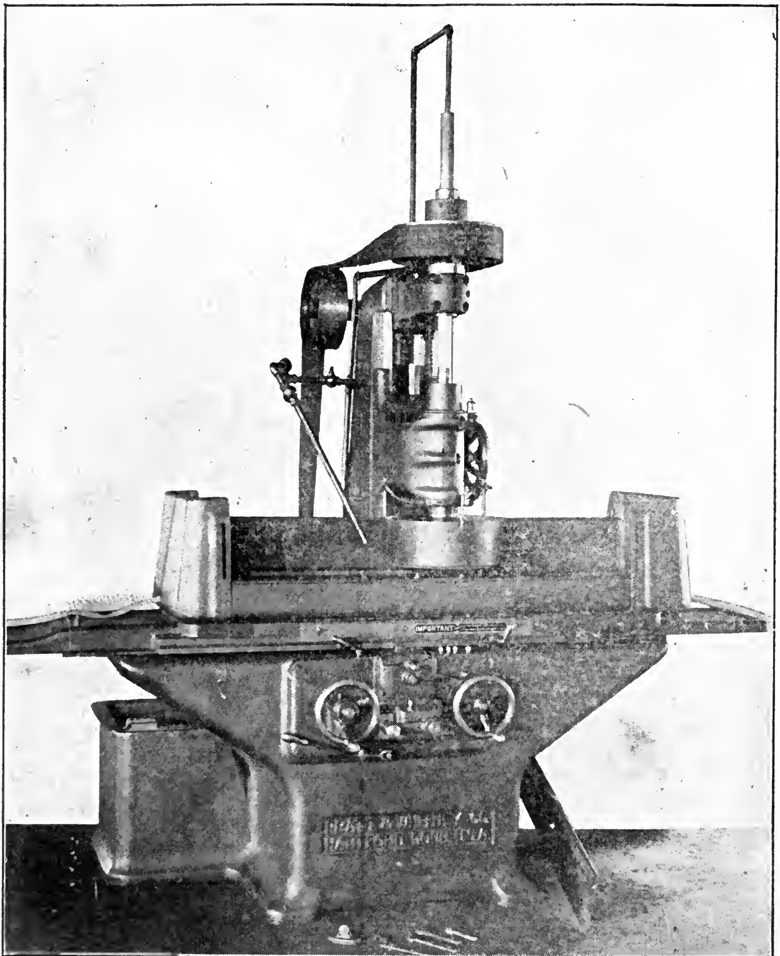


Fig. 339. Pratt and Whitney Grinding Machine Using Magnetic Flat Chuck

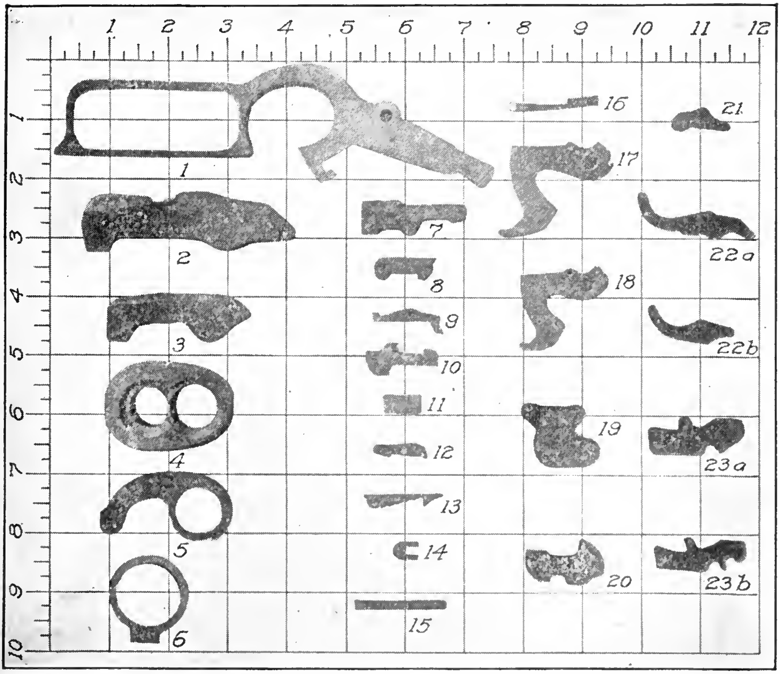


Fig. 340. Gun Parts Ground on Vertical Grinder

MILLING MACHINES

Production milling is done on three distinct types of machines known as the horizontal, the vertical, and the planer type.

Horizontal Milling Machine. Fig. 341 shows a representative machine of this type. Designed and used as shown, this machine is capable of very rapid production. The prominent features are its weight and the size of its working parts, its large bearing surfaces, its all geared driving speed changes, its all geared feeds, and the yoking of the knee to the outer end of the cutter arbor.

Vertical Milling Machine. Fig. 342 is a representative machine of this type. While side milling can be done on this type of machine, its use is very largely confined to the uses of end and face cutting. In common with all high production machines, it has weight, generous bearing surfaces, large table capacity, great driving power, and a possibility for coarse feeding.

Planer Milling Machine. The planer type of milling machine is the most massive and the heaviest machine of the three types.

A typical machine is shown in Fig. 343. It will be noted that by using side head spindles in conjunction with horizontal gangs of cutters, three or more surfaces may be worked upon simultaneously.

Production Cutters. It is evident that the cutter equipment must be equal to the possibilities of the machine if its capacity production is maintained. Fig. 344 is a characteristic cutter used in a horizontal milling machine. Note the large axial hole, making

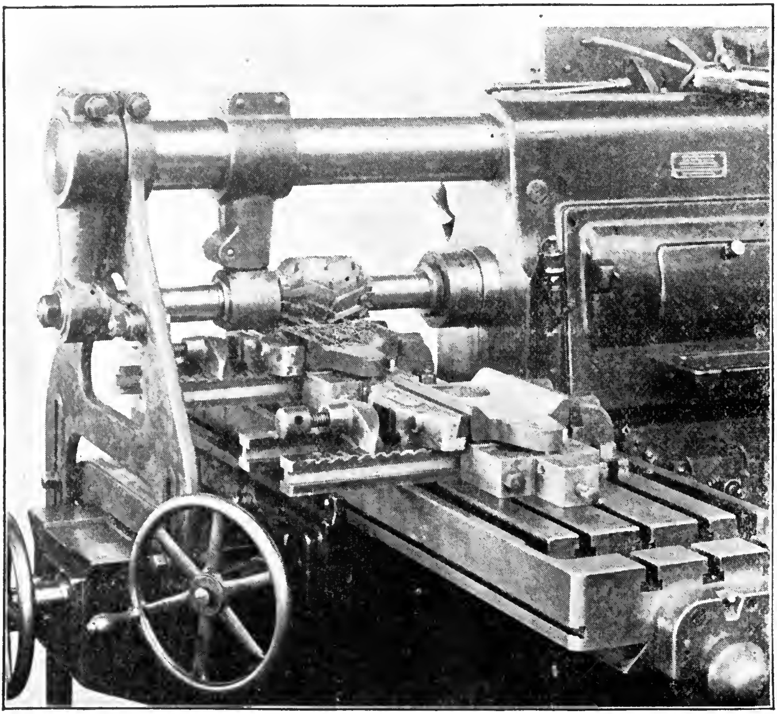


Fig. 341. Horizontal Milling Machine with Work in Process
Courtesy of Cincinnati Milling Machine Company, Cincinnati, Ohio

possible the use of rigid arbors, the greatly increased spacing of the teeth, and the increased cutting rake given by undercutting. Fig. 345 shows the usual type of cutter used when heavy slabbing cuts are taken in a vertical machine. The characteristics of coarse tooth pitch, increased cutting rake, and rigidity of attachment are prominent in this cutter. Either or both of these types of cutter are used on all three types of machine. Fig. 346 shows an inserted tooth gang of Ingersoll production cutters in actual operation.

Work Holding. This problem is usually cared for by special work-holding devices termed "fixtures". These fixtures are constructed to grip and support the work so that the pressures and thrusts of cutting are cared for. The fixtures themselves are bolted directly to the work table. Where it can be done quickly and

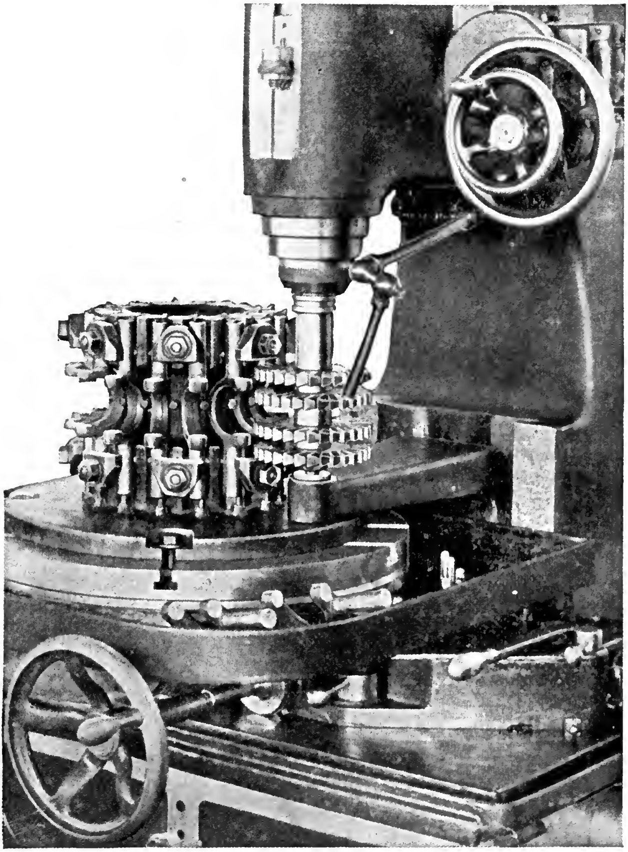


Fig. 342. Vertical Milling Machine in Action. Work-Holding Fixture Rotates at Rate of 10 Inches per Minute; Production 195 Yokes per Hour
Courtesy of Becker Milling Machine Company, Hyde Park, Massachusetts

conveniently the work is held directly upon the work table. Magnetic chucks are used to hold thin work.

Cutting Speeds. These must be proportioned to the materials being milled, their relative hardness, the depth of cut, and the amount the tool can be fed.

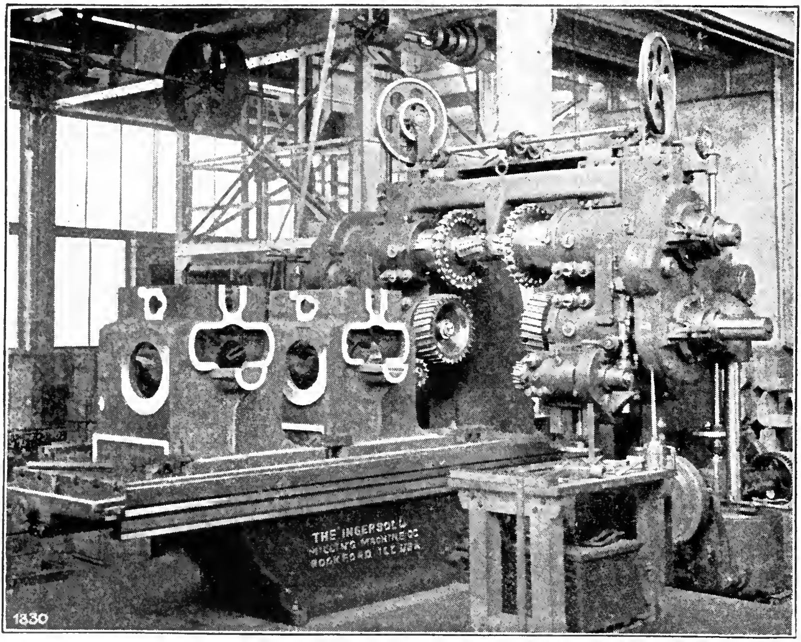


Fig. 343. Ingersoll Horizontal Milling Machine, Milling Gasoline Traction Engine Frames. ½ Inch of Metal Removed from each of Six Surfaces. 14 Bases Finished in 10 Hours.

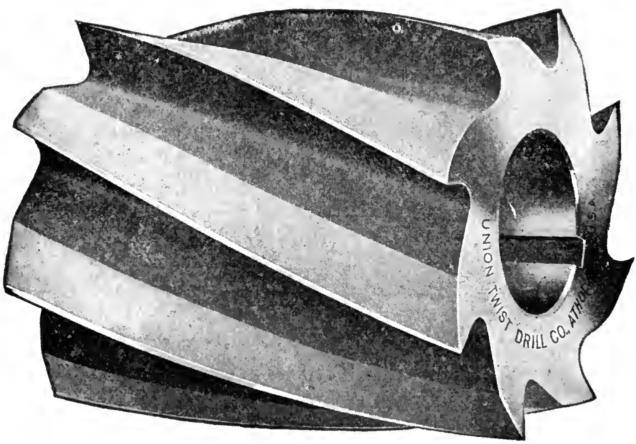


Fig. 344. Production Milling Cutter
Courtesy of Union Twist Drill Company, Athol, Massachusetts

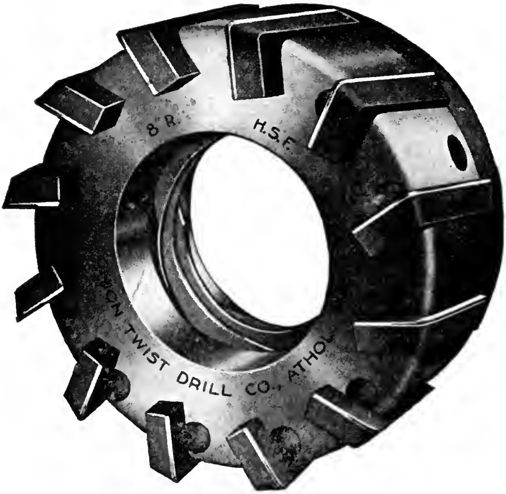


Fig. 315. High-Power Face Mill with High-Speed Steel Teeth
Courtesy of Union Twist Drill Company, Athol, Massachusetts

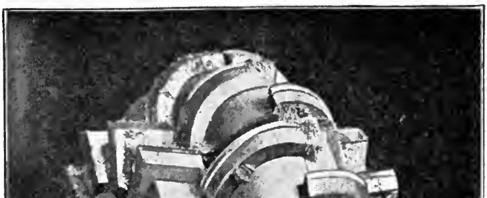


Fig. 316. Production Milling Cutter in Heavy Work
Courtesy of Ingersoll Milling Machine Company, Rockford, Illinois

Cutting Feeds. These also vary with working conditions. The coarsest practical feed is usually found by experiment and maintained, bringing the cutter speed up to meet it.

Tool Lubrication. Cast iron is about the only material milled which is cut "dry". In milling other metals and alloys a copious supply of some cutting lubricant is used. This is pumped to the tool in quantities sufficient to flood not only the cutter but to a large extent the work. This is well shown in Fig. 347 where the cutters are working on steel.

DRILLING MACHINES

Production drilling machines are of two sorts: Those designed for heavy drilling, and those for the lighter jobs.

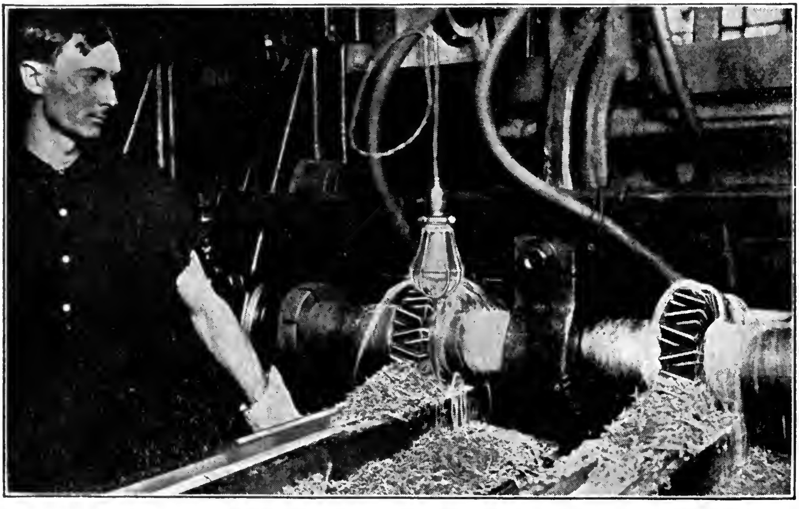


Fig. 347. Ingersoll Horizontal Miller Doing Heavy Milling
Note how lubricant floods the work in milling steel

Heavy High-Speed Drillers. Fig. 348 is fairly representative of the type designed to use high-speed steel drills of the larger sizes to their full capacity. The frame or post of this machine is of a form similar to the frame of a punch or shear press. Pressure tests on a drill of $1\frac{1}{2}$-inch diameter, given a feed of 0.030 inch per revolution, have recorded a total load pressure of nearly three tons. From this it will be seen why the frame is made as shown. Feeds much in excess of 0.030 inch can be obtained in this machine. Use the coarsest feed practicable and balance the speed of cutting to it.

Light High-Speed Drillers. In the lighter jobs of drilling, a feed exceeding 0.015 inch per revolution is seldom used. Rapid production is gained in this case by maintaining a high cutting speed. Tables XVI and XVII, published by the Henry and Wright Company, show certain drilling practice where the feed does not

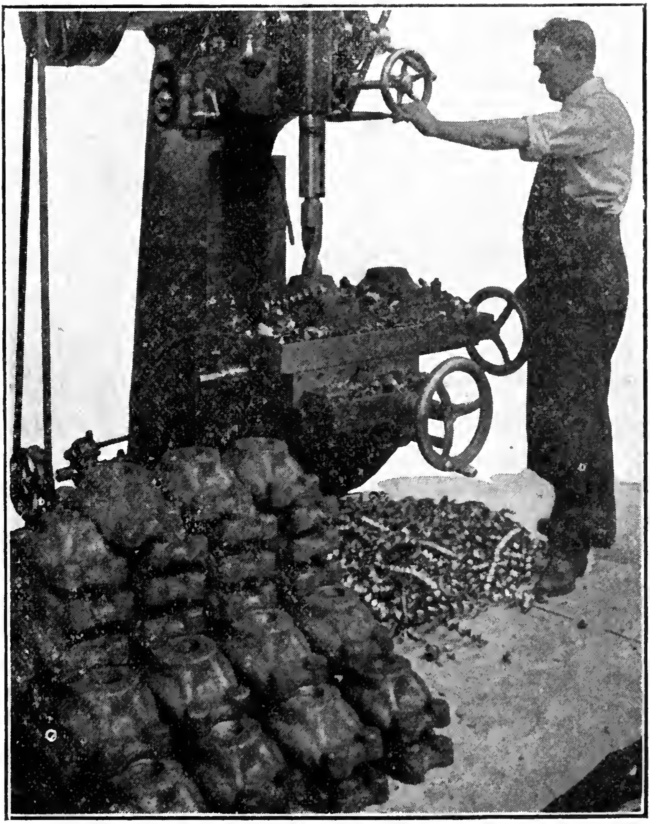


Fig. 348. Baker Driller Driving 2½-Inch Drill through Drop-Forged Wrought-Iron Saddles
Courtesy of Baker Brothers, Toledo, Ohio

exceed 0.016 inch per revolution. Fig. 349 shows a power feed, four-spindle high-speed driller. In designing this machine everything has been done to render its operation rapid and efficient.

Special Drillers. There are many of these, some of which are very complicated. Fig. 350 shows a machine designed for the single

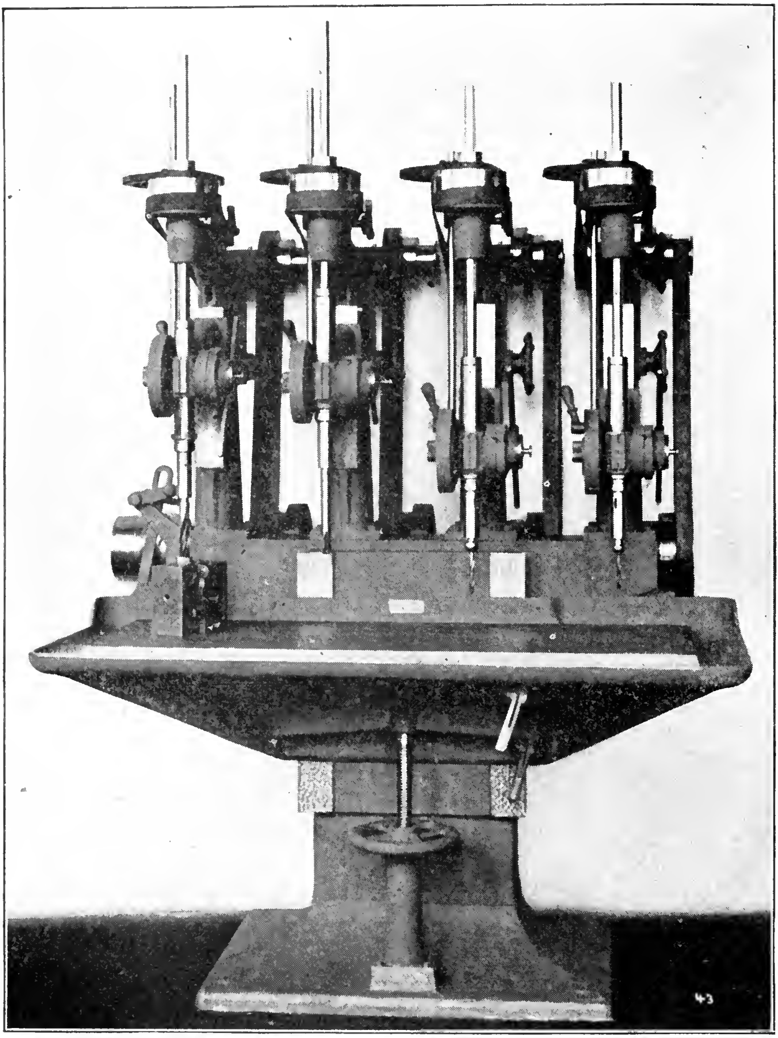


Fig. 349. Four-Spindle High-Speed Ball-Bearing Sensitive Driller
Courtesy of Washburn Shops, Worcester, Massachusetts

purpose of drilling the clearance holes in threading dies. By using four spindles and suitable work-holding table chucks, a die is completed for each stroke of the table.

Production Figures. While there are many records of high production drilling, due to the great variety of drill work, it is impossible to give a table to meet all needs.

TABLE XVI

Carbon-Steel Drills

Size of Drill (in.)	Feed per Rev. (in.)	Bronze Brass 150 Ft. r.p.m.	C. Iron Ann'ld 85 Ft. r.p.m.	Hard C. Iron 40 Ft. r.p.m.	Mild Steel 60 Ft. r.p.m.	Drop Forg. 30 Ft. r.p.m.	Mal. Iron 45 Ft. r.p.m.	Tool Steel 30 Ft. r.p.m.	Cast Steel 20 Ft. r.p.m.
$\frac{1}{16}$	.003	....	5185	2440	3660	1830	2745	1830	1220
$\frac{1}{8}$	.004	4575	2593	1220	1830	915	1375	915	610
$\frac{3}{16}$	.005	3050	1728	813	1220	610	915	610	407
$\frac{1}{4}$	.006	2287	1296	610	915	458	636	458	305
$\frac{5}{16}$	.007	1830	1037	488	732	366	569	366	245
$\frac{3}{8}$	.008	1525	864	407	610	305	458	305	203
$\frac{7}{16}$	.009	1307	741	349	523	261	392	261	174
$\frac{1}{2}$	.010	1143	648	305	458	229	343	229	153
$\frac{5}{8}$	.011	915	519	244	366	183	275	183	122
$\frac{3}{4}$	.012	762	432	204	305	153	212	153	102
$\frac{7}{8}$	.013	654	371	175	262	131	196	131	87
1	.014	571	323	153	229	115	172	115	77
$1\frac{1}{4}$	.016	458	260	122	183	92	138	92	61
$1\frac{1}{2}$	.016	381	216	102	153	77	106	77	51
$1\frac{3}{4}$	.016	327	186	88	131	66	98	66	44
2	.016	286	162	87	115	58	86	58	39

TABLE XVII

High-Speed Drills

Size of Drill (in.)	Feed per Rev. (in.)	Bronze Brass 300 ft. r.p.m.	C. Iron Ann'ld 170 ft. r.p.m.	C. Iron Hard 80 ft. r.p.m.	Mild Steel 120 ft. r.p.m.	Drop Forg. 60 ft. r.p.m.	Mal. Iron 90 ft. r.p.m.	Tool Steel 60 ft. r.p.m.	Cast Steel 40 ft. r.p.m.
$\frac{1}{16}$	.003	....	....	4880	....	3660	....	3660	2440
$\frac{1}{8}$	.004	....	5185	2440	3660	1830	2745	1830	1220
$\frac{3}{16}$	.005	....	3456	1626	2440	1210	1830	1220	807
$\frac{1}{4}$	.006	4575	2593	1220	1830	915	1375	915	610
$\frac{5}{16}$	.007	3660	2074	976	1464	732	1138	732	490
$\frac{3}{8}$	.008	3050	1728	813	1220	610	915	610	407
$\frac{7}{16}$	.009	2614	1482	698	1046	522	784	522	348
$\frac{1}{2}$	.010	2287	1296	610	915	458	636	458	305
$\frac{5}{8}$	.011	1830	1037	488	732	366	569	366	245
$\frac{3}{4}$	.012	1525	864	407	610	305	458	305	203
$\frac{7}{8}$	.013	1307	741	349	523	261	392	261	174
1	.014	1143	648	305	458	229	349	229	153
$1\frac{1}{4}$	.016	915	519	244	366	183	275	183	122
$1\frac{1}{2}$	.016	762	432	204	305	153	212	153	102
$1\frac{3}{4}$	.016	654	371	175	262	131	196	131	87
2	.016	571	323	153	229	115	172	115	77

Work Holding. This is usually accomplished by work-holding jigs. These may be held loosely upon the work table or rigidly fastened to it as their use may warrant. (See "Jig-Making".)

Lubrication. Flood lubrication of the drill and the work is usual when production drilling upon metals other than cast iron,

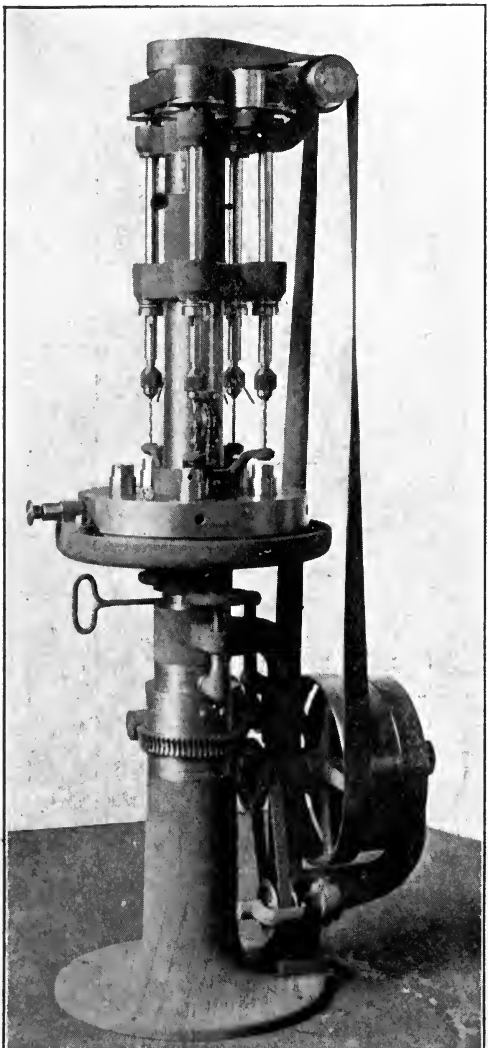


Fig. 350. "Single Purpose" Bemis Driller

and tanks, pumps, and a circulating system of pipes and nozzles are provided on all drilling machines when desired for this purpose.

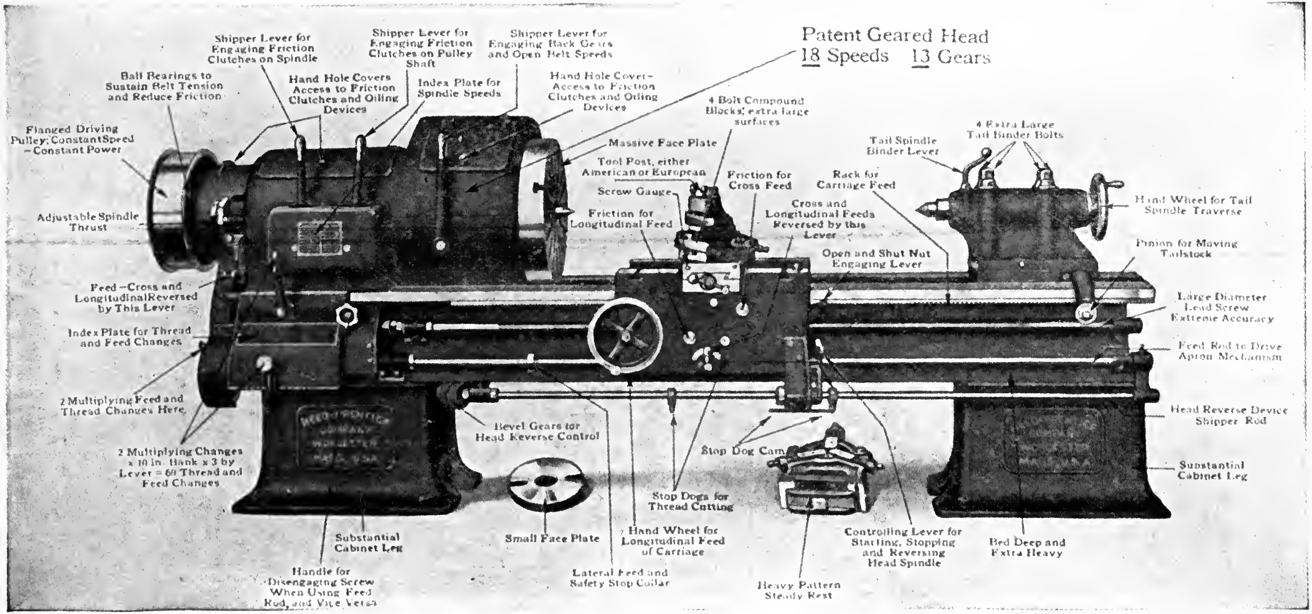


Fig. 351. "Reed" Geared-Drive and Geared-Feed Production Lathe
Courtesy of Reed-Prentice Company, Worcester, Massachusetts

TURNING MACHINES

Special and specialized machines for high speed turning will be illustrated under this heading.

Turning Lathe. Fig. 351 shows a production lathe for rapid turning of machine parts. It is representative of its class. This machine has all-geared drive, all-geared feed, and is capable of removing, when properly operated, several pounds of material per minute from such materials as chrome nickel steel. Its specialized

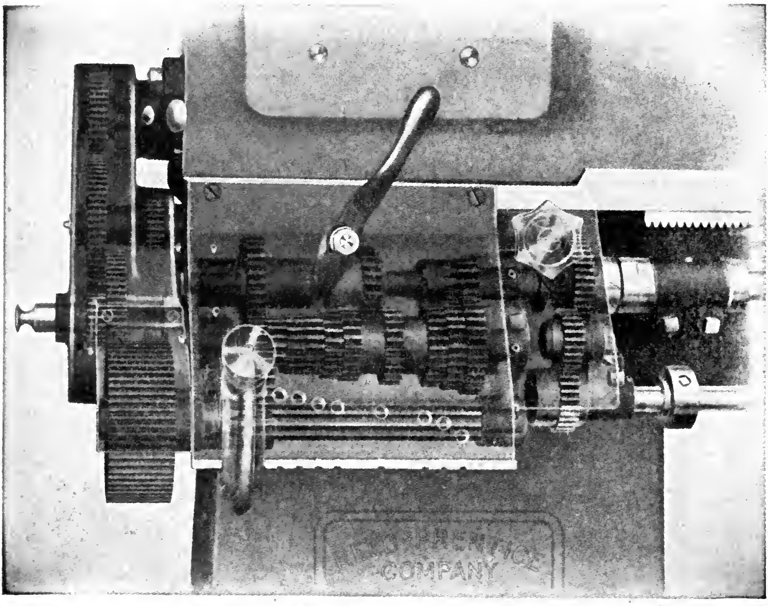


Fig. 352. Transparent View of "Reed" Quick-Change Gear Mechanism

characteristics are coarse feeds, powerful driving capacity, and convenience of operation. Fig. 352 is a transparent view of the geared feed.

Vertical Type. Fig. 353 shows a type of turning machine in which the work is mounted upon a rotating horizontal work table. The advantages of this type for certain classes of work can be readily seen. The tool holding heads are carried upon slides and can be fed both vertically and horizontally. Boring, turning, facing, and threading can be done on this machine. Its massive construction and ease of operation render it a rapid producer. Fig. 354 shows the machine on some characteristic work.

Turret Type. Where several turning operations are to be performed upon bar stock or upon work held in a chuck, recourse is often made to the use of a tool-holding turret. Fig. 355 shows

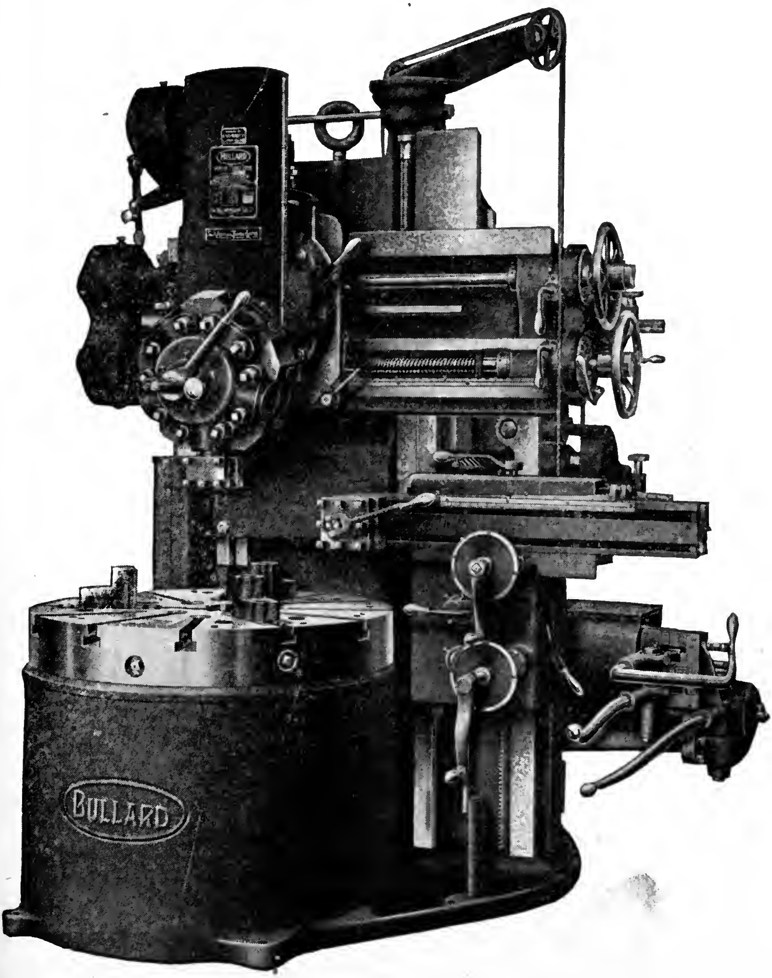
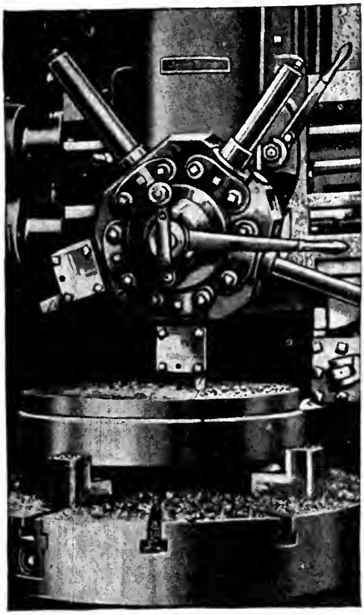


Fig. 353. Bullard Vertical Turret Lathe
Courtesy of Bullard Machine Tool Company, Bridgeport, Connecticut

a horizontal turret machine for making machine parts from bar stock. The cutting tools are fitted with shanks suitable for holding them in the turret, and the cutting principle is the same as in all



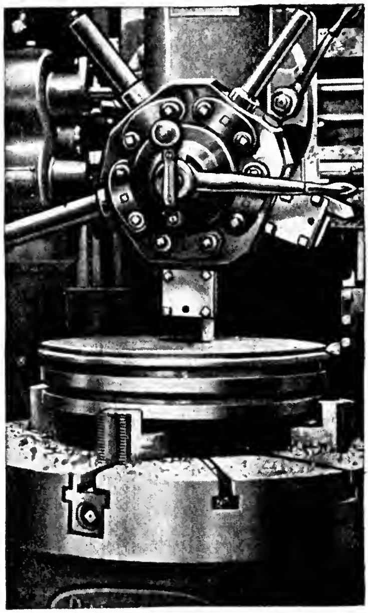
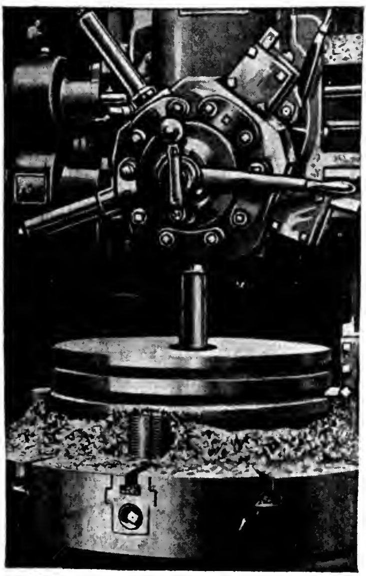


Fig. 354. Three Views of Bullard Turret Lathe in Action
On Piece Shown, Time Required for Setting Tools, Turning, Chamfering, Boring, and Finishing, 80 Minutes.

Courtesy of "Machinery", New York City



cutting tools. Both long and short turning can be done in this machine. The turret provides for six tools.

Fig. 356 shows a similar machine designed to handle iron or steel castings. This machine when properly tooled up, will perform turning and boring

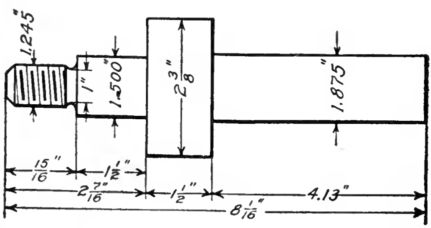


Fig. 355a. Diagram Showing Piece Producted by Turret Lathe, Fig. 355b

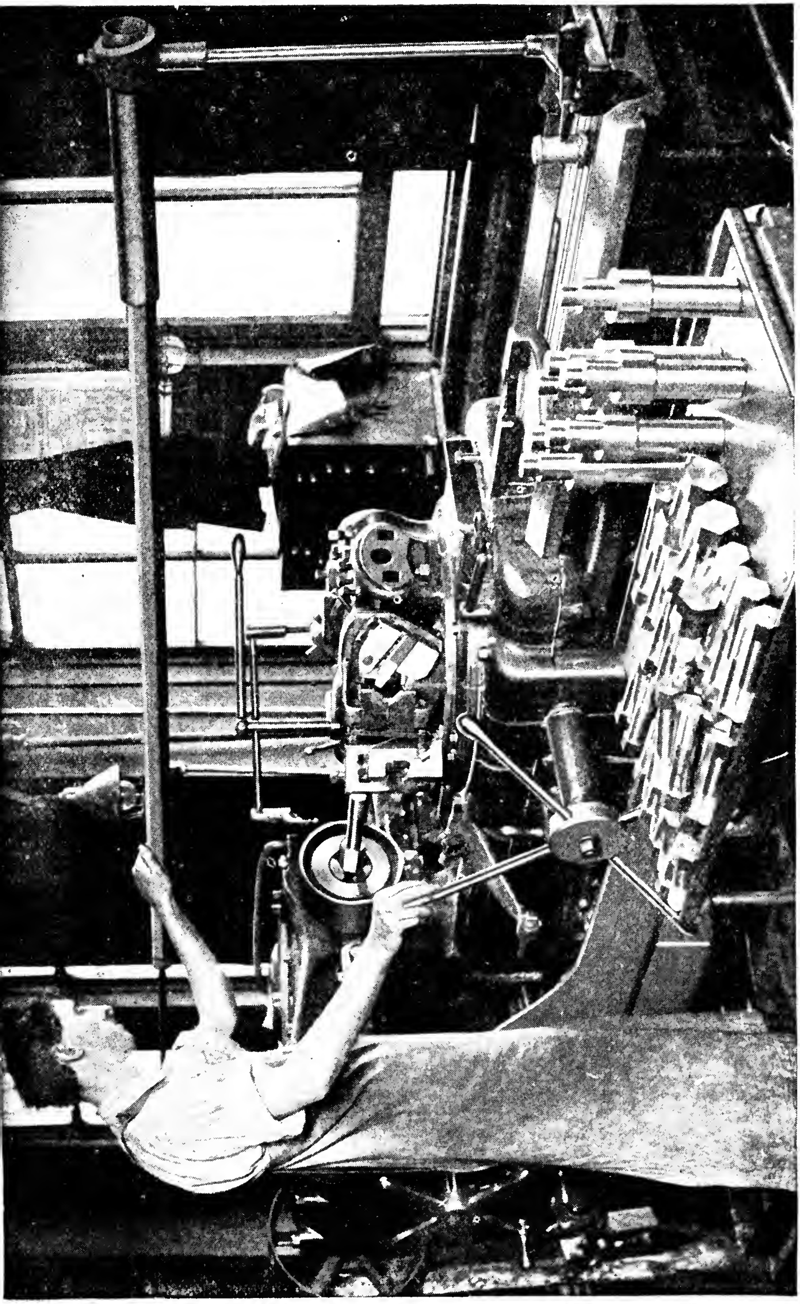
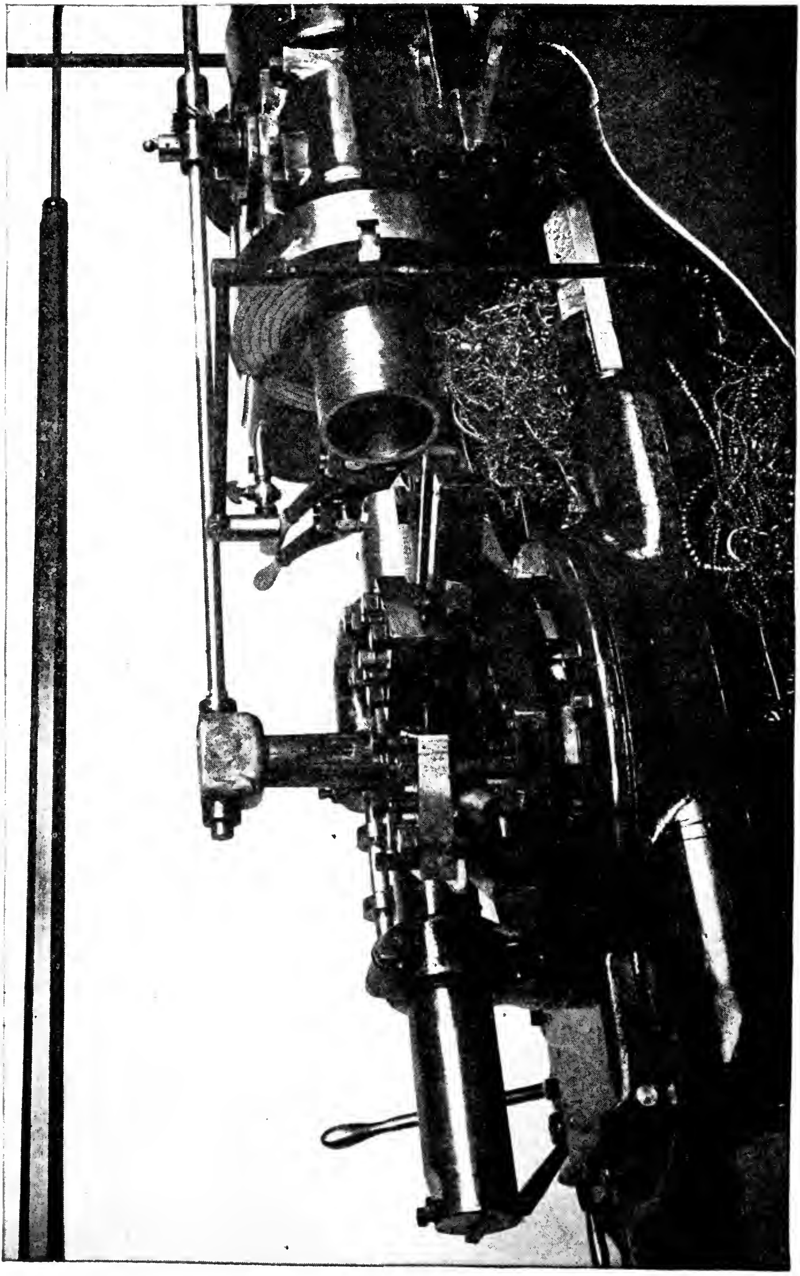


Fig. 355b. Jones and Lamson "Hartness" Turret Lathe Finishing Bar Work. Time 45 Minutes per Piece
Courtesy of "Machinery", New York City



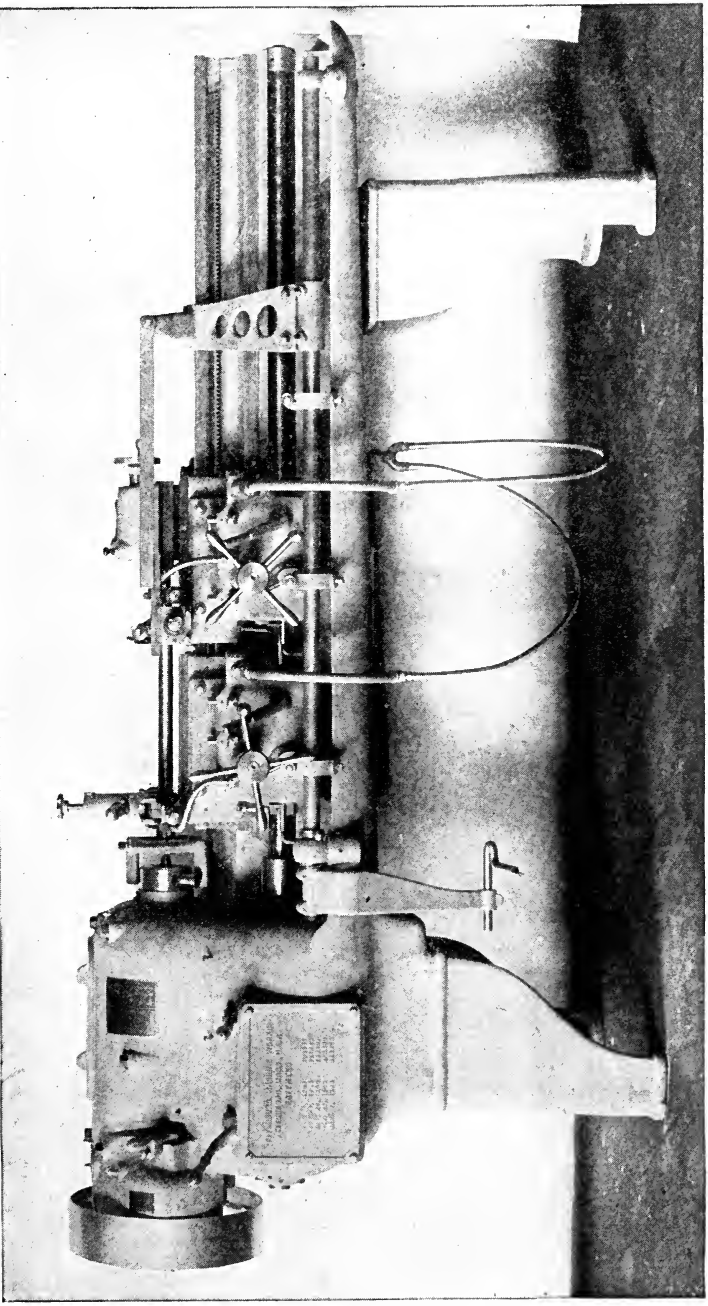


Fig. 357. "Lo-Swing" Turning Machine with Work in Progress
Courtesy of Fitchburg Machine Works, Fitchburg, Massachusetts

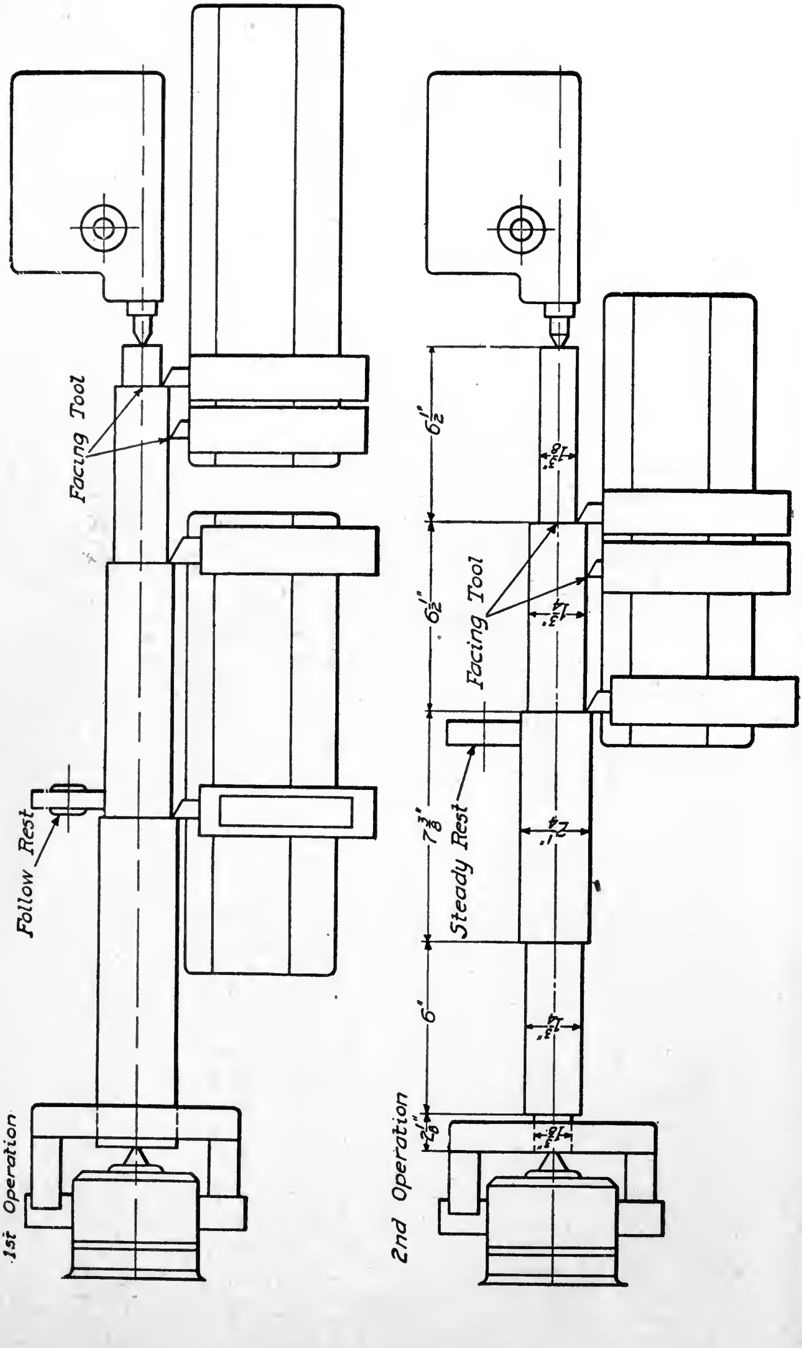


Fig. 358. Illustration of Typical Job of Spindle Turning with Time Taken for Work. Turning Time, Reading for Grinding, 16 Minutes

operations upon a large variety of parts. The fundamental cutting principle is maintained in its tooling. It is an efficient producer.

"Lo-Swing" Type. Fig. 357 shows a highly specialized turning machine in which a *train* of cutting tools may be operated. Roughing out spindles is a particular function of this machine. Fig. 358 illustrates a typical "lo-swing" job.

Lubrication. All production turning machines may be, when desired, equipped with a lubrication system to flood the cutting tool with either oil or compound.

Cutting Speeds and Feeds. All these machines are designed to work any cutting tool to the limit of its endurance.

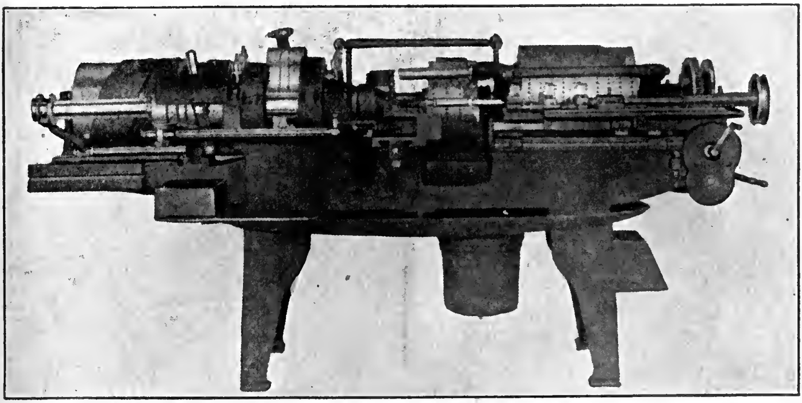


Fig. 359. Cleveland Automatic
Courtesy of Cleveland Automatic Machine Company, Cleveland, Ohio

Automatics. The term "automatic" designates a line of machines, in which, when once properly tooled and adjusted, the functions of the machine are to a considerable extent automatic in their action. By means of cam movements, and link and crank motions, the cutting tools and the work are made to function as desired. In Figs. 359, 360, and 361 are shown representative automatics.

Uses of Automatics. The broadest use of such machines is upon work which, besides being turned, is also drilled and perhaps threaded. The automatic shown in Fig. 359 is for heavy work and takes through its work spindle, bar stock several inches in diameter. The bar is worked upon by both turret and cross-slide cutting tools.

The tool turret is fed by a cylindrical cam grooved to give a powerful feed. The machine can be functioned to complete a piece in one cycle of the machine. As the finished part is dropped, the work bar is automatically advanced to receive another tooling, and goes through the same cycle of operations.

Fig. 360 is representative of a type of machine used in turning and boring special castings. Like other automatics the cutting tools are held in turrets, and are automatically rotated into position and advanced by cam movements.

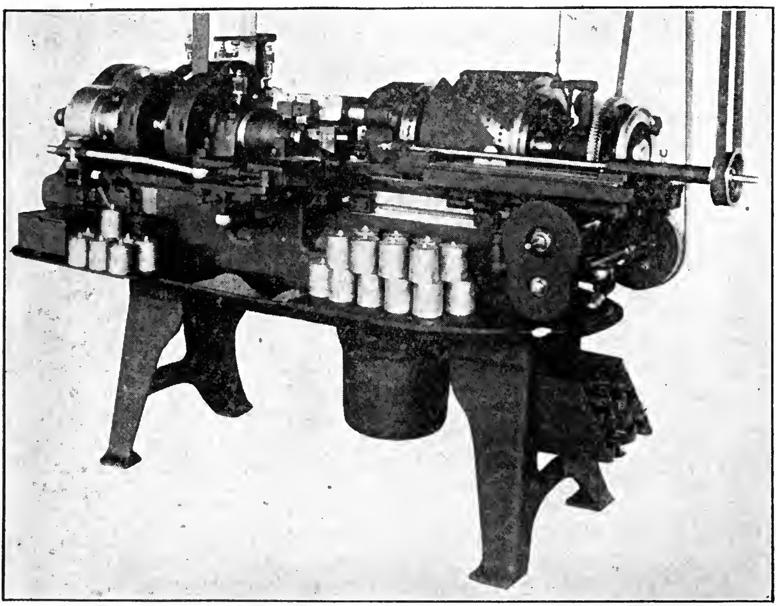


Fig. 360. Typical Automatic Turning and Boring Special Castings

Fig. 361 shows a machine used largely in producing the smaller machine parts, as, for example, the smaller screws, studs, collars, sleeves, etc., used in machine construction.

The automatic shown in Fig. 362 is designed for producing work similar to that produced by the machine, Fig. 361. It, however, is provided with five work spindles. The five feed tubes are shown at the left.

Lubrication. Automatics such as those shown are provided with stream or flood lubrication systems.

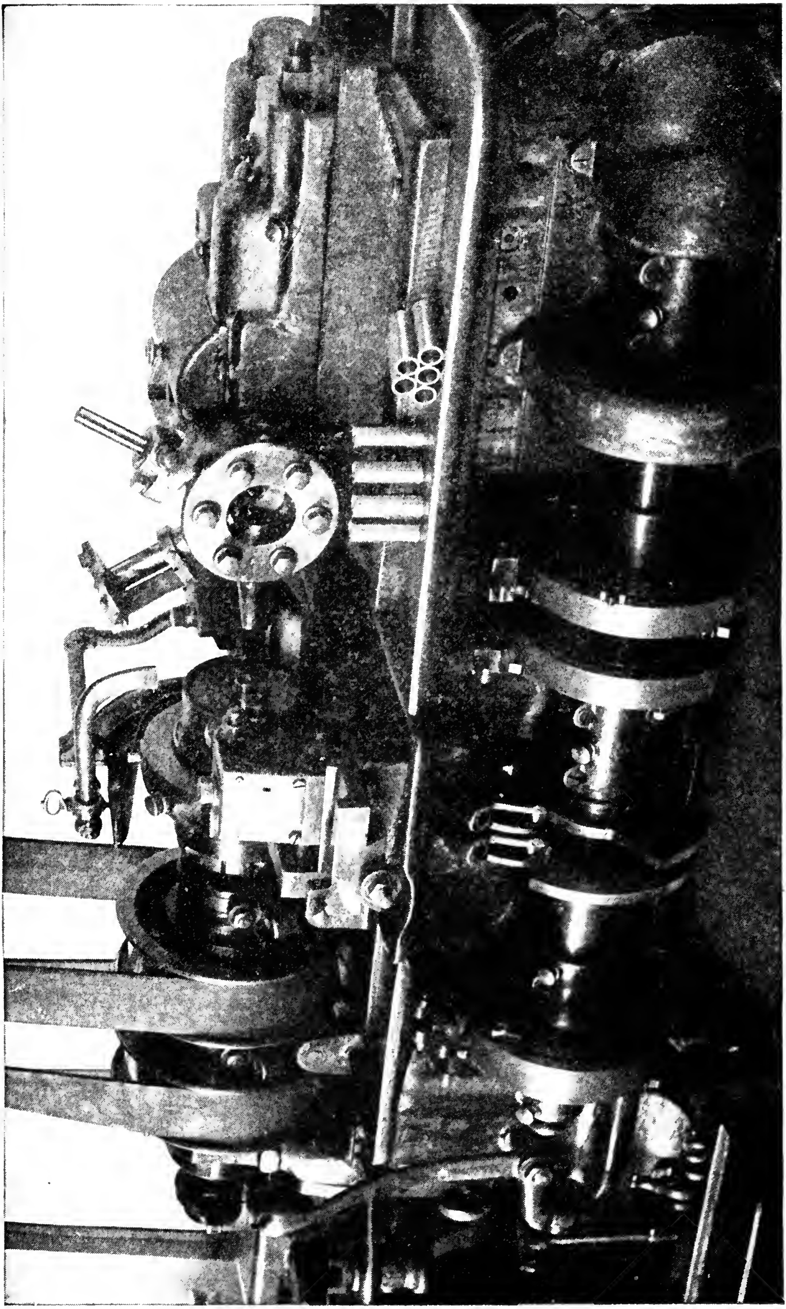


Fig. 361. Automatic at Work on Hollow Cylindrical Sleeves
Courtesy of Brown and Sharpe Manufacturing Company, Providence, Rhode Island

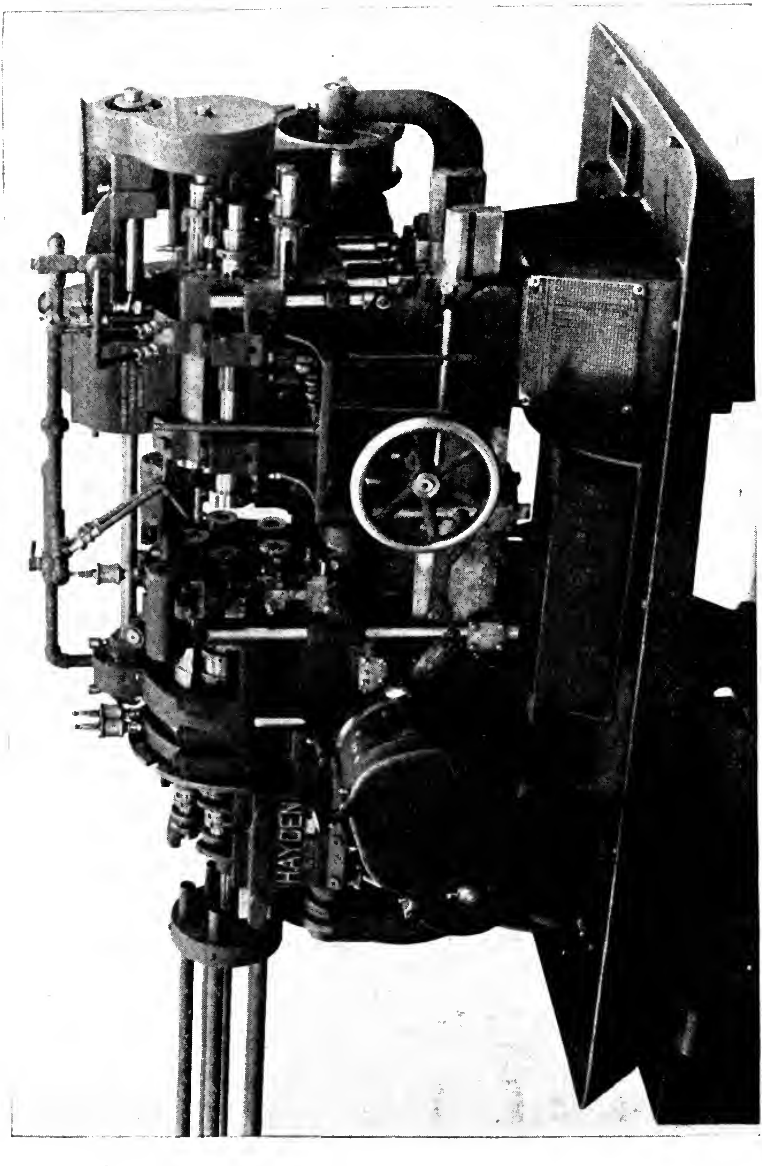


Fig. 362. Hayden Automatic with Five Work Spindles
Courtesy of Cincinnati Automatic Machine Company, Cincinnati, Ohio

PLANING MACHINES

Production Planers. The machine tool shown in Fig. 363 is for quantity production of plane surfaces. Enormous machines of this type are in use, constructed to drive and feed the best of cutting tools to their endurance limits. By the use of several tool-carrying heads tooling can be done on the top and the side surfaces simultaneously.

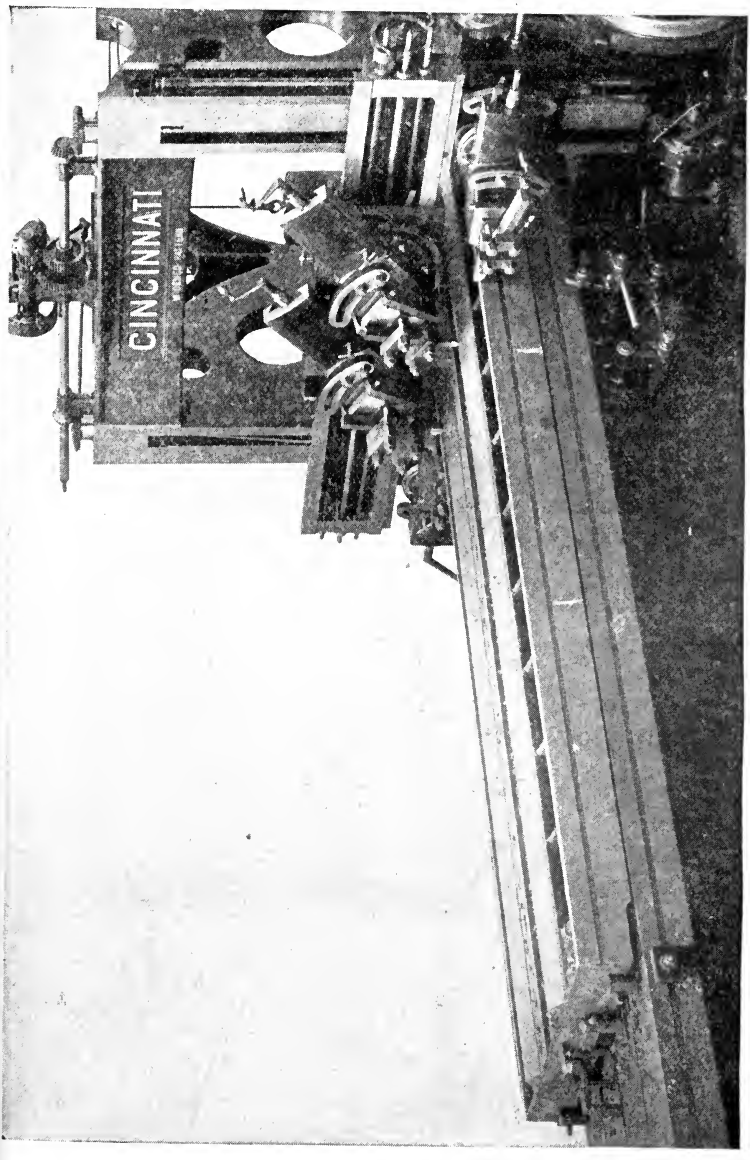


Fig. 363. Cincinnati Planer with Four Tools Cutting
Courtesy of Cincinnati Planer Company, Cincinnati, Ohio

Work Holding. In the case of production work, where size precludes the mounting of more than a single piece on the work table, the work usually rests on the table itself without supporting fixtures. In locating the work and holding it true to its

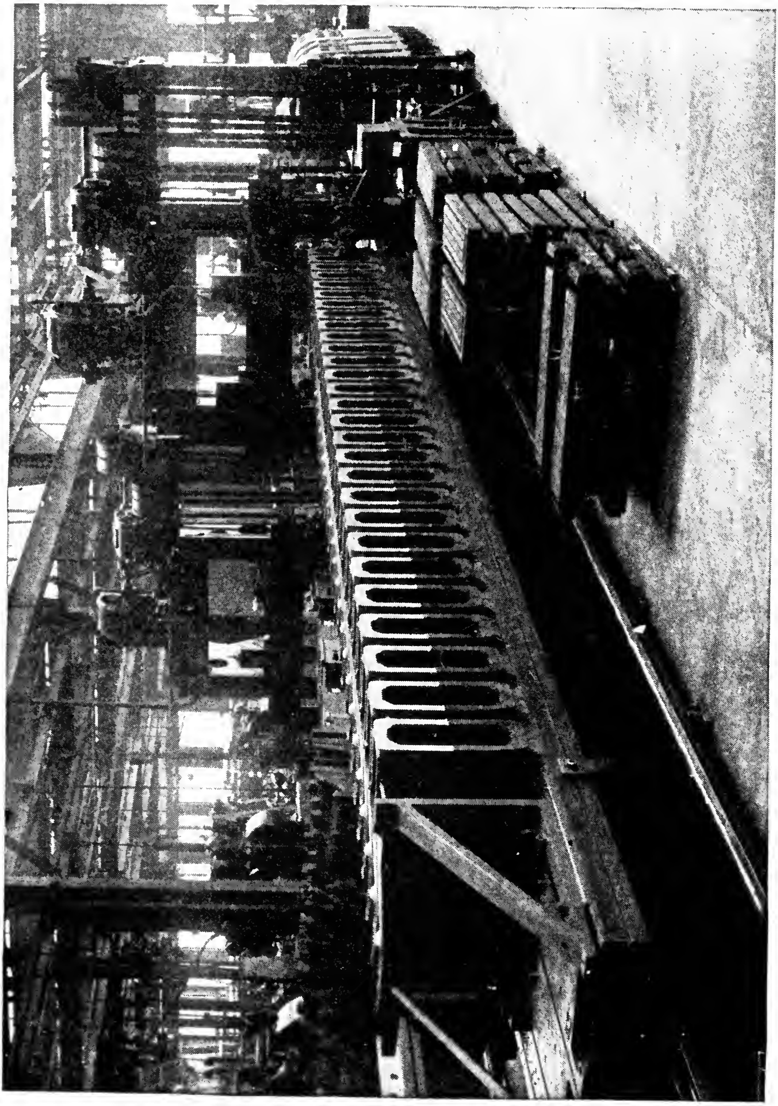


Fig. 364. Production Planer Machining 28 Columns in 12 Hours, Using Gang Tool in Each of Four Tool Heads
Courtesy of Cincinnati Planer Company, Cincinnati, Ohio

location, a variety of bolts, straps, thrust blocks, angle irons, and struts are usually available. Where the size of the work warrants mounting more than a single piece upon the work table, work-holding fixtures, as shown in Fig. 364, are usually provided. These may also, by design, accurately locate the pieces.

Lubrication. In planer work, the cutting tool is seldom lubricated.

BROACHING MACHINES

Types of Machines and Nature of Work. Fig. 365 is representative of a type of machine tool which makes use of a train of

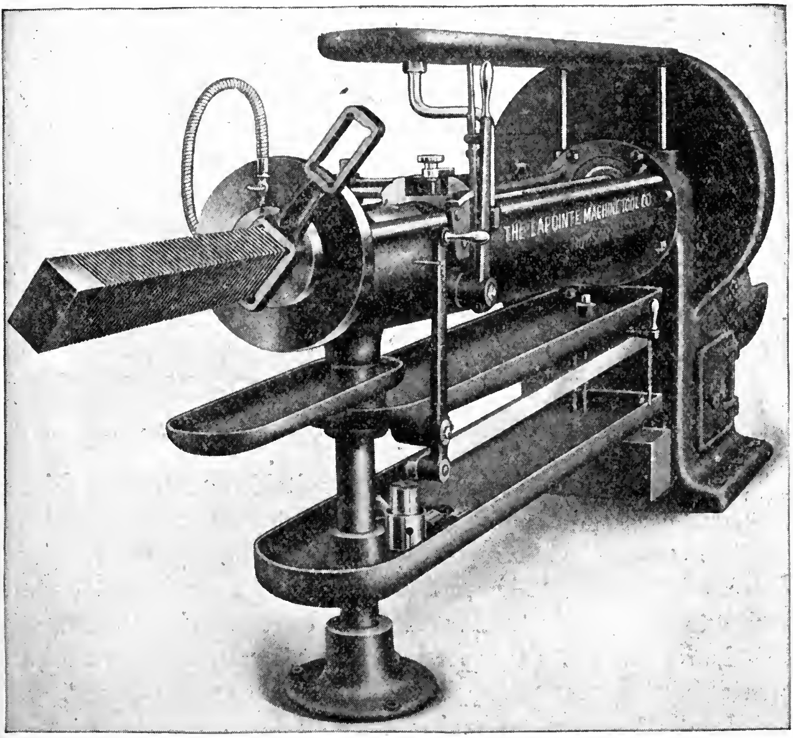


Fig. 365. Typical Broaching Machine
Courtesy of LaPointe Machine Tool Company, Hudson, Massachusetts

cutting edges for roughing and finishing holes in machine parts. Typical broaches are shown in Fig. 366. The cutting edges are usually formed as an integral part of the broach itself.

Operation. The leading end of the broach is passed through the previously drilled or cored hole in the piece of work, and is attached to the power or work spindle. This spindle, as shown in

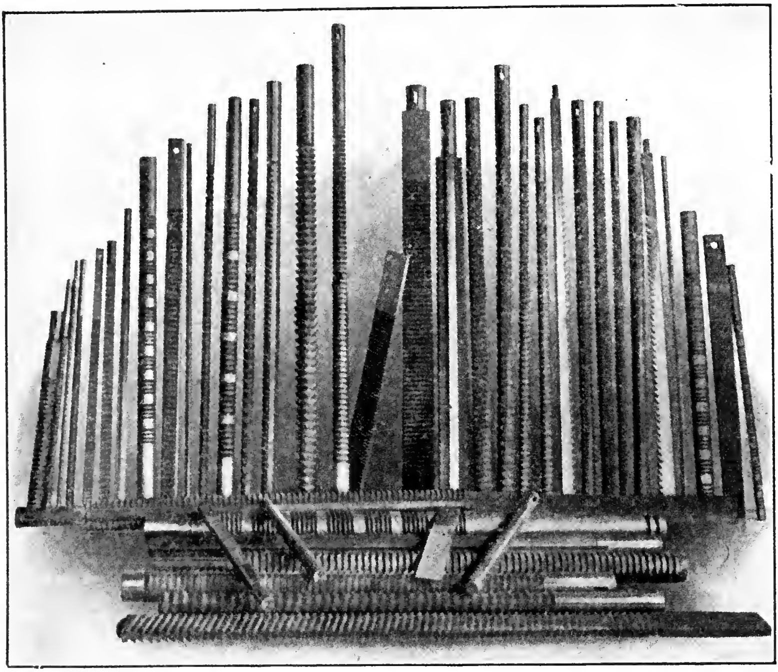


Fig. 366. Typical Broaches
Courtesy of LaPointe Machine Tool Company, Hudson, Massachusetts

Fig. 365, is a threaded bar running in a suitable frame. The driving mechanism screws the threaded spindle along the axis of the machine until the broach has been pulled through the hole in the work.

Work Holding. The work is held against a footing block which resists the thrust due to the pull of the broach.

Lubrication. As the speed of cutting is comparatively slow, the cutting lubricant may be applied with a brush or by use of a drip can.

Production. Holes having other than a circular form are the particular province of the broaching machine. Fig. 367 shows some typical holes and Table XVIII gives rates of production.

TABLE XVIII

Data on Rates of Production with Different Broaching Machines*

Note. Numbers refer to Fig. 367.

No. 1. Hexagon Hole with One Round Side. Distance across flats $1\frac{1}{8}$ in., length $1\frac{1}{2}$ in., material steel. No. 2 Machine. Production 45 pieces per hour.

* *Courtesy of LaPointe Machine Tool Company. Hudson, Massachusetts.*

No. 2. Four Splines. Hole $1\frac{7}{8}$ in. diameter, splines $\frac{3}{4}$ in. × $\frac{3}{16}$ in., $2\frac{1}{4}$ in. long, material steel. No. 3 Machine. Production 20 pieces per hour.

No. 3. Square Hole. Distance across flats 1 in., $1\frac{1}{2}$ in. long, material steel. No. 2 Machine. Production 40 pieces per hour.

No. 4. Four Spiral Keys. Diameter of hole 1 in., keys $\frac{1}{2}$ in. × $\frac{1}{8}$ in., 2 in. long, material steel. No. 3 Machine. Production 15 pieces per hour.

No. 5. Clutch Used on Mining Machinery. Diameter of hole $2\frac{7}{8}$ in. Double depth of slots $3\frac{3}{4}$ in., length 2 in., material steel. No. 3 Machine. Production 20 pieces per hour.

No. 6. Solid Key. Taken from $1\frac{1}{4}$ in. round hole, leaving solid key $\frac{1}{2}$ in. × $\frac{1}{8}$ in., length $2\frac{1}{2}$ in., material steel. No. 3 Machine. Production 15 pieces per hour.

No. 7. Six Radial Splines. Diameter of hole $2\frac{1}{8}$ in., splines $\frac{5}{8}$ in. × $\frac{1}{8}$ in., $2\frac{1}{8}$ in. long, material steel. No. 3 Machine. Production 20 pieces per hour.

No. 8. Housing for Bronze Bearings. Openings $4\frac{1}{2}$ in. × $1\frac{1}{2}$ in., 2 in. through, material C. I. No. 3 Machine. Production from rough casting 20 pieces per hour.

No. 9. Square Hole. Distance across flats 2 in., length $3\frac{1}{8}$ in., material steel. No. 3 Machine. Production from a drilled hole, 15 pieces per hour.

No. 10. Square Hole. Distance across flats 3 in., length 4 in., material steel. No. 4 Machine. Production from drilled hole, 15 pieces per hour.

No. 11. Three Dovetail Splines. Diameter of hole $1\frac{5}{8}$ in., splines 1 in. × $\frac{3}{16}$ in., 2 in. long, material brass. No. 3 Machine. Production 45 pieces per hour.

No. 12. Eight Dovetail Splines. Diameter of hole $3\frac{5}{8}$ in., splines $\frac{3}{4}$ in. × $\frac{3}{16}$ in., 3 in. long, material steel. No. 4 Machine. Production 15 pieces per hour.

No. 13. Square Hole. $1\frac{3}{8}$ in. across flats, 5 in. long, material steel. No. 3 Machine. Production from drilled hole, 15 pieces per hour.

No. 14. Universal Joint Part. Hole $2\frac{7}{16}$ in. across flats, $\frac{3}{4}$ in. through, material C. I. No. 3 Machine. Production 30 pieces per hour.

No. 15. Babbitt Bearing. Diameter 2 in., length $2\frac{1}{4}$ in. Broached to exact size, compressed and burnished. No. 3 Machine. Production 60 pieces per hour.

No. 16. Round Hole. 3 in. diameter, $4\frac{3}{8}$ in. long, material C. I. No. 3 Machine. Production from cored hole 30 pieces per hour.

No. 17. Cruciform Used in Mining Machinery. Splines $\frac{1}{2}$ in. × $\frac{3}{8}$ in., 7 in. long, material steel. No. 3 Machine. Production from $\frac{7}{8}$ in. round hole, 7 pieces per hour.

No. 18. Oval Shaped Holes. $\frac{13}{16}$ in. × $\frac{5}{8}$ in., $\frac{1}{4}$ in. through, material steel. No. 2 Machine. Production approximately 600 holes per hour.

No. 19. Revolver Frame. Size of hole for chamber $1\frac{13}{16}$ in. × $1\frac{1}{2}$ in., $\frac{3}{4}$ in. through, material steel. No. 2 Machine. Production from rough forging 20 pieces per hour.

No. 20. Hexagon Hole. Distance across flats $2\frac{3}{8}$ in., $2\frac{1}{8}$ in. long, material steel. No. 3 Machine. Production from drilled hole 40 pieces per hour.

No. 21. Two-Spline Hole. $1\frac{1}{18}$ in. × $\frac{9}{16}$ in., $3\frac{1}{2}$ in. long, material steel. No. 2 Machine. Production from $\frac{3}{4}$ in. drilled hole, 10 pieces per hour.

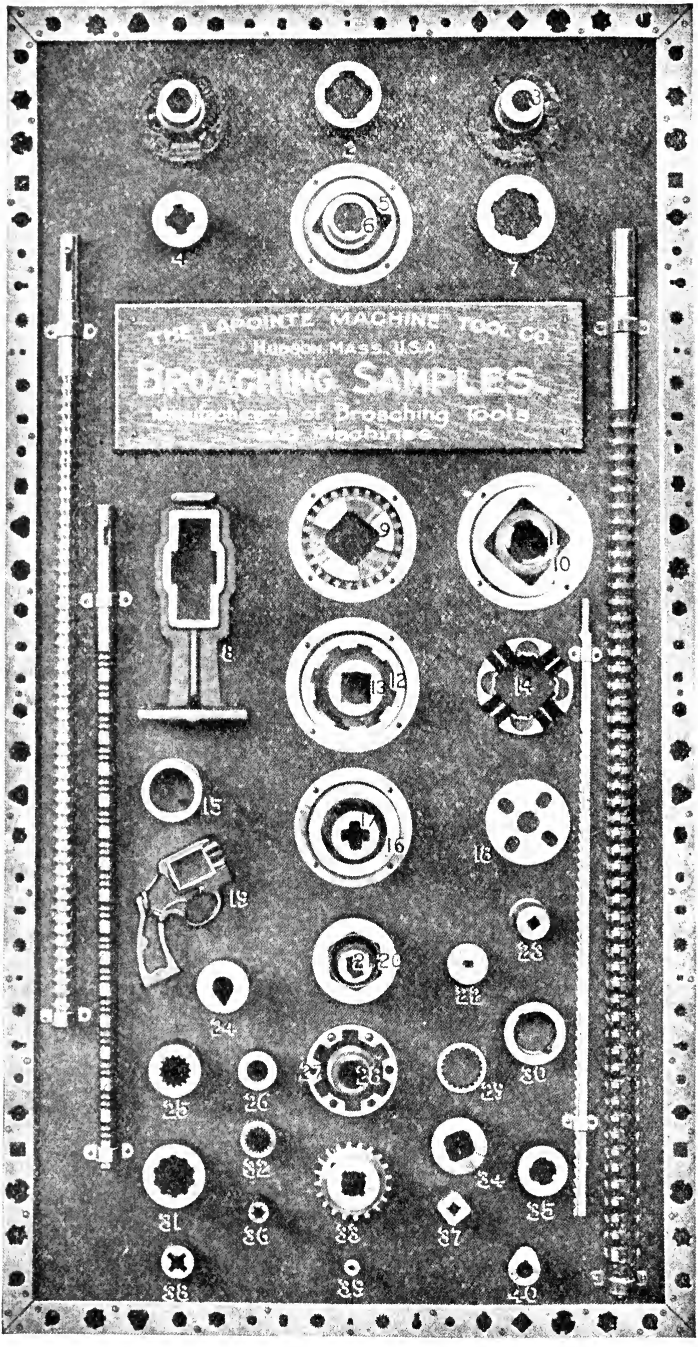


Fig. 367. Samples of Broaching Work
Courtesy of LaPointe Machine Tool Company, Hudson, Massachusetts

No. 22. Hole. $\frac{1}{2}$ in. × $\frac{5}{16}$ in., $\frac{1}{2}$ in. long, material steel. No. 1 Machine. Production from drilled hole 25 pieces per hour.

No. 23. Square Hole. $\frac{1}{2}$ in. across flats, 2 in. long, material steel. No. 1 Machine. Production from drilled hole 20 pieces per hour.

No. 24. Pear Shaped Hole. Diameter of round broach 1 in., $1\frac{3}{8}$ in. long, material steel. No. 2 Machine. Production 20 pieces per hour.

No. 25. Internal Gear. Hole $1\frac{1}{4}$ in., $1\frac{7}{8}$ in. long, 15 teeth, material steel. No. 3 Machine. Production from drilled hole 40 pieces per hour.

No. 26. Internal Ratchet 140 Teeth. Diameter of hole 1 in., length $1\frac{1}{8}$ in., material steel. No. 2 Machine. Production 45 pieces per hour.

No. 27. Six Splines. Diameter of hole $2\frac{3}{4}$ in., splines $\frac{3}{4}$ in. × $\frac{1}{2}$ in., 1 in. long, material drop-forged steel. No. 4 Machine. Production 35 pieces per hour.

No. 28. Bronze Bushing. Hole $\frac{15}{16}$ in. diameter, $1\frac{7}{8}$ in. long. No. 3 Machine. Broached to exact size, compressed and burnished. Production from cored hole 100 pieces per hour.

No. 29. Magneto Coupling. Hole $1\frac{3}{4}$ in. diameter, $\frac{1}{2}$ in. long, 20 teeth, material steel. No. 3 Machine. Production from drilled hole 90 pieces per hour.

No. 30. Two Spiral Keyways. Diameter of hole 2 in., keyways $\frac{1}{4}$ in. × $\frac{1}{8}$ in., $1\frac{7}{8}$ in. long, material steel. No. 3 Machine. Production 40 pieces per hour.

No. 31. Ten Splines. Diameter of hole $1\frac{3}{4}$ in., splines $\frac{1}{4}$ in. × $\frac{1}{8}$ in., $1\frac{1}{4}$ in. long, material steel. No. 3 Machine. Production 45 pieces per hour.

No. 32. Tool Steel Die for Pressing Tin Top on Bottles. Diameter of hole $1\frac{1}{16}$ in., $\frac{7}{8}$ in. long, 21 teeth. No. 2 Machine. Production from drilled hole 60 pieces per hour.

No. 33. Four Spline. Diameter of hole $1\frac{1}{8}$ in., splines $\frac{5}{16}$ in. × $\frac{1}{8}$ in. $1\frac{1}{4}$ in. long, material steel. No. 2 Machine. Production 45 pieces per hour.

No. 34. Taper Square Hole. Distance across flats, small end, $1\frac{1}{4}$ in., large end $1\frac{1}{2}$ in., 2 in. long, material steel. No. 2 Machine. Production 12 pieces per hour.

No. 35. Four Solid Keys. Diameter of hole $1\frac{1}{16}$ in., keys $\frac{5}{16}$ in. × $\frac{1}{8}$ in., $1\frac{5}{8}$ in. long, material steel. No. 3 Machine. Production 20 pieces per hour.

No. 36. Bushing for Trolley Wheel. Diameter of hole $\frac{1}{2}$ in., six spiral keyways $\frac{1}{8}$ in. × $\frac{1}{16}$ in., $1\frac{1}{2}$ in. long, material bronze. No. 2 Machine. Production 100 pieces per hour.

No. 37. Four Splines in Taper Hole. Hole $\frac{1}{2}$ in. diameter at small end, $\frac{5}{8}$ in. diameter at large end, splines $\frac{1}{8}$ in. × $\frac{1}{16}$ in., $\frac{1}{2}$ in. long. Splines parallel with taper, material steel. No. 1 Machine. Production 25 pieces per hour.

No. 38. Four Splines. Diameter of hole $\frac{5}{8}$ in., splines $\frac{1}{4}$ in. × $\frac{1}{4}$ in., $\frac{3}{4}$ in. long, material steel. No. 1 Machine. Production 15 pieces per hour.

No. 39. Single Keyway. Diameter of hole $\frac{1}{4}$ in., keyway $\frac{5}{64}$ in. × $\frac{1}{16}$ in., $\frac{3}{8}$ in. long, material brass. No. 1 Machine. Production approximately 250 pieces per hour.

No. 40. Single Keyway. Diameter of hole $\frac{3}{4}$ in., keyway $\frac{3}{16}$ in. × $\frac{3}{32}$ in., 1 in. long, material steel. No. 1 Machine. Production 160 pieces per hour.

PRODUCTION TOOLS, JIGS, AND FIXTURES

CUTTING TOOLS

Materials. *Iron.* Iron is one of the commonest metals in use. In nature it is found in a form known as iron ore. In this form it has many impurities from which it must be separated before it is valuable as an article of commerce. By well-known methods commercially pure iron is obtained from the iron ore. Combining this commercially pure iron with other ingredients under well-known methods of heating, the various grades of steels are produced.

Tool Steel. For generations cutting tools as used in machine shop practice have been made from that grade of steel commercially known as tool steel, the principal constituents of which are pure iron and carbon. In recent years, the metallurgist has combined other metals with iron to produce steels suitable for cutting tools, which have in many cases superseded the older grades of tool steel. To distinguish the older grades from the newer, the former are now generally termed carbon tool steels or simply carbon steels. In all the steels iron is the principal constituent. For example, carbon tool steel may have less than one per cent of carbon in its make-up and seldom has to exceed 1.250 per cent of carbon for ordinary shop cutting tools. In designating percentages of constituents, the steel-maker and user usually refers to them as so many "points". For example, instead of saying that a certain steel has eighty hundredths of one per cent of carbon, he would say that the steel was eighty point carbon; this is usually written "80 point". All tool steels have the peculiar quality of acquiring an intense hardness when heated to the requisite degree of temperature and then cooled suddenly. If this is properly and scientifically done, a beautiful cutting quality results. The older carbon steel cutting tool has this weakness, however, that it loses its hardness at a comparatively low cutting temperature. As rapid metal cutting generates considerable quantities of heat, this tendency of the carbon steel cutting tool to lose its extreme hardness precludes rapid cutting and holds the operator to low cutting speeds. A glance at the accompanying speed tables clearly shows this.

High-Speed Steel. In 1894 and 1895, Messrs. Taylor and White sought by experiment to produce a steel for cutting tools which would show a greater cutting efficiency in the shop. They finally developed the so-called Taylor and White high-speed steel, the forerunner of numerous brands of high speed steels. Cutting tools

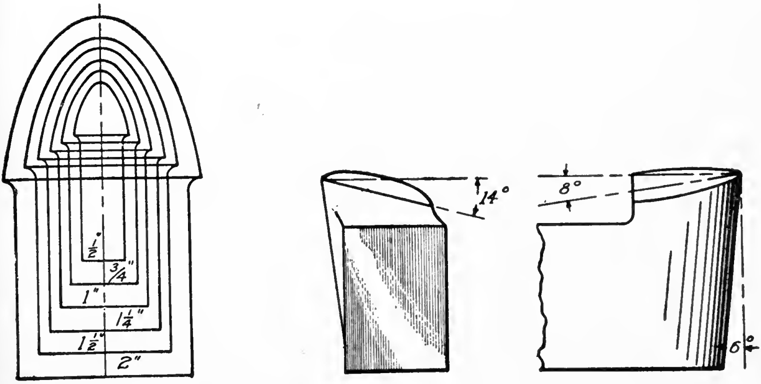


Fig. 368. Taylor Standard Cutting Contours
Courtesy of Ready Tool Company, Bridgeport, Connecticut

made from these steels have the peculiar quality of retaining their hardness at cutting temperatures much in excess of those sustained by tools made from carbon tool steel. For this reason cutting speeds have been materially increased. It is well to understand that the increased speed of cutting is not due to the new steels taking a greater hardness when heat treated, than the older steels, simply that they retain their hardness at temperatures which soften the cutting edges of carbon steel cutting tools to such an extent that their keenness is lost.

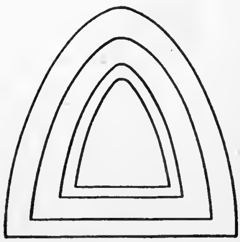


Fig. 369. Red-E Standard Cutting Contours

Production Tools. In Machine Shop Work, Parts I–IV, the usual cutting tools have been treated. We will now discuss the more specialized forms used in production machine work.

Turning Tools. Fig. 368 shows diagrammatically the Taylor form of cutting tools as used for rough and for finish turning. Fig. 369 shows these as modified by one manufacturer of lathe tool holders. Cutting tools shaped to these contours are much used in production turning. Fig. 373 shows how the tool approaches its cut.

As all cutting is a process of splitting it is very important that the cutting tool be properly set up as relates to its cut.

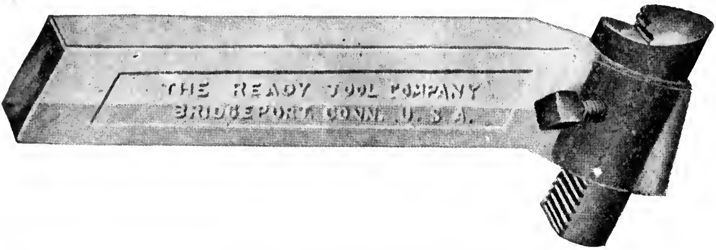


Fig. 370. Red-E Roughing Tool
Courtesy of Ready Tool Company, Bridgeport, Connecticut

Fig. 327 illustrates the kind of surface these tools produce when correctly used.

Planing Tools. The set of tools shown in Fig. 371 are correctly ground for planer use. Due to the nature of their use, planer tools are necessarily of many contours. Their use is well illustrated in Fig. 372.

Milling Tools. The older type of milling cutter with its finer pitched teeth does not work well under production conditions of coarse feeding and heavy cuts. Coarse pitch cutters with maxi-

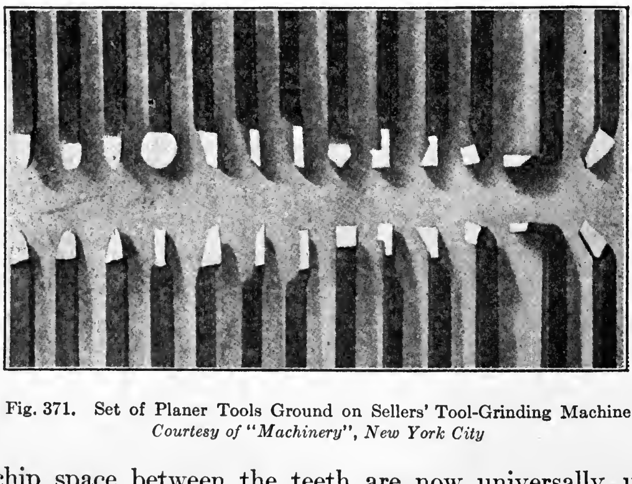


Fig. 371. Set of Planer Tools Ground on Sellers' Tool-Grinding Machine
Courtesy of "Machinery", New York City

mum chip space between the teeth are now universally used in production milling. Fig. 346 shows a milling cutter which is constructed especially for coarse feeds and heavy cuts.

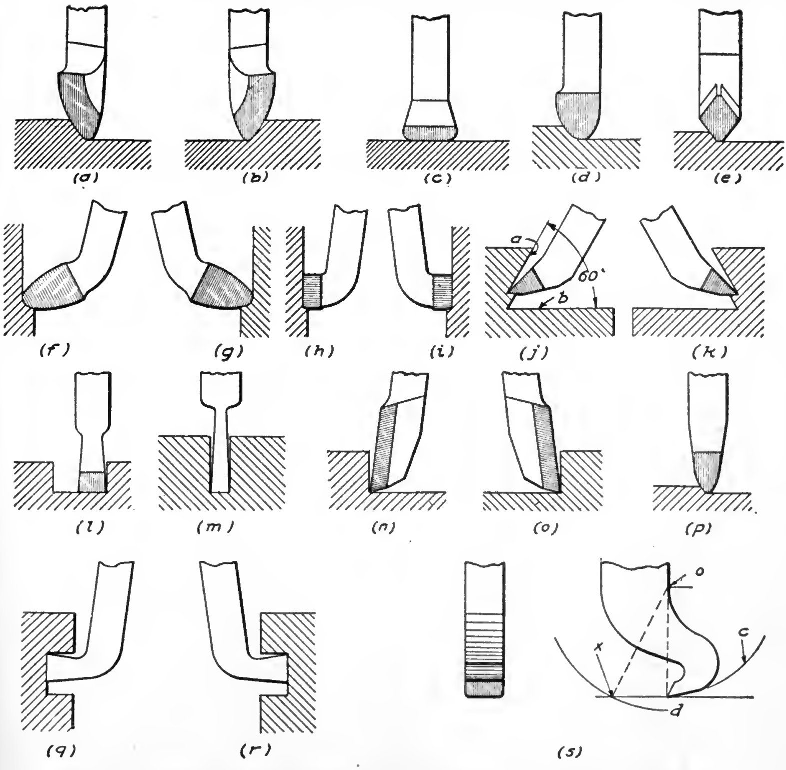


Fig. 372. Planer Tools of Different Form and Work to Which They Are Adapted
Courtesy of "Machinery", New York City

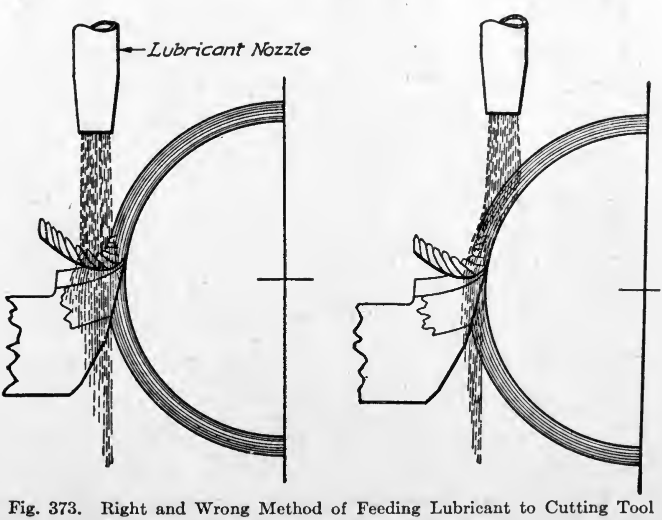


Fig. 373. Right and Wrong Method of Feeding Lubricant to Cutting Tool
Courtesy of "Machinery", New York City

Drilling Tools. High-speed drills for production are shown in Figs. 348 and 349. In experimental tests on cast iron, drills made from high-speed steel are reported to have been fed $\frac{1}{10}$ inch per revolution and at a cutting speed sufficiently high to give a hole depth of about 60 inches per minute.

Cutting Lubrication. Lubrication of the cutting tool is common when production cutting is being done upon wrought iron or steel. It has been found that at times an increased production of nearly 50 per cent can be obtained by forcing a heavy stream of cutting lubricant upon the cutting tool at the point where the metal is being separated. The lubricant appears to be most effective when it reaches the cutting edge at a slow velocity and in sufficient quantities to submerge the tool at the point of contact. Fig. 373 shows diagrammatically right and wrong methods of application.

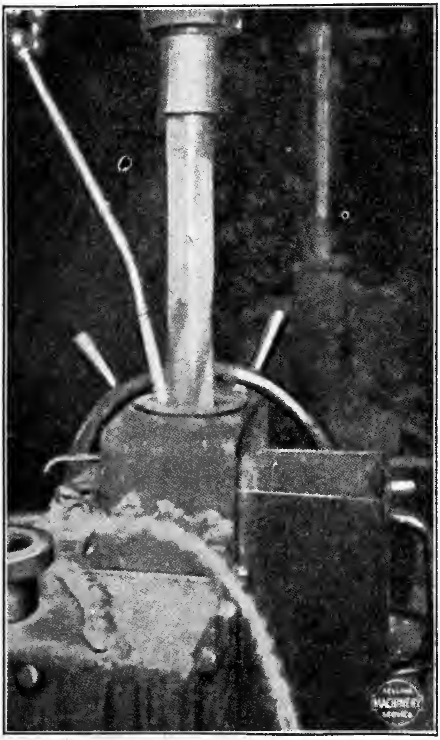


Fig. 374. Drilling Operation Showing How Lubricant Floods the Work
Courtesy of "Machinery", New York City

In Fig. 338 the grinding wheel is nearly hidden by the flood of lubricant and Fig. 374 shows how generously the cutting lubricant is flooded to a drill when cutting steel.

Lubricants. The common cutting lubricants used in heavy machining operations are lard oil, mixtures of lard oil and paraffin oil, and the various mixtures of water, oil, soft soap, and sal soda, commonly termed "compounds". Several mixtures of this sort are sold under specific trade names.

Most of the modern manufacturing machine tools are provided with a system for handling the cutting lubricant in large quantities. This usually consists of a supply tank with a settling chamber, an effective geared pump, and the distributing pipes.

JIGS AND FIXTURES

General Classification. The terms "jigs" and "fixtures" are rather loosely used by shopmen. While this is necessarily so in some cases, in most instances it is more correct to apply the term *jig* to a device which holds the work and automatically locates the cutting tool so that each piece produced is a duplicate of all the others. Fixtures, on the other hand, do not automatically locate the cutting tool. While fixtures may be used to produce duplicates, this result is usually gained by means of a cutting tool locating jig separated from the fixture itself. Fixtures are essentially work-holding devices.

Object of These Tools. While several effects are gained by using jigs and fixtures, they all reduce to one thing, namely, *production.* For example, by the proper use of jigs and fixtures, production is made more uniform, giving interchangeability of parts. If jigs and fixtures are properly used, production is attended by a reduction of labor cost, both when the machine parts are being produced, and when the parts are assembled to produce the completed machine.

Importance. That jigs and fixtures are an important factor in modern production is clearly shown by a study of the various production cuts in this book. These illustrations for the most part show the machine in a working condition, and in nearly every case some special fixture or jig is holding the work or is guiding the tool. In some cases, the special work-holding device is a simple work chuck or a magnetic work chuck, in others the special devices are rather elaborate.

Jig Design and Construction

Many of the rules governing jig design hold true for fixtures, and jig design will be taken up first.

Fundamental Principles of Design. *Use of Jig.* In jig design it is usual to first consider the uses to which it is to be put. If, for example, the piece for which the jig is made is to finally bear a fixed relation to some other machine part, it becomes necessary to consider not only the part being jigged, but also its relation to the other parts with which it is to be assembled. Again, if the piece being jigged is of special accuracy, the jig design may be different from that of a machine part in which no special accuracy is required. In one case, the jig is both a rapid production tool and an interchangeability tool. In the other case, the jig is merely a convenient tool for getting rapid production.

As a Work Holder. It is usual in the design of jigs to next consider how the piece shall be held in the prospective jig. The points or surfaces upon the piece which are those best suited for location points and surfaces are decided upon. If the piece has been previously machined, the surface machined usually offers the best location to work from. If, on the other hand, the surfaces of the stock are rough, as in an ordinary casting, the selection of the locating surfaces or surface is usually a more difficult one. Usually some surface or hole will be essentially more important than all the remaining surfaces or holes. In such a case, the jig designer uses location points which will position the important hole or surface, afterward considering the points of lesser importance. This he terms "working to or working from the important point". A flat surface, if it has previously been machined, is usually located against a flat surface; if not previously machined, a flat surface should be given line or point contact. It is customary to locate a curved surface against a V or against points.

Clamping. This refers to the particular devices which hold the piece being jigged against the location points or surfaces. The design should be such that the least number of clamping devices may be used, so that no unnecessary time is consumed in charging the jig, as this limits production unless the jigs are charged as a separate job.

All clamping devices should exert their pressure, wherever possible, directly in line with the supporting points. If this is done the piece clamped will not be sprung out of shape. As an aid in understanding the already mentioned points, a simple jig will be illustrated and its construction described.

Drill Jigs. While a study of the illustrations in this book will show the student that jigs are an important factor in all production machines, perhaps in no other machine is their importance so complete as in the drilling of holes. For this reason a drill jig will be used to illustrate jig construction. In the line drawing, Figs. 375 and 376, are shown the top and bottom views of a simple jig of the open box type designed to rapidly produce duplicate work. In Fig. 377 are shown two views of a jig of the closed box type for rapid production of duplicate parts. While neither of these jigs are elaborate in either design or construction, they fairly represent their types.

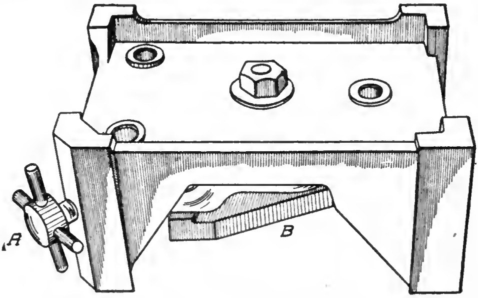


Fig. 375. Typical Open Box Drill Jig
Courtesy of "American Machinist"

Types of Drill Jigs. Drill jigs are of three forms (a) plate jigs; (b) open box; (c) closed box. The plate jig usually consists

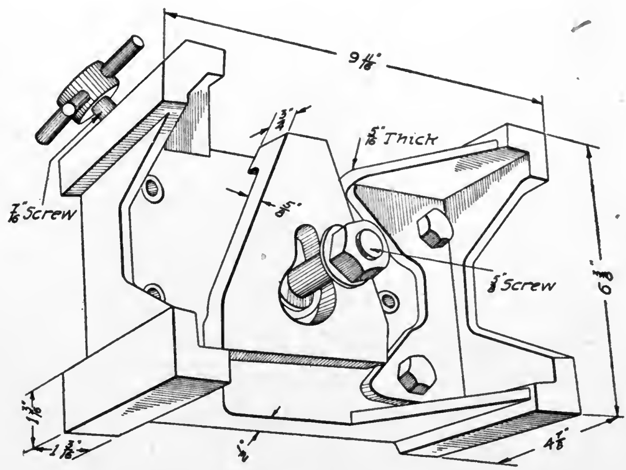
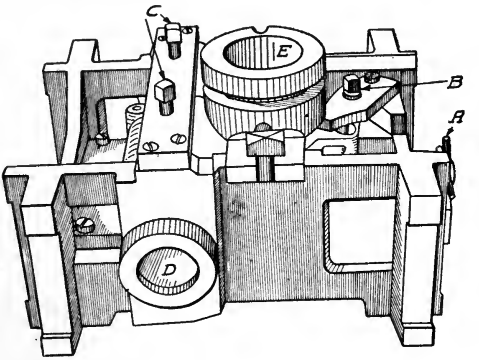


Fig. 376. Bottom View of Box Drill Jig Shown in Fig. 375
Courtesy of "American Machinist"

of a flat plate with located bushings which is positioned on the work and clamped to it. The open box type, as shown in Figs. 375 and 376, consists of a casting provided with legs or feet. The piece jigged is clamped to the lower or under surface of the jig body.

The closed box type is such that the piece to be jigged is positioned in a box which may be entirely or partially closed. In the lower view, Fig. 377, the box, as shown, is open on one side and partially so on another side.



Locating Work in Drill Jigs. Fig. 378 shows the use of pins or studs used as side-locating points in simple jig work, and Fig. 379 shows how V's are similarly used on curved surfaces. While these are simple examples, they illustrate a principle which can easily be applied to more complicated cases.

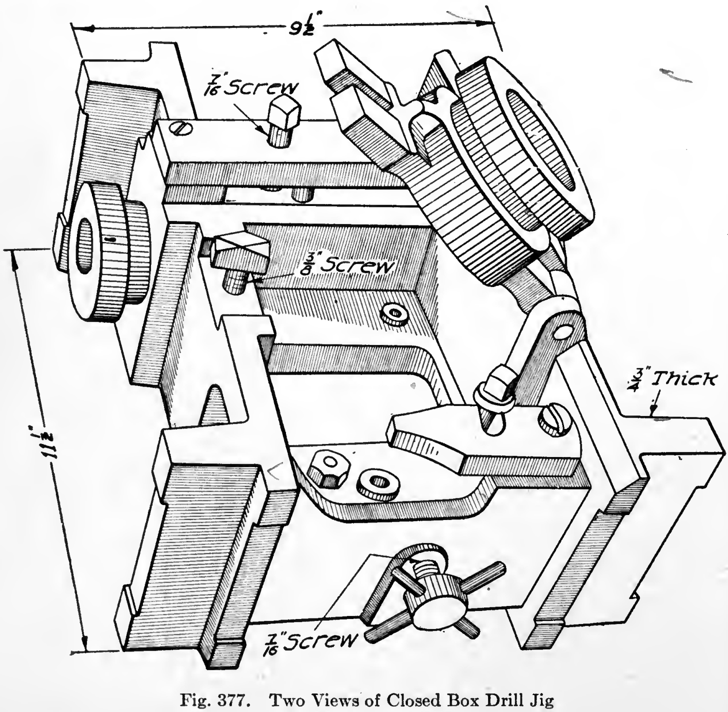


Fig. 377. Two Views of Closed Box Drill Jig
Courtesy of "American Machinist"

The use of locating pads is shown in Fig. 380, and Fig. 381 shows how an inserted pin may be used for supporting a plane surface. Where pins are used for location points, Fig. 378, the sides against which the pieces are located are usually flatted somewhat to bring surface contact rather than line contact. Hardening the pins will also prevent excessive wear.

Fig. 378. Method of Using Locating Stubs or Pins

Locating Points with Adjustments. In some cases, it is well to have locating surfaces or points adjustable. In Fig. 381 the inserted pin, if threaded into base *B* could, for example, be raised to some other position from that shown. Some jig designers, instead of the V-block shown in Fig. 379, use two set screws horizontally set at an angle of 45 degrees with one another, bringing the curved surface against their points.

Clamping. This is done in a great variety of ways and many of the devices are very ingenious. However, they nearly all reduce to some form of clamp either straight, bent, or forked, pressed against the work by either a set screw, a cap screw, or a cam. In Fig. 375 it will be noted that the clamping is done by a strap similar to that shown in Fig. 382, and the piece is pushed into position by knurled head set screws. In Fig. 377 set screws are used, supplemented

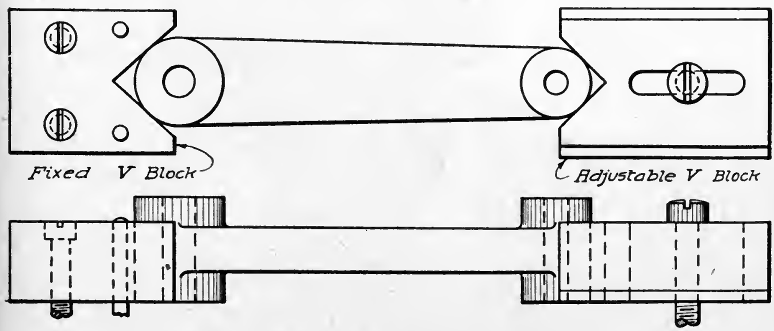


Fig. 379. Diagrams Showing Fixed and Adjustable V's

by a swinging-wing clamp at the side pressing against the piece of work. Fig. 383 shows favorite forms of cam clamping devices.

Jig Body. While steel may be used for the body or frame of a jig, it is a usual thing to use cast iron. If cast iron is used the jig can be more or less completely worked out in the pattern, and possibilities of alteration in design may show as desirable. When it is realized that many shops use jigs weighing hundreds of pounds

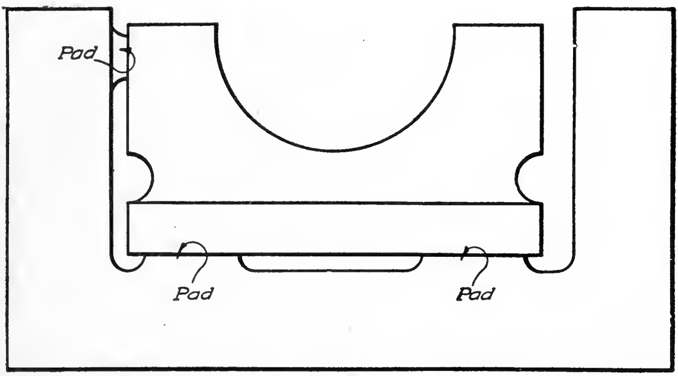


Fig. 380. Diagram Showing Use of Locating Pads

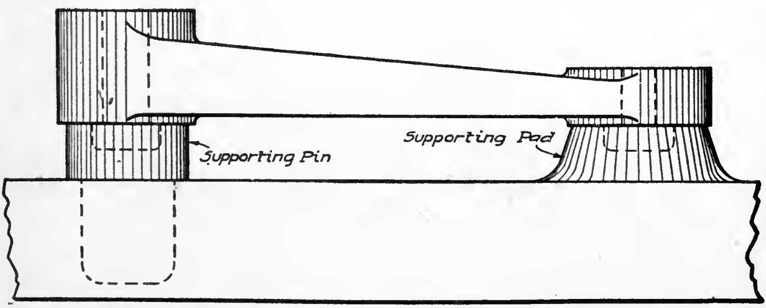


Fig. 381. Sketch Showing Adjustable Locating Points

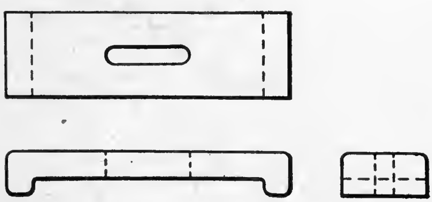


Fig. 382. Clamp Strap

in their production work, it is clearly seen why cast iron is largely used for jig bodies.

Bearing Points. Only in the smaller sizes do drill jigs rest upon a surface of any considerable area. It will be noted, by reference to Figs. 375, 376, and 377, that supporting points, termed feet, are provided on those sides of the jig which are to rest upon the work table. The height of the feet must be sufficient to clear all bushings, holding screws, or other projecting parts. Also their bearing area must be sufficiently large to prevent their slipping into the bolt

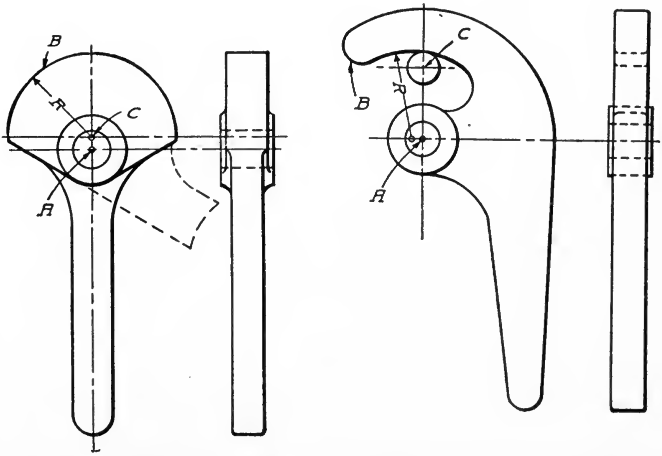


Fig. 383. Diagrams Showing Cams or Eccentrics Used for Clamping
Courtesy of "Machinery", New York City

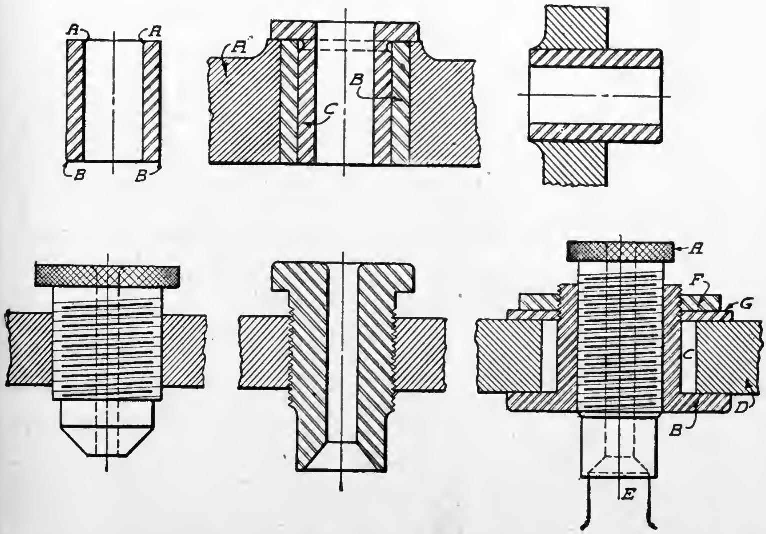
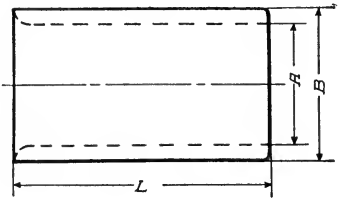


Fig. 384. Typical Bushings: Upper Line—Guiding Lining Bushings for Drill Jigs; Lower Left—Screw Bushing for Locating Work Central with Hole; Lower Center—Screw Bushing for Locating Round Work by Recesses; Lower Right—Floating Bushing
Courtesy of "Machinery", New York City

slots often found in work tables. Whenever possible the jig should be provided with four feet instead of three.

TABLE XIX

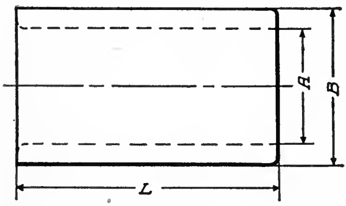
Dimensions of Stationary Drill Bushings*



A	B	L	A	B	L	A	B	L	A	B	L
$\frac{1}{16}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{9}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{7}{16}$	2	$1\frac{9}{16}$	$1\frac{15}{16}$	$2\frac{3}{4}$
$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{5}{8}$	2	2
$\frac{3}{16}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{11}{16}$	$\frac{15}{16}$	$1\frac{3}{8}$	$1\frac{3}{16}$	$1\frac{9}{16}$	$2\frac{1}{8}$	$1\frac{11}{16}$	$1\frac{1}{8}$	$2\frac{1}{8}$
$\frac{1}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{13}{16}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{13}{16}$	$2\frac{5}{16}$	$2\frac{5}{16}$
$\frac{3}{8}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{3}{16}$	$1\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$2\frac{3}{8}$	$1\frac{7}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$
$\frac{7}{16}$	$\frac{5}{8}$	$\frac{7}{8}$	$\frac{15}{16}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{7}{16}$	$1\frac{13}{16}$	$2\frac{1}{2}$	$1\frac{15}{16}$	$2\frac{7}{16}$	$2\frac{7}{16}$
$\frac{1}{2}$	$\frac{11}{16}$	1	1	$1\frac{3}{8}$	$2\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{5}{8}$	2	$2\frac{5}{8}$	$2\frac{5}{8}$

TABLE XX

Dimensions of Lining Bushings*

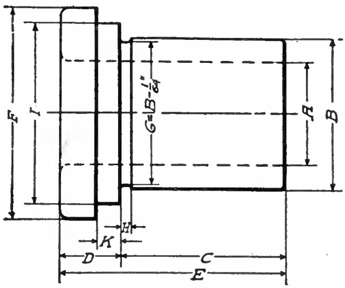


A	B	L	A	B	L	A	B	L
$\frac{5}{16}$	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{8}$	$2\frac{5}{8}$	$2\frac{5}{8}$
$\frac{3}{8}$	$\frac{9}{16}$	$\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$2\frac{3}{16}$	$2\frac{11}{16}$	$2\frac{3}{4}$
$\frac{7}{16}$	$\frac{5}{8}$	$\frac{5}{8}$	$1\frac{5}{16}$	$1\frac{11}{16}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$2\frac{7}{8}$
$\frac{9}{16}$	$\frac{13}{16}$	$\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{7}{8}$	$2\frac{5}{16}$	$2\frac{7}{8}$	$2\frac{7}{8}$
$\frac{5}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{7}{16}$	$1\frac{13}{16}$	2	$2\frac{3}{8}$	3	3
$\frac{11}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	$1\frac{9}{16}$	$1\frac{15}{16}$	$2\frac{1}{8}$	$2\frac{9}{16}$	$3\frac{3}{16}$	$3\frac{1}{8}$
$\frac{3}{4}$	1	1	$1\frac{5}{8}$	2	$2\frac{1}{8}$	$2\frac{5}{8}$	$3\frac{1}{4}$	$3\frac{1}{4}$
$\frac{13}{16}$	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{4}$	$2\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{11}{16}$	$3\frac{5}{16}$	$3\frac{3}{8}$
$\frac{15}{16}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{13}{16}$	$2\frac{5}{16}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$
1	$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{7}{8}$	$2\frac{3}{8}$	$2\frac{3}{8}$	...	...	..
$1\frac{1}{16}$	$1\frac{7}{16}$	$1\frac{1}{2}$	$1\frac{15}{16}$	$2\frac{7}{16}$	$2\frac{1}{2}$	...	...	..

*Courtesy of "Machinery", New York City.

TABLE XXI

Dimensions of Removable Drill Bushings*



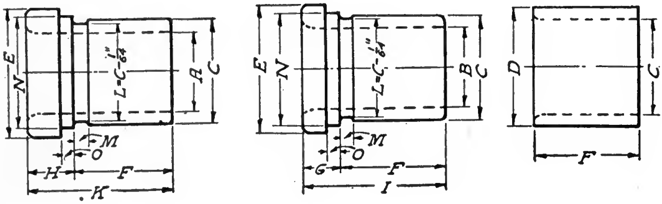
A	B	C	D	E	F	H	I	K
1/8	5/16	1/2	1/8	5/8	5/8	1/8	1/2	1/32
3/16	3/8	1/2	1/8	5/8	5/8	1/8	1/2	1/32
1/4	7/16	5/8	1/8	3/4	3/4	1/8	5/8	1/32
5/16	9/16	5/8	1/8	3/4	7/8	1/8	3/4	1/32
3/8	5/8	3/4	1/8	7/8	7/8	1/8	3/4	1/32
7/16	11/16	7/8	1/8	1	1	1/8	7/8	1/32
1/2	3/4	1	1/8	1 1/8	1	1/8	7/8	1/32
9/16	13/16	1 1/8	1/8	1 1/4	1 1/8	1/8	1	1/32
5/8	15/16	1 1/4	3/16	1 7/16	1 1/4	1/8	1 1/8	1/16
11/16	1	1 3/8	3/16	1 9/16	1 1/4	1/8	1 1/8	1/16
3/4	1 1/16	1 1/2	3/16	1 11/16	1 3/8	1/8	1 1/4	1/16
13/16	1 1/8	1 1/2	3/16	1 11/16	1 3/8	1/8	1 1/4	1/16
7/8	1 1/4	1 5/8	3/16	1 13/16	1 1/2	1/8	1 3/8	1/16
15/16	1 5/16	1 3/4	3/16	1 15/16	1 5/8	1/8	1 1/2	1/16
1	1 3/8	1 7/8	1/4	2 1/8	1 3/4	3/16	1 5/8	3/32
1 1/16	1 7/16	2	1/4	2 1/4	1 7/8	3/16	1 3/4	3/32
1 1/8	1 9/16	2 1/8	1/4	2 3/8	2	3/16	1 13/16	3/32
1 3/16	1 5/8	2 1/8	1/4	2 3/8	2	3/16	1 13/16	3/32
1 1/4	1 3/4	2 1/4	5/16	2 9/16	2 1/8	3/16	1 15/16	1/8
1 5/16	1 13/16	2 1/4	5/16	2 9/16	2 1/4	3/16	2 1/16	1/8
1 3/8	1 7/8	2 3/8	5/16	2 11/16	2 1/4	3/16	2 1/16	1/8
1 7/16	1 15/16	2 1/2	5/16	2 13/16	2 3/8	3/16	2 3/16	1/8
1 1/2	2 1/8	2 5/8	3/8	3	2 1/2	3/16	2 5/16	1/8
1 9/16	2 3/16	2 3/4	3/8	3 1/8	2 5/8	3/16	2 7/16	1/8
1 5/8	2 1/4	2 7/8	3/8	3 1/4	2 5/8	3/16	2 7/16	1/8
1 11/16	2 5/16	2 7/8	3/8	3 1/4	2 3/4	3/16	2 9/16	1/8
1 3/4	2 3/8	3	3/8	3 3/8	2 3/4	3/16	2 9/16	1/8
1 13/16	2 9/16	3 1/8	1/2	3 5/8	3	1/4	2 13/16	5/32
1 7/8	2 5/8	3 1/4	1/2	3 3/4	3 1/8	1/4	2 15/16	5/32
1 15/16	2 11/16	3 3/8	1/2	3 7/8	3 1/8	1/4	2 15/16	5/32
2	2 3/4	3 1/2	1/2	4	3 1/4	1/4	3 1/16	5/32

Guide Bushings. The soft body of the jig cannot be used to guide the drill if much service is required of the jig. In all production work, the guide holes for the drills are lined with hardened

*Courtesy of "Machinery", New York City.

TABLE XXII

Bushings for Holes Reamed with Rose Chucking Reamers*



A	B	C	D	E	F	G	H	I	K	M	N	O
3/4	11/16	1 1/4	1 5/8	1 1/2	1 1/4	3/16	1/4	1 7/16	1 1/2	1/8	1 3/8	1/16
13/16	3/4	1 5/16	1 11/16	1 5/8	1 5/16	3/16	1/4	1 1/2	1 9/16	1/8	1 1/2	1/16
7/8	13/16	1 3/8	1 3/4	1 5/8	1 3/8	3/16	1/4	1 9/16	1 5/8	1/8	1 1/2	1/16
15/16	7/8	1 7/16	1 13/16	1 3/4	1 7/16	3/16	1/4	1 5/8	1 11/16	1/8	1 5/8	1/16
1	15/16	1 1/2	1 7/8	1 3/4	1 1/2	1/4	5/16	1 3/4	1 13/16	3/16	1 5/8	1/8
1 1/16	1	1 9/16	1 15/16	1 7/8	1 5/8	1/4	5/16	1 7/8	1 15/16	3/16	1 3/4	1/8
1 1/8	1 1/16	1 5/8	2	1 7/8	1 11/16	1/4	5/16	1 15/16	2	3/16	1 3/4	1/8
1 3/16	1 1/8	1 11/16	2 1/8	2	1 3/4	1/4	5/16	2	2 1/16	3/16	1 7/8	1/8
1 1/4	1 3/16	1 13/16	2 5/16	2 1/8	1 7/8	5/16	3/8	2 3/16	2 1/4	3/16	2	1/8
1 5/16	1 1/4	1 15/16	2 7/16	2 1/4	2	5/16	3/8	2 5/16	2 3/8	3/16	2 1/8	1/8
1 3/8	1 5/16	2	2 1/2	2 1/4	2 1/8	5/16	3/8	2 7/16	2 1/2	3/16	2 1/8	1/8
1 7/16	1 3/8	2 1/16	2 9/16	3 3/8	2 1/4	5/16	3/8	2 9/16	2 5/8	3/16	2 1/4	1/8
1 1/2	1 7/16	2 1/8	2 5/8	2 3/8	2 3/8	5/16	3/8	2 11/16	2 3/4	3/16	2 1/4	1/8
1 9/16	1 1/2	2 3/16	2 11/16	2 1/2	2 1/2	3/8	7/16	2 7/8	2 15/16	3/16	2 3/8	1/8
1 5/8	1 9/16	2 3/8	3	2 5/8	2 5/8	3/8	7/16	3	3 1/16	3/16	2 1/2	1/8
1 11/16	1 5/8	2 7/16	3 1/16	2 3/4	2 3/4	3/8	7/16	3 1/8	3 3/16	3/16	2 5/8	1/8
1 3/4	1 11/16	2 1/2	3 1/8	2 7/8	2 7/8	3/8	7/16	3 1/4	3 5/16	3/16	2 3/4	1/8
1 13/16	1 3/4	2 9/16	3 3/16	3	3	7/16	1/2	3 7/16	3 1/2	1/4	2 13/16	3/16
1 7/8	1 13/16	2 5/8	3 1/4	3	3 1/8	7/16	1/2	3 9/16	3 5/8	1/4	2 13/16	3/16
1 15/16	1 7/8	2 11/16	3 5/16	3 1/8	3 1/4	7/16	1/2	3 11/16	3 3/4	1/4	2 15/16	3/16
2	1 15/16	2 3/4	3 3/8	3 1/8	3 3/8	7/16	1/2	3 13/16	3 7/8	1/4	2 15/16	3/16
2 1/16	2	2 15/16	3 9/16	3 1/2	3 1/2	1/2	5/8	4	4 1/8	1/4	3 1/4	3/16
2 1/8	2 1/16	3	3 5/8	3 1/2	3 1/2	1/2	5/8	4	4 1/8	1/4	3 1/4	3/16
2 3/16	2 1/8	3 1/16	3 13/16	3 5/8	3 5/8	1/2	5/8	4 1/8	4 1/4	1/4	3 3/8	3/16
2 1/4	2 3/16	3 1/8	3 7/8	3 5/8	3 3/4	1/2	5/8	4 1/4	4 3/8	1/4	3 3/8	3/16
2 3/8	2 5/16	3 3/8	4 1/8	3 7/8	3 7/8	1/2	5/8	4 3/8	4 1/2	1/4	3 5/8	3/16
2 1/2	2 7/16	3 1/2	4 1/4	4	4	1/2	5/8	4 1/2	4 5/8	1/4	3 3/4	3/16
2 5/8	2 9/16	3 5/8	4 3/8	4 1/8	4 1/8	1/2	5/8	4 5/8	4 3/4	1/4	3 7/8	3/16
2 3/4	2 11/16	3 3/4	4 1/2	4 1/4	4 1/4	1/2	5/8	4 3/4	4 7/8	1/4	4	3/16

tool steel bushings, ground true inside and out to accurate dimensions. Fig. 384 illustrates different forms of guide bushings and Tables XIX, XX, XXI, and XXII give accepted dimensions. The several types of bushings are known, from their use or by their construction, as tight bushings, lining bushings, slip bushings, screw bushings, etc.

*Courtesy of "Machinery", New York City.

Tolerances. A jig is usually a duplicating tool as well as a production tool. In all machine work certain standards of accuracy prevail. Exact dimensions are hard to obtain in any work, and certain commercial variations from the exact dimensions are allowable. Such variations from exactness of dimensions are known as tolerances. For example, an allowable tolerance of 0.0005 inch plus or minus (±) might be used in grinding a certain piece of work, and all pieces ground would, if within these limits, be considered commercially exact.

In jig construction certain tolerances are agreed upon by the user of the tool, as commercially possible. The following tolerances are from the practice of the Taft-Pierce Company, and are those used for tool and jig design:

Information and Limits to Be Placed on Drawings

The following are two important essentials that must be carefully executed on all drawings before the drawings are submitted to the checker for his signature, and are to be considered as aids for the better conception and reasoning of the workman, in whose hands the work is placed when "doping out" the intent and purpose of the drawings.

Next to the accuracy, the efficiency and clearness with which these aids are accomplished are of the greatest importance:

(1) State accurately the amount of limits of tolerance that may be permitted on all dimensions. (See sheet describing methods of expressing limits.)

(2) Issue with each drawing specifications written on information blanks provided for the purpose, describing the requirements of the drawing and giving any information that will be of value to the workmen.

Limits of Tolerance as Adopted by the Taft-Pierce Company

Statement: If a limit can be permitted above and below the dimension, specify the limit thus: (±) giving the amount of limit tolerated. If a limit can only be permitted below the dimension, specify it thus: (−) giving the amount of limit tolerated. If a limit can only be permitted above the dimension specify it thus: (+) giving the amount of limit tolerated.

Fractions. Unless limits are specified, vulgar fractions are capable in the main of a wide variation of limitation. For the purpose of fixing a standard, however, it shall always be understood that in the event that a fraction is not accompanied by a limit, a minimum limit of (±) .010 is permissible. *Fractions that must be held closer than this must be accompanied by a specified amount of limit.*

Amounts: 2-Place Decimals. If tolerance is not added, a limit of (±) .005 is permissible.

3-Place and 4-Place Decimals. A 3- or 4-place decimal should be used only when absolutely necessary. If tolerance is not added, a limit of (±) .0015 is permissible.

3-Place and 4-Place Decimals. Whenever through necessity three or four places *must* be accurately obtained, the dimension shall be marked EXACT.

Guide Bushings. *Locating the Guide Bushings.* While there are a great variety of methods used when locating the centers of the holes, if exactness is desired, the located centers are usually positioned by making use of the jig buttons shown in Fig. 385. These are hardened and ground tool steel cylinders with the ends ground parallel. In use the center distances, called for on the drawing of the jigged piece, are located approximately in position on the face of the jig. Each button as purchased is furnished with a clamping screw whose body fits loosely in the axial hole in the button. Figs. 386 and 387 show how the buttons may be accurately positioned using precision tools. It will be noted that in each case shown the buttons are first positioned by lightly clamping them to an approximately accurate layout, and afterward bringing them to accurate position by measurements made with precision tools.

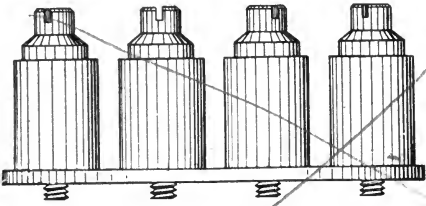


Fig. 385. Tool-Maker's Buttons with Screws and Washers for Jig Work

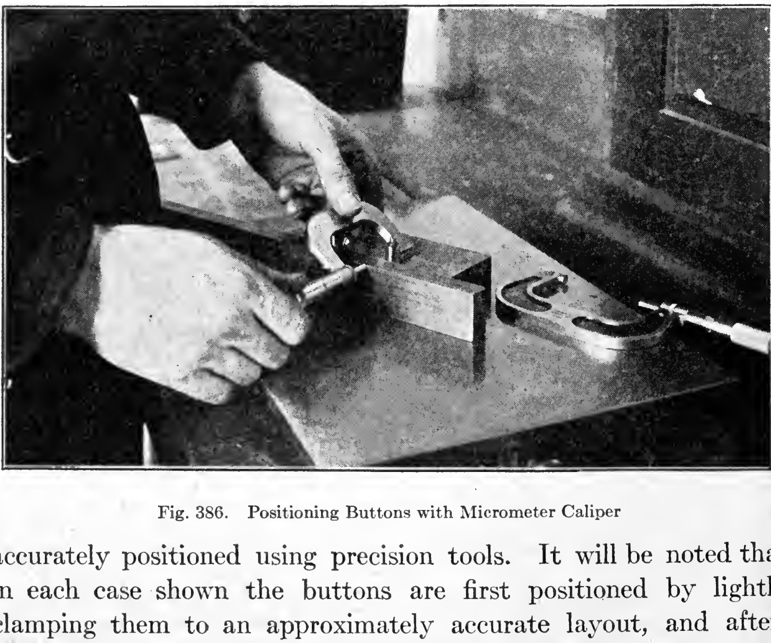


Fig. 386. Positioning Buttons with Micrometer Caliper

Boring Hole for Guide Bushings. Fig. 388 shows the hole being bored. Previous to the boring, the plate is clamped to a lathe face-plate and shifted to a position where the accurately positioned button will indicate true with the feeler of a good indicator placed against its surface. When the button rotates true, it is removed, the hole is roughly drilled, afterward accurately bored, as shown in the cut, and the hardened and ground tool steel bushings pressed into place.

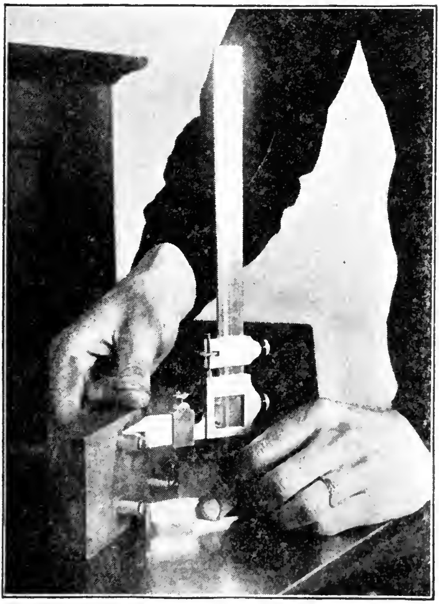


Fig. 387. Positioning Buttons with Vernier Caliper

Operating the Jig. If the jig is of a proper design and construction, the operator should have little trouble in its use. All locating points and surfaces should be plainly visible,

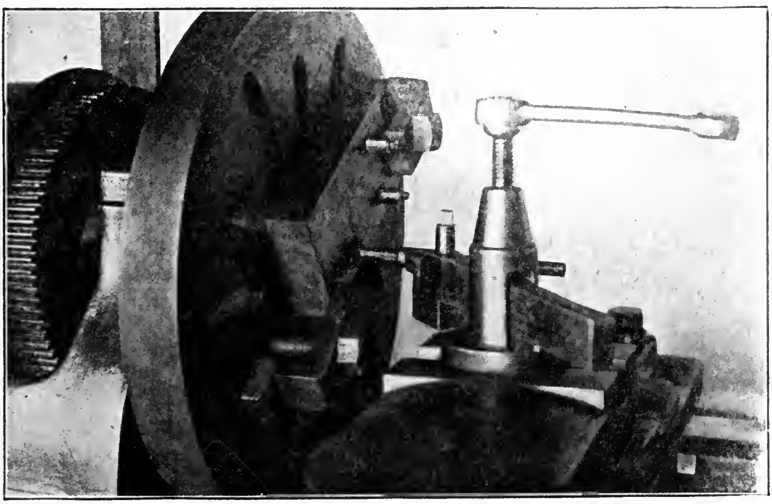


Fig. 388. Boring Hole for Guide Bushing

the work should go into the jig only when properly positioned and the clamping done with despatch, the various tools should spindle as shown in Fig. 349, and the operator should handily use each spindle in logical order. The jig is then discharged and newly recharged.

Spotting. Hand scraped or other plane surfaces are given an attractive appearance by what is termed "spotting". A skilful

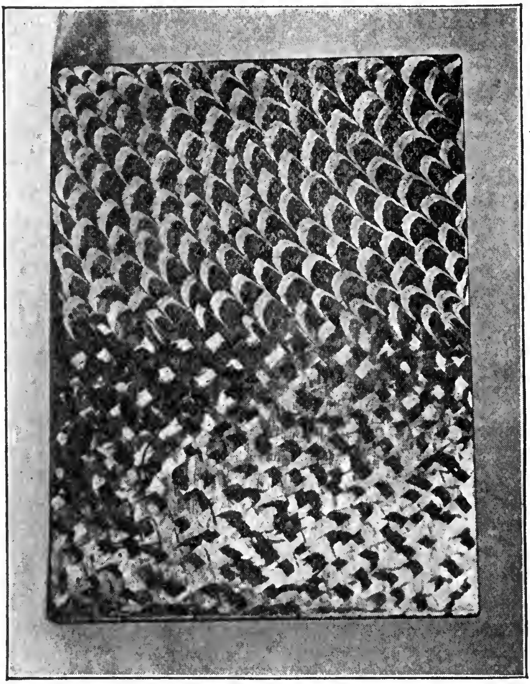


Fig. 389. Typical "Spotting" Pattern on Surface Plate

worker with the hand scraper will cover a plane surface with regular spots in an artistic manner. Fig. 389 shows sections so treated. If the spots are small rectangles, the result is termed "snow flaking". Another method of handling the scraper results in small crescents or "half moons", this result is known as "frosting". In all cases where work is spotted, it results in a pleasing effect, and adds to the "classiness" of the machine or jig. The scraping pattern has also the effect of making the workman more careful of such surfaces.

Fixtures

Importance. When work-holding devices are used in machine practice they are ordinarily termed fixtures. That these are important adjuncts of the modern machine tool is made evident by a study of the various production illustrations in this book. For example, take the milling jobs shown, and it at once becomes apparent that the fixtures are a principal item in the production figures given, and so on through the whole list of production machines.

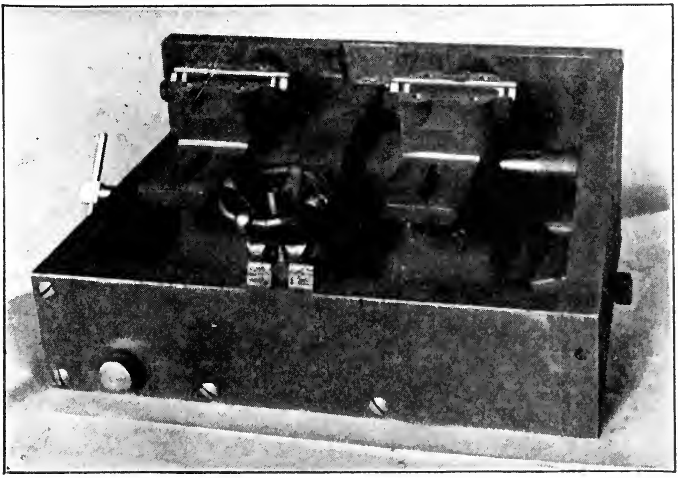


Fig. 390. Typical Milling Fixture

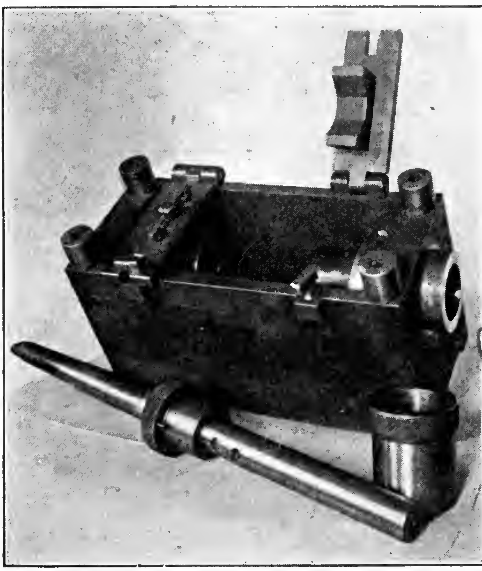


Fig. 391. Typical Boring Fixture

Milling Fixtures. While in some cases fixtures can be used interchangeably upon planers, shapers, boring mills, and milling machines, it is more usual to find them designed for the particular machine on which they are to be used. In Fig. 390 is shown a milling machine fixture of a simple form and construction designed to hold the base of a small bench grinder, while the upper surfaces of the bearing boxes are being machined. This is done with the gang of cutters shown in the illustration. Such fixtures as this cost little and can be used by inexperienced employes. The increased

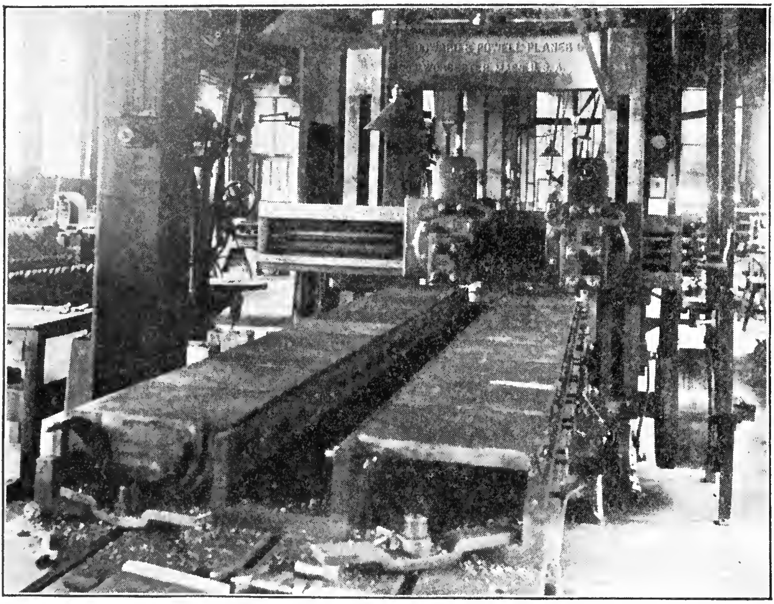


Fig. 392. Typical Planer Fixture, Showing Set-Up for Planing Twenty Square Tables at One Setting
Courtesy of Worcester Polytechnic Institute Shops, Worcester, Massachusetts

production alone, made possible by even so simple a fixture as the one shown, warrants its construction.

Boring Fixtures. Fig. 391 shows a fixture used in boring out the head casting of a ball-bearing lathe. In this fixture, the casting is held while being bored. As the spindle holes are located by the bushed holes for the boring bar, it is perhaps more of a "jig" than a "fixture". However, its use is evident from the cut.

Planer Fixtures. Planer fixtures are usually simpler in design and construction than those in use on either the boring or the milling machine. Fig. 392 is illustrative of the simplicity of planer fixtures. The cut shows it as made for holding a string of square tables such as are used on sensitive drillers. As shown in the illustration, a double string of tables are mounted and both of the tool heads are used.

BALL BEARINGS

Uses of Ball Bearings. The claims made for the use of ball bearings in preference to plain bearings are several in number as

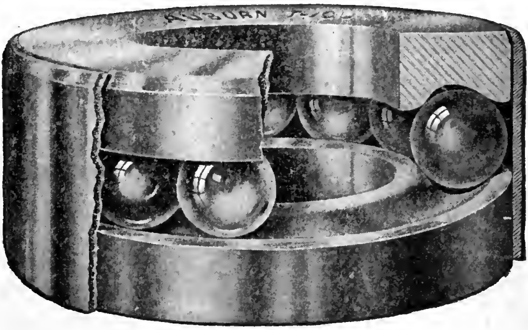


Fig. 393. Auburn Self-Contained Ball Thrust Bearing
Courtesy of Auburn Ball Bearing Company, Rochester, New York

follows: Less wear, less frictional resistance, more compact, non-heating in use, less fitting than plain bearings, better shaft alignment.

Until recently very little reliable information could be obtained relative to ball bearings and today it is probable that their use on machine tools is much less than it should be. Their extended use on motor cars and bicycles has shown definitely just what their value is in such lines, but machine tool builders have probably been ultra-conservative in their use. In the high-speed drilling machines, their use has been remarkably successful. Any of the reliable manufacturers of such bearings will furnish performance figures showing the possibilities of their use.

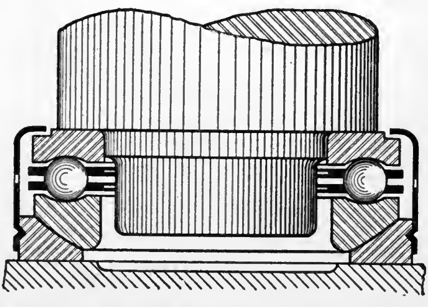


Fig. 394. Hess-Bright Thrust Bearing with a Lining Washer and Enclosing Case

Types of Bearings. Ball bearings are known generally under two headings: "Radial" and "Thrust". In the radial bearing, the load pressure is at right angles or normal to the shaft axis, while in the thrust bearing the load pressure is parallel to the axis, or, in other words, the pressure is axial.

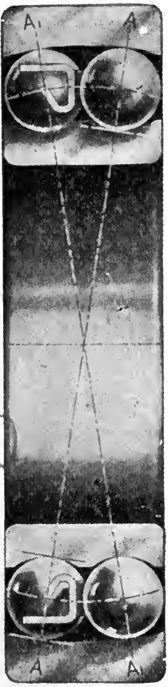


Fig. 395. S. K. F. Radial Ball Bearing

Fig. 393 is representative of the usual thrust bearing, while Fig. 394 illustrates diagrammatically the Hess-Bright thrust bearing with ball separating retainers.

Figs. 395 and 396 are representative of the best type of radial ball bearings. Radial ball bearings are made in what is known as the single type and the double type. In other words, bearings may be obtained with either a single row or race of balls, or they may be obtained with two rows of balls. While radial bearings are not generally supposed to take an axial load or thrust, many of the better radial types will allow a certain amount of axial thrust under favorable conditions.

Load Capacities. Tables XXIII and XXIV give load carrying capacities of radial and of axial ball bearings used under light, medium, and heavy loading.

Lubrication. While it was at one time thought that ball bearings needed no lubrication, this was

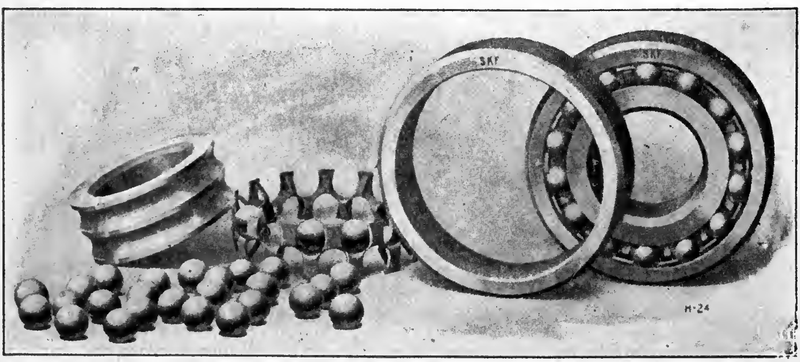


Fig. 396. S. K. F. Radial Bearing Showing Parts and Assembled Bearing Complete

TABLE XXIII

Load Capacities of Radial Ball Bearings*

Diameter Bore		Outside Diameter		Width		Revolutions per Minute			
Milli-meters	Inches	Milli-meters	Inches	Milli-meters	Inches	300	600	1200	2400
						Maximum Load, Pounds			
EXTRA HEAVY TYPE									
17	0.6693	62	2.4409	20	0.7874	1,100	880	680	540
20	0.7874	72	2.8346	23	0.9055	1,450	1,150	860	710
25	0.9843	80	3.1496	25	0.9843	2,000	1,600	1,200	980
30	1.1811	90	3.5433	28	1.1024	2,400	1,925	1,450	1,175
35	1.3780	100	3.9370	30	1.1811	2,850	2,290	1,700	1,400
40	1.5748	110	4.3307	33	1.2992	3,300	2,650	2,000	1,650
45	1.7717	120	4.7244	35	1.3780	3,850	3,075	2,400	1,890
50	1.9685	130	5.1181	37	1.4567	4,400	3,500	2,650	2,150
55	2.1654	140	5.5118	40	1.5748	5,100	4,075	3,100	2,500
60	2.3622	150	5.9055	42	1.6536	5,700	4,560	3,500	2,800
65	2.5591	160	6.2992	45	1.7717	6,800	5,450	4,200	3,350
70	2.7559	180	7.0866	50	1.9685	8,000	6,400	4,850	3,925
75	2.9528	190	7.4803	53	2.0867	9,200	7,350	5,500	4,500
80	3.1496	200	7.8740	57	2.2441	10,600	8,500	6,400	5,200
85	3.3465	210	8.2677	60	2.3622	12,000	9,600	7,300	5,900
90	3.5433	225	8.8583	63	2.4803	13,600	10,900	8,200	6,650
95	3.7402	250	9.8425	67	2.6378	15,400	12,250	9,200	7,550
100	3.9370	265	10.4331	70	2.7559	17,400	13,900	10,400	8,550
HEAVY TYPE									
17	0.669	62	2.441	17	0.669	750	600	450	370
20	0.787	72	2.835	19	0.748	1,000	800	600	490
25	0.984	80	3.150	21	0.827	1,200	960	750	590
30	1.181	90	3.543	23	0.905	1,650	1,325	920	810
35	1.378	100	3.937	25	0.984	1,850	1,475	1,100	910
40	1.575	110	4.331	27	1.063	2,200	1,750	1,300	1,075
45	1.772	120	4.724	29	1.142	3,000	2,400	1,750	1,475
50	1.968	130	5.118	31	1.220	3,400	2,725	2,100	1,675
55	2.165	140	5.512	33	1.299	4,000	3,200	2,400	1,950
60	2.362	150	5.905	35	1.378	4,400	3,525	2,650	2,150
65	2.559	160	6.299	37	1.457	5,100	4,100	3,100	2,500
70	2.756	180	7.087	42	1.654	5,700	4,550	3,500	2,800
75	2.953	190	7.480	45	1.772	7,000	5,600	4,200	3,400
80	3.150	200	7.874	48	1.890	8,600	6,875	5,100	4,200
85	3.346	210	8.268	52	2.047	9,200	7,350	5,500	4,500
90	3.543	225	8.858	54	2.126	10,000	8,000	6,200	4,900
95	3.740	250	9.842	55	2.165	12,000	9,600	7,000	5,900
100	3.937	265	10.433	60	2.362	13,900	11,100	8,400	6,800

* S. K. F Ball Bearing Company.

an absurd attitude and ball bearings are now greased in some way. Whatever the oil or grease used, it must be such as will prevent rust and be free from any acid or alkali likely to attack the surfaces of the balls or the ball races. A good oil or grease is one that keeps the surfaces bright and brilliant after months of use, and besides furnishes the desired lubrication. Vaseline, vaseline oil, or mineral

TABLE XXIII—(Continued)

Load Capacities of Radial Ball Bearings

Diameter Bore		Outside Diameter		Width		Revolutions per Minute			
						300	600	1200	2400
Millimeters	Inches	Millimeters	Inches	Millimeters	Inches	Maximum Load, Pounds			
MEDIUM TYPE									
10	0.393	35	1.378	11	0.433	290	230	175	140
12	0.472	37	1.456	12	0.472	330	265	200	165
15	0.590	42	1.653	13	0.511	375	300	220	185
17	0.669	47	1.850	14	0.551	490	390	290	240
20	0.787	52	2.047	15	0.590	600	480	360	295
25	0.984	62	2.440	17	0.669	880	705	530	430
30	1.181	72	2.834	19	0.748	1,100	880	660	540
35	1.378	80	3.149	21	0.826	1,400	1,125	840	685
40	1.574	90	3.543	23	0.905	1,650	1,325	990	800
45	1.771	100	3.937	25	0.984	2,200	1,760	1,300	1,100
50	1.968	110	4.330	27	1.063	2,750	2,200	1,650	1,350
55	2.165	120	4.724	29	1.141	3,300	2,650	2,000	1,600
60	2.362	130	5.118	31	1.220	3,850	3,100	2,300	1,850
65	2.559	140	5.511	33	1.299	4,200	3,350	2,550	2,050
70	2.755	150	5.905	35	1.378	4,500	3,600	2,750	2,200
75	2.952	160	6.299	37	1.456	5,300	4,250	3,100	2,600
80	3.149	170	6.692	39	1.535	6,000	4,800	3,500	2,950
85	3.346	180	7.086	41	1.614	7,500	6,000	4,400	3,700
90	3.543	190	7.480	43	1.692	8,400	6,700	5,100	4,125
100	3.937	215	8.464	47	1.850	10,400	8,325	6,200	5,100
110	4.330	240	9.448	50	1.968	13,200	10,500	7,900	6,500
LIGHT TYPE									
10	0.393	30	1.181	9	0.354	220	175	120	108
12	0.472	32	1.259	10	0.393	240	195	140	115
15	0.590	35	1.378	11	0.433	290	230	175	140
17	0.669	40	1.574	12	0.472	350	280	210	170
20	0.787	47	1.850	14	0.551	440	350	260	215
25	0.984	52	2.047	15	0.590	530	425	310	260
30	1.181	62	2.440	16	0.629	820	655	480	400
35	1.378	72	2.834	17	0.669	880	780	530	430
40	1.574	80	3.149	18	0.708	1,200	960	700	590
45	1.771	85	3.346	19	0.748	1,450	1,150	860	710
50	1.968	90	3.543	20	0.787	1,650	1,350	970	810
55	2.165	100	3.937	21	0.826	1,800	1,450	1,100	880
60	2.362	110	4.330	22	0.866	2,200	1,750	1,300	1,080
65	2.559	120	4.724	23	0.905	2,550	2,050	1,550	1,250
70	2.755	125	4.921	24	0.944	2,750	2,200	1,650	1,350
75	2.952	130	5.118	25	0.984	3,100	2,480	1,850	1,520
80	3.149	140	5.511	26	1.023	3,750	3,000	2,200	1,835
85	3.346	150	5.905	28	1.102	4,000	3,200	2,400	1,960
90	3.543	160	6.299	30	1.181	4,400	3,520	2,650	2,150
100	3.937	180	7.086	34	1.338	5,700	4,560	3,500	2,830
110	4.330	200	7.874	38	1.496	7,500	6,000	4,400	3,650

oil, are each good for the purpose. Usually these are combined in quantities to give the desired consistency for the speed at which the bearing is rotated.

TABLE XXIV

Loads for Thrust Collar Bearings*

No. of Balls	Size of Balls	Revolutions per Minute								
		1500	1000	500	300	150	100	50	25	10
		MEDIUM WEIGHT, LOAD IN POUNDS								
8	$\frac{1}{4}$	145	190	245	285	333	395	540	660	1,100
10	$\frac{1}{4}$	185	245	310	365	430	505	660	825	1,320
13	$\frac{1}{4}$	240	320	395	485	550	650	870	1,080	1,760
16	$\frac{1}{4}$	295	395	495	585	680	770	1,045	1,355	2,200
18	$\frac{1}{4}$	330	440	550	660	770	880	1,175	1,520	2,420
17	$\frac{5}{16}$	440	550	660	880	990	1,285	1,725	2,245	3,300
18	$\frac{5}{16}$	550	660	770	990	1,210	1,395	1,905	2,400	3,520
17	$\frac{3}{8}$	660	770	880	1,210	1,540	1,890	2,585	3,255	4,620
19	$\frac{3}{8}$	770	880	1,100	1,430	1,760	2,110	2,880	3,650	5,060
18	$\frac{7}{16}$	880	1,100	1,320	1,650	2,200	2,465	3,255	4,355	6,380
19	$\frac{7}{16}$	990	1,210	1,540	1,870	2,420	2,605	3,430	4,620	6,820
18	$\frac{1}{2}$	1,210	1,430	1,760	2,200	2,640	3,235	4,235	5,720	8,360
19	$\frac{1}{2}$	1,320	1,540	1,980	2,420	3,080	3,300	4,335	6,070	8,800
20	$\frac{1}{2}$	1,430	1,650	2,090	2,530	3,300	3,485	4,555	6,380	9,240
19	$\frac{9}{16}$	1,540	1,760	2,420	2,640	3,740	4,180	5,455	8,790	11,000
19	$\frac{5}{8}$	1,870	2,090	2,860	3,300	4,400	4,950	6,600	9,295	13,200
20	$\frac{5}{8}$	1,980	2,200	2,970	3,520	4,620	5,225	6,950	9,790	13,860
19	$\frac{11}{16}$	2,200	2,530	3,520	4,180	5,280	5,995	7,965	11,255	15,400
20	$\frac{11}{16}$	2,420	2,640	3,740	4,400	5,500	6,510	8,745	11,440	16,280
19	$\frac{3}{4}$	2,640	3,080	3,960	4,840	5,940	7,370	9,845	12,640	17,600
19	$\frac{13}{16}$	2,860	3,520	4,840	5,500	7,040	8,635	11,605	14,830	22,000
19	$\frac{7}{8}$	3,080	4,180	5,280	6,380	8,140	10,340	13,970	17,600	24,200
19	1	3,740	4,840	6,600	8,140	10,560	13,510	18,215	23,010	28,600
		LIGHT WEIGHT, LOAD IN POUNDS								
21	$\frac{5}{16}$	640	770	900	1,155	1,410	1,630	2,200	2,970	4,180
23	$\frac{5}{16}$	705	860	990	1,265	1,540	1,760	2,420	3,255	4,620
21	$\frac{3}{8}$	860	990	1,210	1,595	1,980	2,245	3,035	4,005	5,500
22	$\frac{3}{8}$	905	1,045	1,265	1,675	2,090	2,355	3,170	4,180	5,940
21	$\frac{7}{16}$	1,100	1,320	1,705	2,090	2,530	2,970	4,025	5,280	7,480
22	$\frac{7}{16}$	1,155	1,385	1,785	2,200	2,775	3,125	4,225	5,500	7,920
23	$\frac{7}{16}$	1,210	1,455	1,870	2,310	2,860	3,255	4,400	5,785	8,140
25	$\frac{7}{16}$	1,320	1,585	2,035	2,530	3,080	3,520	4,775	6,270	9,020
27	$\frac{7}{16}$	1,430	1,715	2,200	2,750	3,300	3,830	5,170	6,765	9,680
28	$\frac{7}{16}$	1,485	1,785	2,310	2,860	3,410	3,960	5,370	7,040	10,120
29	$\frac{7}{16}$	1,540	1,850	2,420	2,970	3,520	4,115	5,545	7,260	10,340
30	$\frac{7}{16}$	1,595	1,915	2,530	3,080	3,630	4,270	5,720	7,525	10,780

* The Hess-Bright Manufacturing Company.

MAGNETIC CHUCKS

Uses in Production Work. A magnetic chuck is essentially an electromagnet provided with a flat work face. Fig. 397 shows a magnetic chuck of the type commonly used on planers, milling machines, boring mills, and other machines producing plane surfaces. Fig. 398 shows how the magnetic chuck is adapted to a rotating spindle. Each of these tools are of the greatest service in machining small and rather thin pieces, as magnetic holding leaves the work surface clear for tooling.

The magnetic chuck shown in Fig. 397 is really two standard style 10-inch×32-inch Heald magnetic chucks, butted together end to end, used on a surface grinding machine. In the illustration

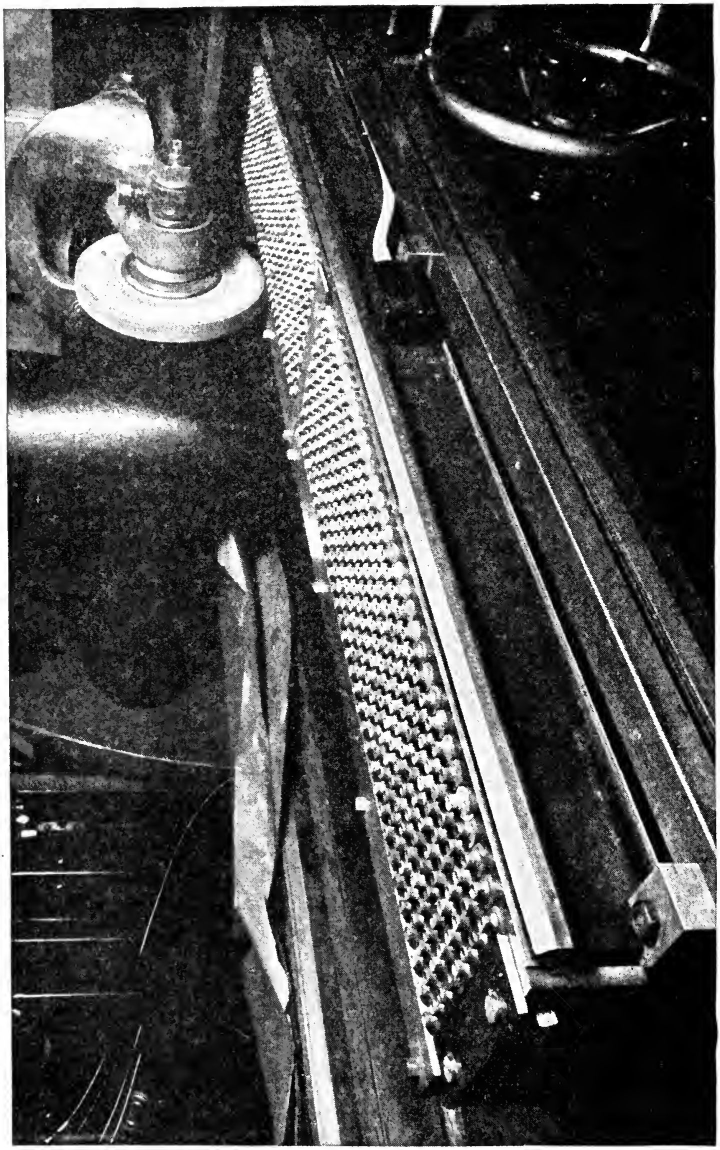


Fig. 397. Heald Magnetic Chucks Holding 528 Cones in Place for Grinding. With Ordinary Methods of Holding Work, Time Required 5 Hours; with Magnetic Chucks, Job Done in 1 $\frac{3}{4}$ Hours
Courtesy of Heald Machine Company, Worcester, Massachusetts

528 cones are in position. Time for placing does not exceed twelve minutes. The cones are end ground to a limit of 0.002 inch.

The total time for the job from start to finish is $1\frac{3}{4}$ hours. Such a job illustrates the usefulness of the magnetic chuck upon a surface grinding machine. The results are similar when used upon the milling machine and for certain planer work.

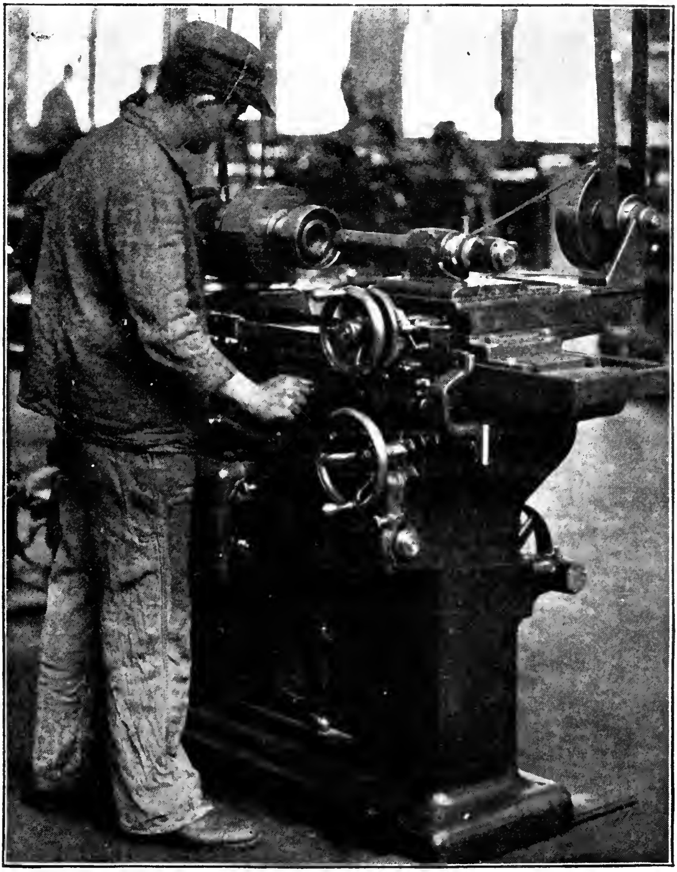


Fig. 398. Heald Internal Grinder Fitted with Magnetic Chuck
Courtesy of Heald Machine Company, Worcester, Massachusetts

Fig. 398 shows the possibilities of a rotary magnetic chuck used in the grinding of holes, while Fig. 399 is illustrative of its use in lathe work. The essential quality of magnetic chucks is that the holding power is exerted upon the work without material straps, bolts, or other devices, which of themselves take up space and may

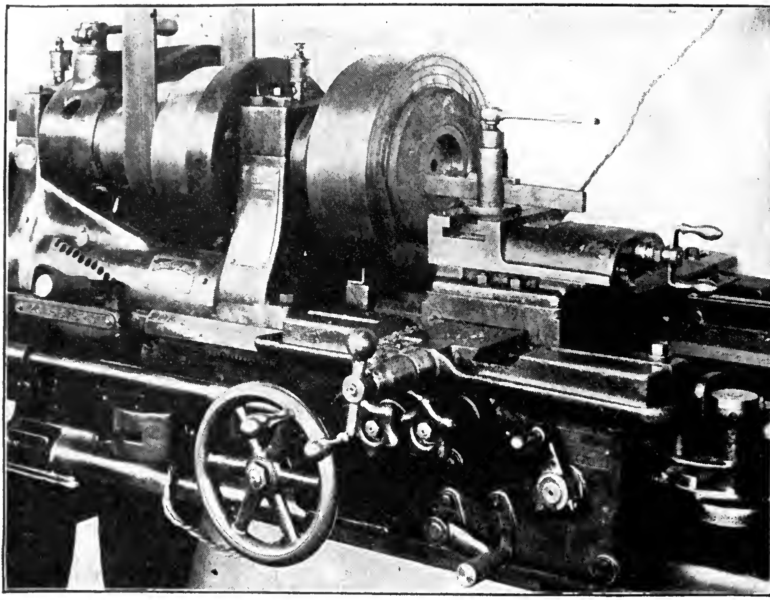


Fig. 399. Close View of Heald Chuck Holding Disc for Turning Operation

interfere with the tooling which needs to be accomplished. Also they are instantaneously discharged by pulling a simple switch.

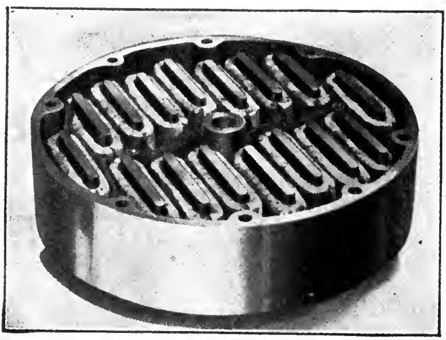


Fig. 400. View of Magnetic Chuck Casting and Unit Coils

Courtesy of Heald Machine Company, Worcester, Massachusetts

The diagram, Fig. 400, illustrates the simple construction of the magnetic chuck.

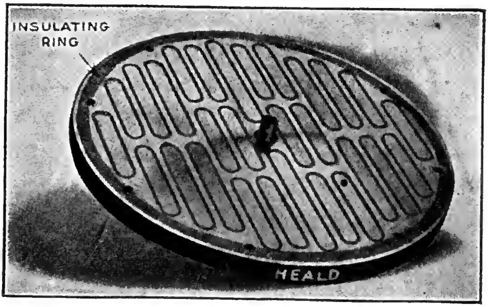


Fig. 401. Heald Magnetic Chuck Faceplate

SAFETY FIRST

A growing apprehension of the possibilities of so safeguarding machines that the operator is reasonably sure that he incurs little risk of life or limb, would seem to render timely a few words on this subject.

Safety Devices on Machines. It is well perhaps to note that no machine can be absolutely safeguarded and be operative. The danger to the operator can, however, with care, be reduced to a minimum, and much is now being done to safeguard such portions of machine tools as the gearing, the clutches, clutch couplings, belts, set screws, etc.

While the whole subject of "safety first" includes the building in which the machines are located, as well as the machines themselves, in general the machines should receive the first consideration. It is the truth that nothing can safeguard a machine against ignorance, bravado, or heedlessness on the part of the operative, and he must either educate himself or be educated to a point where he will voluntarily endeavor to protect himself against injury.

While it is usually true that the employe has very little direct authority in the matter of providing safeguards for the machines at which he may work, also in regard to the building in which he works, he may, by means of tactful suggestions made to the proper person, do much indirectly to promote the cause of safety. While usually the building in which the machinery is located must be taken as it is, many improvements can be made with safety first in view.

Means of Safeguarding. *Fire Hazard.* One of the common hazards is the danger of fire. This is a real danger to the employes' life if the building exceeds the height of a single story; and properly guarded stairways and fire escapes should provide easy exit. All exits should be designated by the word EXIT in prominent characters and all doors should open outward. Unobstructed passage to any and all exits should be maintained at all times, and all stairways should preferably be of a generous width and without bends or crooks. All stairways or other floor openings, as for example, elevator wells, should be safeguarded by suitable railings or nettings.

Power Transmission. The transmission of power by means of shafting, pulleys, and belting, is a prominent hazard to safety unless it is properly safeguarded. Power driven gears, pulleys, and flywheels should be encased to at least 6 feet from the floor. All chain drives should be entirely encased, as should trains of gearing. Belts should be guarded to a height of at least 6 feet from the floor or any adjacent platform.

Shafting. All line shafting, even if, as is usually the case, it is suspended from the ceiling, should be provided with necessary safeguards, as for example, smooth couplings, flush set screws, proper provision for belts when not on the pulleys, etc.

Electrical Transmission. All switchboards should stand out from the wall to have a free and clear space sufficient for easy and safe inspection. This space should be enclosed with provision for padlocked entrances and exits. It should have also a prominent sign DANGER.

Wherever it is possible for the operative to accidentally make a dangerous ground connection, rubber matting should be provided and kept in a dry condition. High voltage lines should have prominently attached red signs stating the voltage. All switches should be guarded from accidental contacts.

Machinery. All those machines which receive their power through a system of gearing, screws, spindles, pulleys, etc., should have all the working mechanisms covered. It will be noted that in essentially all of the production machines shown in this course, all moving parts have been encased wherever it was possible to do so without interfering with the convenient operation of the machine.

Woodworking Machinery. This is a very dangerous class of machinery and should receive special care in providing guards. The floor adjacent to such machinery as this should, as in the case of electrical apparatus, be covered with rubber matting.

Grinding Machines. Owing to the high rotative speed given to abrasive wheels in modern grinding, especial precautions should also be made to safeguard the workmen from a possible wheel explosion. While the manufacturer is painstaking in his efforts to safeguard his machines, it is not possible for him to prevent an ignorant or careless operative from rendering such safeguards inoperative.

Use of Goggles. In all operations which result in flying chips, the use of goggles is recommended. This includes such operations as snagging, chipping, hand grinding, and many other jobs.

Press Work. All machines for punching, shearing, or pressing metals or other materials should, in addition to the ordinary safeguards, be provided with special safeguards at the working opening. These should absolutely prevent the closing of the machine while the operatives' hands are exposed to injury.

In General. The art of safeguarding the workman is one that requires thought, ingenuity, and an unwillingness to ignore any little detail that will in any way achieve the end sought—*Safety First.*

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