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STEAM ENGINEERING DRAWING AND MACHINE
DESIGN AND SHOP PRACTICE

NUMBER 101

AUTOMATIC SCREW MACHINE PRACTICE

PART III

CIRCULAR FORM AND CUT-OFF TOOLS FOR THE BROWN & SHARPE AUTOMATIC SCREW MACHINE

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49-55 Lafayette Street, New York City

Automatic Screw Machine Practice for the Brown & Sharpe automatic screw machines is covered in eight Reference Books, Nos. 99 to 106, inclusive. Reference Book No. 99, "Operation of the Brown & Sharpe Automatic Screw Machines," deals with the construction of these machines and the setting-up of the tools. No. 100, "Designing and Cutting Cams for Automatic Screw Machines," gives detailed instruction on cam design, and describes a simplified method for milling cams. No. 101, "Circular Form and Cut-off Tools for the Automatic Screw Machine," deals with the general arrangement and the calculations of these tools, and describes the different methods employed in their making. No. 102, "External Cutting Tools for the Automatic Screw Machine," deals with the design and construction of box-tools, taper turning tools, hollow mills, and shaving tools. No. 103, "Internal Cutting Tools for the Automatic Screw Machine," deals with centering tools, cross-slide drilling attachments, counterbores, reamers, and recessing tools. No. 104, "Threading Operations on the Automatic Screw Machine," treats on cam design for threading operations, threading dies, taps and tap drills, die and tap holders, and thread rolling. No. 105, "Knurling Operations [illegible] the Automatic Screw Machine," describes the construction of knurling holders, and gives directions for the making of knurls and the design of tools and cams used in connection with knurling operations. No. 106, "Milling, Cross-drilling and Burring Operations on the Automatic Screw Machine," describes screw-slotting attachments, index drilling attachments, and burring attachments, giving directions for their use and for the design of cams for them.

CHAPTER I

GENERAL ARRANGEMENT OF CIRCULAR FORM AND CUT-OFF TOOLS

When any given piece of work is to be made on the screw machine, the methods of arranging the operations and the tools to be used should be decided upon before designing the cams. One of the first things to consider is the method of applying the circular form and cut-off tools. The methods, of course, will vary to a considerable extent, according to the shape of the piece to be made.

Forming with circular tools as shown in Fig. 1, when the piece permits, is usually the best and quickest method; it is quicker than using the turret tools, on account of eliminating the necessity of revolving the turret. The tools can also be easily and quickly changed when setting up for another piece. This method is recommended when the length of the work is not more than 2½ times the smallest diameter of the piece when finished. For example, when the smallest diameter *a* in Fig. 1 is ¼ inch and dimension *b* not more than ⅝ inch, it is most economical to use the form and cut-off tool method. The operations for making the piece would be as follows: The stock is first fed out to the stop, then the form tool *A* is brought in, forming the body *a*, and just as the tool *A* is finishing, the tool *B* is brought in and severs the piece from the bar. Another example is shown in Fig. 2 where a shouldered screw is being made; here the tool *C* is brought in and forms the part *c* and the neck *e;* then the die threads the screw, and the tool *D* is brought in and severs the piece from the bar, and forms the part *d* for the next screw at the same time; the stock is then fed out to the stop and the operations continued. This order of operations necessitates one complete revolution of the turret, for each screw, and if the time utilized by the tools *C* and *D* is not long enough to allow the turret to be revolved, so as to bring the stop into position for the next piece, additional time would have to be allowed for revolving the turret.

Applications of Circular Tools

When making short screws similar to that shown at *A*, Fig. 3, where the circular form and cut-off tools finish the screw, except for the threading, it is good practice to apply the circular tools as shown, and if the time utilized by the tools is not long enough so that the turret can be revolved to bring the stop into position for the next piece, two sets of tools, *viz.*, two stops and two die holders, should be used in the turret. The method shown at *B*, Fig. 3, is not commendable, inasmuch as the feeding of the stock varies to such an extent that the form tool will break off the screw when the latter is much reduced at *a*, in case there be an excessive amount to face off the end of the screw. The turret would also require to be indexed, to clear the slotting arm, so that very little time could be saved by adopting a method of this description, except when the part *a* is large in diameter and the screw is short in length.

When a box-tool or hollow-mill follows the forming operation, the forming tool should be beveled, as shown at *e* in *C;* this leaves a beveled shoulder on the pieces, so that when the box-tool or hollow-mill is fed as shown at C_1, it completely removes the superfluous material without leaving the objectionable ring which would be produced if the face of the form tool were square, as shown at *b* in C_2. This ring of metal is shown at *c* in C_3; it prevents the finishing box-tool or die from being fed up to the shoulder. It is clearly seen that the ring would have to be removed in any case. The cut-off tool should bevel the end of the stock, as shown at *d* in *C*, in order to permit the starting of the box-tool on a light cut, until the back rests have a good support; the bevel also locates the hollow-mill and equalizes the cutting pressure on the teeth. The previous examples apply to the making of screws, but the principles involved are also, of course, applicable to the forming of other parts.

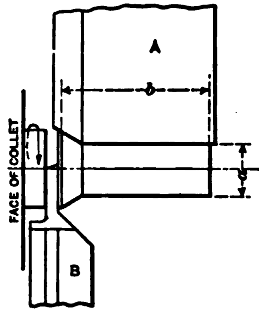

Fig. 1. Illustration showing Relation between Smallest Diameter of Work and Length of Forming Tool

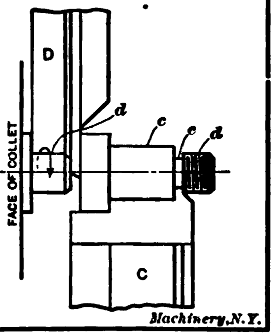

Fig. 2. Illustration showing a Case where the Cut-off Tool forms Part of the Piece

It is obvious that, as the conditions under which the work is done and the limits allowed on it vary widely, it would be impracticable to lay down hard and fast rules in regard to the application of circular tools, but the following suggestions will be found applicable to general conditions. At *D*, Fig. 3, is shown a method sometimes used to advantage in making shouldered screws or other pieces of a similar character. This forming operation is not recommended when the piece to be made is required to be very accurate, as a slight eccentricity in the spring collet would cause the part *f* to be out of true with the part *g*. In cases where accuracy is required, the part *g* could be roughed down with the cut-off tool and a light finishing cut taken with a box-tool. At D_1 is shown an improved method of forming the same piece, as the form tool here removes the burr from the head.

In applying circular tools, the question of gaging the pieces must be carefully considered, as in some cases, when difficult shapes are to be

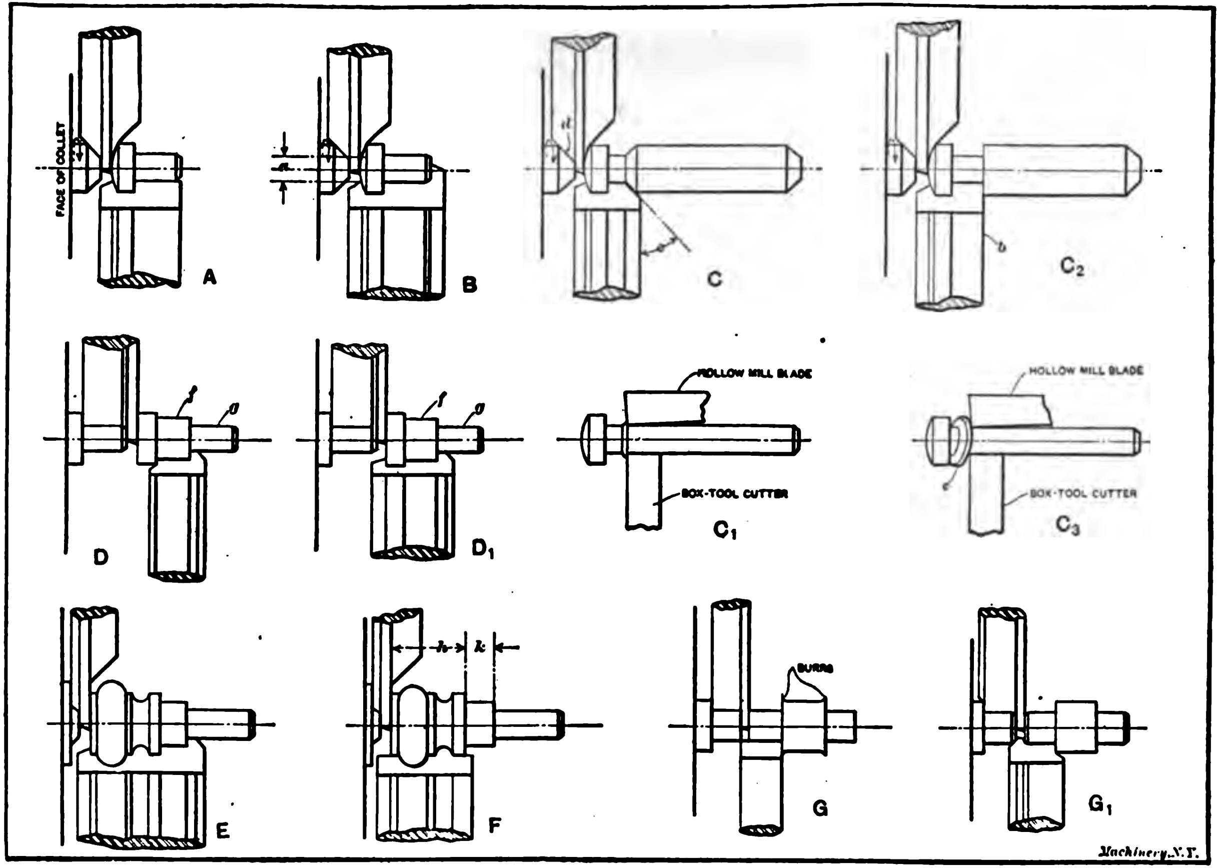

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Fig. 3. Examples of Applications of Circular Form and Cut-off Tools

formed, it is advisable, if possible, to use the forming tool for this purpose, thus avoiding the making of expensive gages, which is usually necessary when more than one tool is used. The piece shown at *E*, Fig. 3, will require a box-tool, forming tool and cut-off tool; if made as shown, it will be seen that no gaging is necessary, except for diameters and over-all length, the latter not being required to be very accurate. At *F*, a piece of the same shape is shown; three tools are used as before, but the cut-off tool is used to finish part *h* to the required length and the box-tool to finish the shoulder *k* to correct length. It will readily be seen that a more expensive gage will be required for gaging the parts *h* and *k*, and considerable time will be lost in setting up the tools, after grinding, in their correct relation to each other, so as to insure that the part *h* of the piece to be made be formed the correct length.

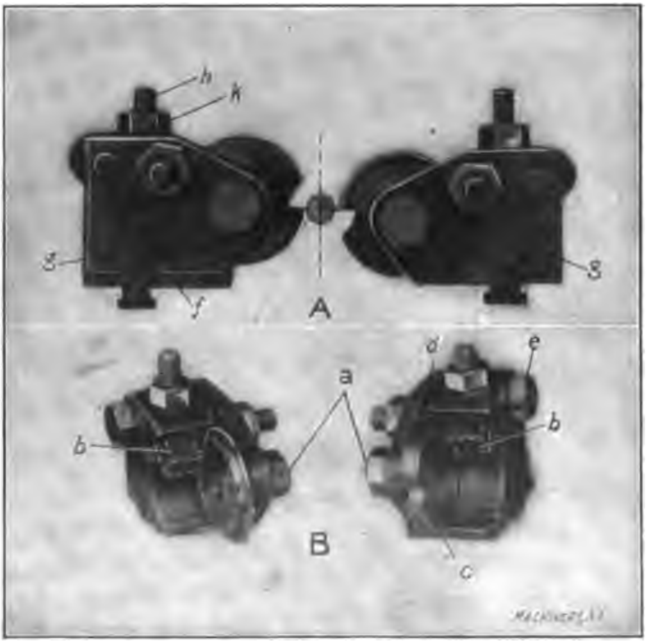


Fig. 4. Holders for Circular Form and Cut-off Tools

It is generally necessary to provide means for removing the objectionable burrs thrown up by the forming tools, as shown at *G*, Fig. 3. The burrs are caused by the tools becoming dull and by the rubbing of the forming tools on the sides of the cut, due to lack of side clearance on the side of the forming tools. By adding a beveled edge to the tools as shown at G_1, the burrs are removed; this adds slightly to the cost of the tools, but in the majority of cases the results produced warrant the extra expense.

Holding Circular Form and Cut-off Tools

The method by which circular tools are held should be carefully considered, otherwise satisfactory results will not be obtained. If, for instance, the tool-holder is light and improperly supported, chattering will result when long work is formed. To prevent this, the tool-holder should be well proportioned and held rigidly upon the cross-slide. The half-tones *A* and *B*, Fig. 4, illustrate a suitable holder for general work, which is supplied by the Brown & Sharpe Mfg. Co. with their various types of automatic screw machines. This holder embodies all the essential features necessary for obtaining good results, *viz.:* rigidity, means to prevent the tool from rotating while cutting, suitable adjustment, provision for periphery clearance, means for adjusting the tool at right angles to the work, and means for the securing of the holder to the cross-slide.

The form tool is firmly clamped against the face of the holder by means of cap-screw *a* and clamping bolt *b;* the latter is used to keep the tool from turning while cutting. Care should be taken when designing the circular tools, so that the clamping bolt *b* gets an ample bearing on the side of the tool as otherwise the clamping bolt will in time become bent, as shown by the dotted lines in the half-tone *B*, which would impair its efficiency as a clamping device. Plate *d* and eccentric bolt *e* are provided for obtaining a slight adjustment when setting the cutting-edge of the tool in the correct relation to the center of the work. The block *f* is used for raising the tool when the cutting edge is cut below the center. At *g* are two screws, not shown in the half-tone, by means of which the tool can be set at right angles to the work. The holder is clamped to the cross-slide by the bolt *h* and nut *k*. Numerous types of holders for holding circular tools have been designed, the principles involved being in most cases similar to those of the one described.

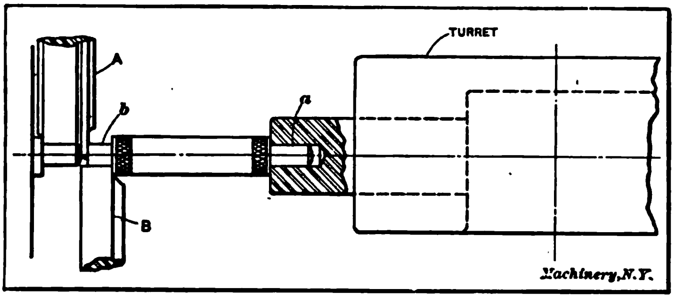


Fig. 5. Method of Supporting Long Work

Supporting Long Work while Forming

It is sometimes found necessary to support long work while forming, especially when the piece being formed is turned down on both ends. The work is generally supported by a support held in the turret, which, in the majority of cases, can also be used as a stop. In Fig. 5

is shown a piece which is being supported in this manner. The part *a* is formed by the tool *A* and the stock is then fed out into the support which in this case also acts as a stop; the tool *B* then forms the part *b*. This kind of a support works satisfactorily on work which is not required to be very accurate and which is left plain, *i. e.*, not threaded on part *a*. In some cases both ends are to be knurled; then a support of this description cannot be used to advantage.

In Fig. 6 is shown a method which will work satisfactorily when the piece is threaded or knurled. The work operated on is shown in position, supported by a movable slide *A* held in a holder *B;* slide *A* carries two hardened and ground supporting rollers *C*. It is forced up against the work by cam *D*, which in turn is operated by the cam attachment *E*. To fasten the cam attachment to the machine, as shown in Fig. 6, the stop which is used for locating the slotting arm when it is in position to travel onto the work, is removed, and the cam attachment is screwed down in its place. Two dowel pins *a* have been added to the cam attachment to hold it rigid.

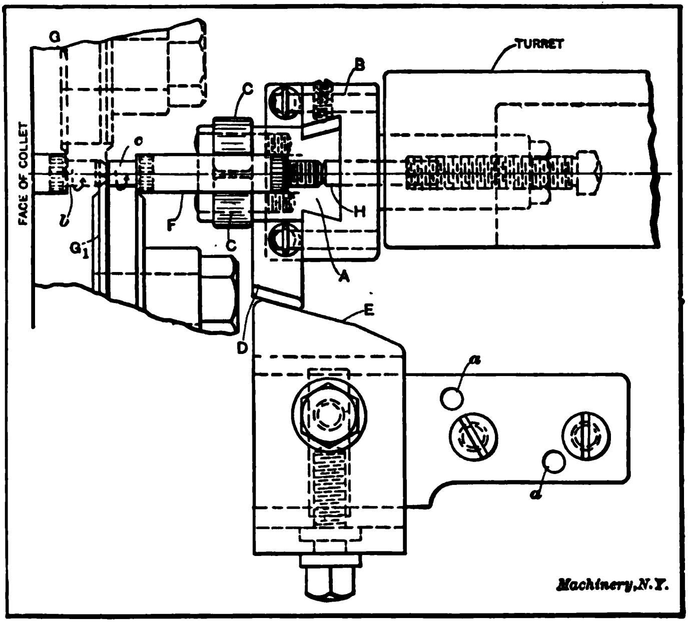


Fig. 6. Improved Method of Supporting Long Work

A detailed view of the cam attachment is shown in Fig. 7, from which the operating parts can be clearly understood; the combination stop and support is shown in Fig. 8. The operations to produce the piece *F*, Fig. 6, would be as follows: The part *b* is left to project out of the chuck far enough so as to allow it to be threaded. To start the operations, the part *b* is formed and threaded; then, after the die

leaves the work, the turret is revolved, the support is brought into position and the stock is fed out and gaged to length by the stop *H*. The spindle is left running backwards and the tool G_1 forms the part

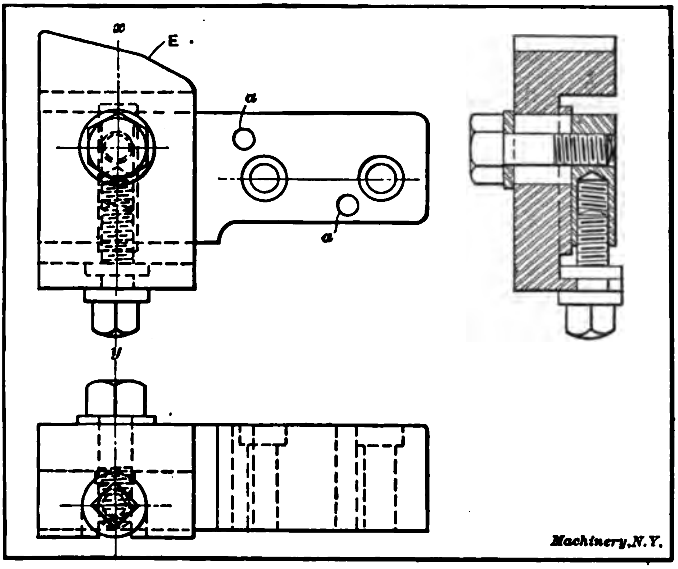


Fig. 7. Cam Attachment used in Connection with the Arrangement for Supporting Long Work shown in Fig. 6

c. After the form tool G_1 has finished its work, a knurl-holder, not shown in the illustration, travels over the work and knurls the ends. The cut-off tool *G* severs the finished piece from the bar, at the same time forming the part *b* of the next piece. The support can be withdrawn after knurling, or left in position until the piece is cut off, when the turret is revolved and the piece drops out.

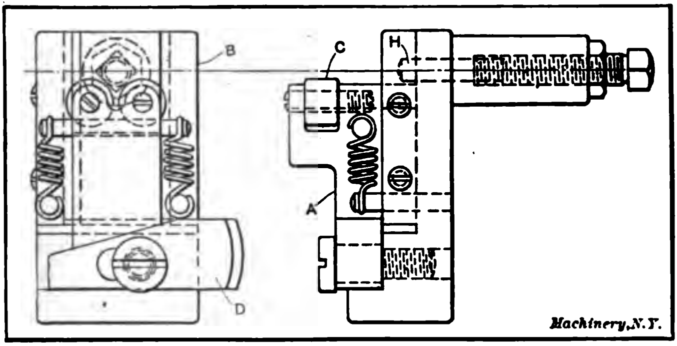


Fig. 8. Combination Stop and Support used in Arrangement for Supporting Long Work shown in Fig. 6

Arrangement of Circular Tools

When applying circular tools to the Brown & Sharpe automatic screw machines, the arrangement of the tools has an important bearing on the results obtained. The various ways of arranging the circular tools, with relation to the rotation of the spindle, are shown at *A*, *B*, *C*, and *D*, Fig. 9. These diagrammatical views are to be considered as being seen looking from the turret towards the face of the chuck. The arrangement at *A* gives good results for long forming on brass, steel or gun-screw iron, for the reason that the pressure of the cut is downward and hence the work is supported and held more rigidly than when the form tool is turned upside down on the front slide as shown at *B;* here the stock turning up towards the tool has a tendency to lift the cross-slide, causing chattering; therefore, the arrangement shown at *A* is recommended when a high finish is desired. The arrangement at *B* works satisfactorily when forming short steel pieces which do not require a high finish, as it allows the cuttings to drop clear of the work, and also allows a good supply of oil to reach the tools. This arrangement gives good results when making screws when the form and cut-off tools operate after the die, as no time is lost in reversing the spindle. The arrangement at *C* is recommended for heavy cutting on large work, when both tools are used for forming the piece; a rigid support is then necessary for both tools and a good supply of oil is also required. The arrangement at *D* is objectionable, and should be avoided, being used only when a left-hand thread is cut on the piece, and when the cut-off tool is used on the front slide, leaving the heavy cutting to be performed from the rear slide. In all "cross-forming" work, it is essential that the spindle be kept in good condition, and that the collet or chuck have a parallel contact upon the bar which is being formed.

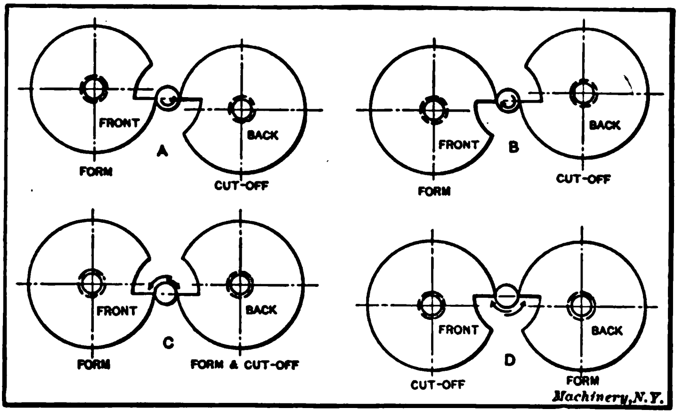


Fig. 9. Different Arrangements of Circular Tools

CHAPTER II

CALCULATIONS FOR FORMING TOOLS

In the making of spherical head screws or other spherical work, the circular form tool is generally used for forming part of the head, leaving the part attached to the bar to be finished by the cut-off tool. This method has become general practice on the Brown & Sharpe automatic screw machines and has proved, without a doubt, to be the most economical and efficient method of performing operations of this description. In order to produce the best results by the above method, the radius of the cut-off tool should be struck off in "advance" of the edge of the tool, as will be described later; otherwise a result will be produced as shown at *a*, Fig. 12, a ridge being formed on the head. The circular form tool should be designed first, and should be made so that the circular cut-off tool will have as little as possible to form when cutting the piece from the bar. The amount that the form tool reduces the bar, as shown at *b*, Fig. 12, is governed by the operations following the forming cut. If heavy cuts are taken, the part *b* should be strong enough to resist the twisting action produced; therefore, it is not always advisable to cut a thread (especially if it be of coarse pitch) after the piece has been considerably reduced by the form tool.

In designing the form tool, there are certain dimensions which must be derived by calculation. Referring to Fig. 10:

Let $r =$ radius of stock $= \frac{D}{2}$,

$R =$ radius of head of screw or piece,
$D_1 =$ distance from axis of head to point of tool,
$D =$ diameter of head of piece,
$T =$ thickness of head,
$r_1 =$ radius of body of screw or piece,
$O =$ the dimension required to be found by calculation.

Then $O = \sqrt{R^2 - D_1^2} - (R - T)$.

For example, let $r = 0.175$ inch, $R = 0.178$ inch, $D_1 = 0.062$ inch, $T = 0.156$ inch.

Then $O = \sqrt{0.178^2 - 0.062^2} - (0.178 - 0.156) = 0.145$ inch.

Assume further that a form tool is to be made to form a piece as shown in Fig. 10; $r = 0.175$ inch; $r_1 = 0.043$ inch; then assume the largest diameter A of the form tool to be 1.750 inch; the diameter B will then be:

$A - 2(D_1 - r_1) = 1.750 - 2(0.062 - 0.043) = 1.712$ inch, and the diameter C will be:

$A - 2(r - r_1) = 1.750 - 2(0.175 - 0.043) = 1.486$ inch.

In the above calculations the "cut-down" below the horizontal center line is not taken into consideration when finding the various diameters, but if the forms produced require to be accurate, the differences should be calculated. This question will be treated further on in this chapter.

The feed of the circular cut-off tool should be decreased at the end of the cut, so as to leave as small a teat as possible on the work. The teat varies according to the radius of the formed piece, the size of the piece, and the nature of the material. It is, therefore, impossible to specify any exact size of teat, but the results of a few experiments would not be out of place here, as they will give a fair idea of the sizes of teats left on various classes of work. The teat left on small brass screws varies from 0.010 inch to 0.025 inch in diameter; on small screws made from gun-screw iron from 0.012 inch to 0.030 inch; on small steel screws from 0.015 inch to 0.035 inch. A good method of overcoming great variations in the size of the teat, is to make the angle of the cut-off tool similar to the enlarged view shown at *b*, Fig. 11, where the flat portion should be half the thickness of the cut-off tool blade. This method tends to decrease the pressure on the piece, thus preventing it from breaking off too soon.

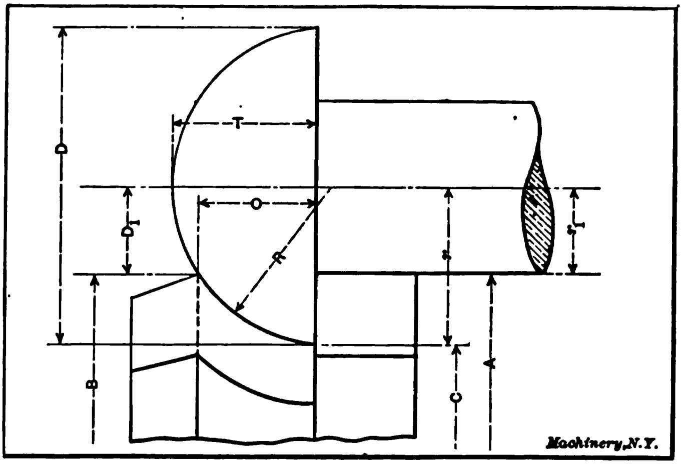


Fig. 10. Diagram for Calculating Dimensions of Circular Tools forming Spherical Screw Heads

As previously stated, the radius on the cut-off tool, if not struck off in "advance" of the edge of the tool, will give a result as shown at *a*, Fig. 12. There will be a mark left on the head where the form tool finishes cutting, because the screw breaks off from the bar before the point of the tool has reached the center, and consequently the correct form on the piece has not been obtained. It is therefore necessary (especially for small radii) to use the method termed "laying off the radius in advance" of the cutting edge of the tool. This method is clearly shown in Fig. 11, where *d* is the distance the center is in advance of the point of the tool. Then, to determine the dimensions of the tool, take any approximate dimension D as required, and also take any angle which will suit the radius of the tool, and cut away that portion of the tool which is not required for forming. In order to determine the dimension X (see Fig. 11) it will be necessary to make the following calculations:

$$A = \frac{180 \text{ deg.} - \theta}{2}$$

$$\phi = 90 \text{ deg.} - \theta$$

$$\beta = A - \phi$$

Then $a = r \times \cos \phi$; $H = a \times \tan \beta$; $B = D - H$;
$Y = B \times \cot \theta$; $X = Y + a - d$; $C = D - h$;
$h = r - \sqrt{r^2 - d^2}$.

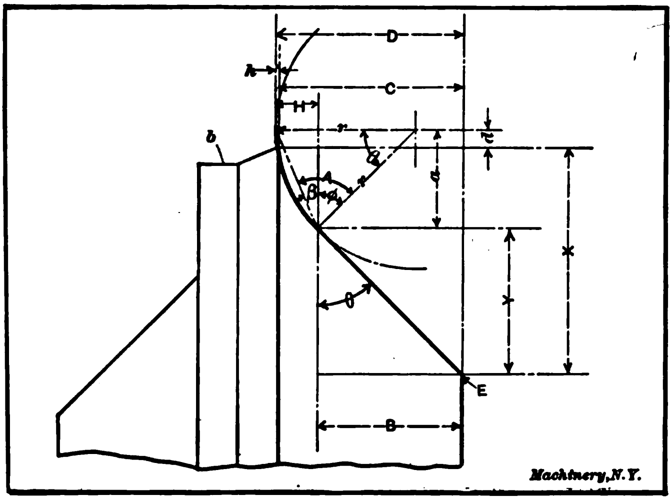


Fig. 11. Diagram for Determining Dimensions of Circular Cut-off Tool which forms Part of a Spherical Screw Head

Where h works out to less than 0.002 inch, it can be disregarded for all practical purposes.

For example, let $D = 0.2343$ inch; $r = 0.175$ inch; $\theta = 45$ deg.; $d = 0.021$ inch.

$$\text{Then } A = \frac{180° - 45°}{2} = 67° \ 30'.$$

$$\phi = 90° - \theta = 45°.$$

$$\beta = 67° \ 30' - 45° = 22° \ 30'.$$

$$a = 0.175 \times \cos 45° = 0.1237.$$

$$H = a \times \tan \ 22° \ 30' = 0.0512.$$

$$B = 0.2343 - 0.0512 = 0.1831.$$

$$Y = 0.1831 \times \cot \ 45° = 0.1831.$$

$$X = 0.1831 + 0.1237 - 0.021 = 0.2858.$$

$$h = r - \sqrt{r^2 - d^2} = 0.175 - 0.1737 = 0.0013.$$

Therefore, in this case, for all practical purposes, the dimension *C* would equal the dimension *D*. When the largest diameter of the circular tool is 2.250 inch, the diameter of the tool at point *E* will be 2.250 — (0.2858 × 2) = 1.6784 inch.

Angle on Blade for Cutting-off Various Materials

The object of the angle at the point of a cut-off tool (see angle *a*, Fig. 13) is to reduce the teat on the end of the work by minimizing the cutting pressure which becomes greater as the angle that the tool edge makes with the work decreases. Therefore, as the material becomes harder, the angle on the tool may decrease, since the material will stand more pressure before breaking. It is obvious, therefore, that certain angles are better suited for the various kinds of materials than others. The values given in Table I have been found to give good results on the materials specified.

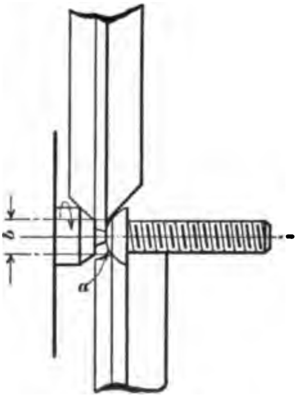


Fig. 12. Spherical Screw Head formed by Combination of Forming and Cut-off Tools

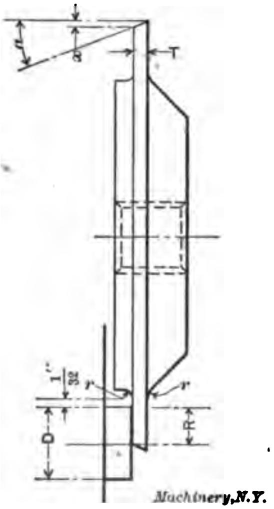


Fig. 13. Diagram showing Dimensions of Circular Cut-off Tools

Thickness of Blade on Cut-off Tools

The thickness of the blade is an important point in the design of circular cut-off tools. It is governed by the angle on the edge of the tool and also by the diameter and hardness of the material being operated upon. It is obvious that a circular tool with an acute angle (about 23 degrees) and a narrow blade would not work satisfactorily on hard material, as the blade would not stand the cutting pressure and would bend, producing a concave surface on one end of the piece

TABLE I. DIMENSIONS FOR CIRCULAR CUT-OFF TOOLS (For Notation See Fig. 13)

Diameter of Stock	Soft Brass and Copper			Hard Brass			Gun Screw Iron			Norway Iron and Mach. Steel			Drill Rod and Tool Steel		
	Angle a = 23 Deg.			Angle a = 20 Deg.			Angle a = 18 Deg.			Angle a = 15 Deg.			Angle a = 10 Deg.		
	T	x	2x	T	x	2x	T	x	2x	T	x	2x	T	x	2x
1/16	0.031	0.013	0.026	0.033	0.012	0.024	0.035	0.011	0.023	0.039	0.010	0.021	0.043	0.009	0.018
1/8	0.044	0.019	0.038	0.047	0.017	0.034	0.050	0.016	0.032	0.055	0.015	0.030	0.062	0.013	0.026
3/16	0.052	0.022	0.044	0.058	0.021	0.042	0.061	0.020	0.040	0.068	0.018	0.036	0.076	0.016	0.032
1/4	0.062	0.026	0.053	0.067	0.024	0.049	0.071	0.023	0.046	0.078	0.021	0.042	0.088	0.019	0.038
5/16	0.069	0.029	0.059	0.075	0.027	0.055	0.079	0.026	0.052	0.087	0.023	0.047	0.098	0.021	0.042
3/8	0.076	0.032	0.065	0.082	0.030	0.060	0.087	0.028	0.057	0.095	0.025	0.051	0.107	0.023	0.046
7/16	0.082	0.035	0.070	0.088	0.032	0.064	0.094	0.031	0.062	0.103	0.028	0.056	0.116	0.025	0.050
1/2	0.088	0.037	0.075	0.095	0.035	0.070	0.100	0.033	0.066	0.110	0.029	0.059	0.124	0.026	0.052
9/16	0.093	0.039	0.079	0.100	0.036	0.073	0.106	0.034	0.069	0.117	0.031	0.063	0.131	0.028	0.056
5/8	0.098	0.042	0.084	0.105	0.038	0.076	0.112	0.036	0.073	0.123	0.033	0.066	0.137	0.029	0.058
11/16	0.103	0.044	0.088	0.111	0.040	0.081	0.118	0.038	0.077	0.129	0.035	0.070	0.145	0.031	0.062
3/4	0.107	0.045	0.091	0.116	0.042	0.084	0.123	0.040	0.080	0.134	0.036	0.072	0.152	0.032	0.064
13/16	0.112	0.047	0.095	0.121	0.044	0.088	0.127	0.041	0.082	0.141	0.038	0.076	0.158	0.033	0.067
7/8	0.116	0.049	0.098	0.125	0.046	0.092	0.133	0.043	0.086	0.146	0.039	0.078	0.164	0.035	0.070
15/16	0.120	0.051	0.102	0.130	0.047	0.095	0.137	0.045	0.090	0.151	0.040	0.081	0.170	0.036	0.072
1	0.124	0.053	0.106	0.134	0.049	0.098	0.141	0.046	0.092	0.156	0.042	0.084	0.175	0.037	0.074

and a convex surface on the other. This has been thoroughly experimented with by the writer and an empirical formula has been derived which has given good results. For standard circular cut-off tools, as shown in Fig. 13, where the tool is not required to form part of the work, the formula is as follows:

$$T = \sqrt{\frac{D \times \cot a}{3}} \times 0.14,$$

in which T = thickness of blade in inches,

D = the diameter of the stock in inches,

a = the angle on the edge of cut-off blade.

The value of r (the radius to obviate cracking in hardening) for standard circular cut-off tools for cutting off various diameters of stock is as follows:

From 1/8 to 3/8 inch diameter = 1/32 inch,
From 3/8 to 3/4 inch diameter = 1/16 inch,
From 3/4 to 1 inch diameter = 3/32 inch.

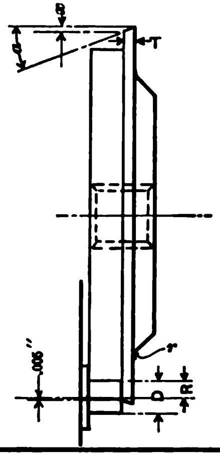
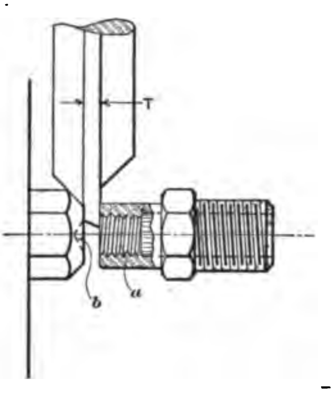


Fig. 14. Diagram showing Dimensions of Circular Cut-off Tool when it is used both for cutting-off and forming part of the Work



Machinery,N.Y.

Fig. 15. Illustration showing a Case where a Cut-off Tool with Increased Thickness of Blade is required

The actual length of the blade on cut-off tools is found by the formula:

$$L = R + x + r + 1/32,$$

where L = actual length of blade in inches,
R = radius of stock in inches,
x = dimension as shown in Fig. 13,
r = radius to obviate cracking while hardening, as shown in Fig. 13.

For example, let $D = 3/8$ inch; $a = 20$ degrees.

$$\text{Then } T = \sqrt{\frac{D \times \cot a}{8}} \times 0.14 = \sqrt{\frac{0.375 \times 2.747}{8}} \times 0.14 = 0.082 \text{ inch.}$$

$L = R + x + r + 1/32$, where $R = 0.1875$; $x = \tan 20° \times 0.082 = 0.364 \times 0.082 = 0.0298$; $r = 1/32$ inch.

Therefore, $L = 0.1875 + 0.0298 + 0.0312 + 0.0312 = 0.2797$ inch.

The thickness of the cut-off tool blade, and the value of x and $2x$ are tabulated in Table I. The above formula is applicable when the cut-off tool does not form the stock. It will be necessary to change the formula somewhat when calculating the thickness of blade when the tool is used for partly forming the work, as shown in Fig. 14.

When Cut-off Tool Forms Stock

When the cut-off tool is used to form the end of the stock, as shown at Fig. 14, the following formula is used for finding the thickness of the blade:

$$T = \sqrt{\frac{D \times \cot a}{5}} \times 0.17,$$

in which T = thickness of blade on cut-off tool in inches,
D = diameter of end of piece in inches,
a = angle on edge of tool blade (see Fig. 14).

The actual length of the cut-off tool blade $= R + x + 0.005$ inch,
in which R = radius on end of piece in inches,
x = dimension as shown in Fig. 14.

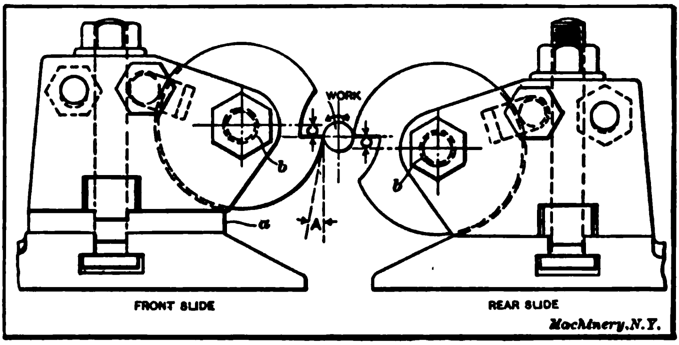


Fig. 16. Circular Form Tools and Holders showing Location of Center of Tool in Relation to Center of Piece being formed

The dimension 0.005 inch is the clearance to pass the center.

To find the value of x multiply T by tan a as before.

For example, let $D = 0.250$ inch, $a = 20$ degrees.

$$\text{Then } T = \sqrt{\frac{0.250 \times \cot 20^\circ}{5}} \times 0.17 = \sqrt{0.1373} \times 0.17 = 0.063$$

$L = R + x + 0.005$, where $R = 0.125$ inch; $x = 0.063 \times \tan 20^\circ = 0.023$ inch.

Then $L = 0.125 + 0.023 + 0.005 = 0.153$ inch.

In cases where pieces are being made similar to that shown in Fig. 15, in which the tapped hole a passes through the piece, the blade on the cut-off tool should be of sufficient width to remove the portion taken up by the chamfer on the tap. Otherwise, if the blade is too narrow, the hole b will extend part way into the next piece to be made. Then, if the drill had a tendency to run eccentric, the centering tool would not remove the eccentric hole thus formed by the drill, which would result in the drill running out, and finally in the breaking of the tap before many pieces would be completed.

The amount of chamfer required on taps for various pitches is as follows:

From 14 to 24 threads	2½ threads.
From 26 to 32 threads	3 threads.
From 36 to 48 threads	4 threads.
From 56 to 80 threads	5 threads.

When the thickness of the blade as derived by the formulas is not equal to the amount required for the chamfer on the tap, the thickness of the blade must be increased.

Periphery Clearance

To provide for sufficient periphery clearance on circular tools, the center of the tool is located a certain amount above or below the cutting edge, as shown in Fig. 16. The hole *b* in the tool holders is raised or lowered, depending on the position of the tools and the direction in which the spindle is rotating. The block *a* is provided for raising or lowering the hole in the tool holder. Raising or lowering the cutting edge of the tool relative to its center, changes the clearance angle *A* and also changes the form produced with the same tool. Clearance angles and the relation of the holes in the toolposts to the center of the spindle are, therefore, points which require careful con-

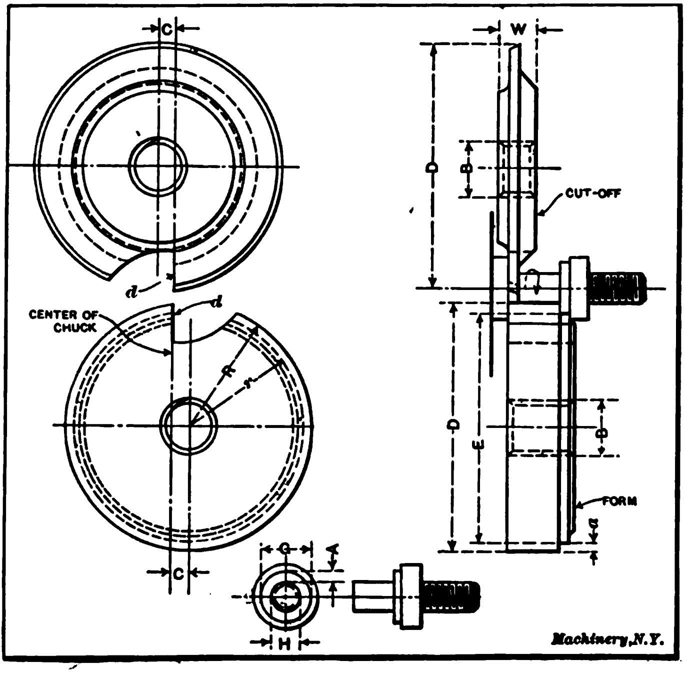


Fig. 17. Diagram showing Principal Dimensions of Circular Form Tools

sideration. With a given material, the larger the diameter of the work, the greater the clearance angle required. With the same dimension *C*, Fig. 16, a small tool diameter causes a greater clearance angle than a large diameter. The maximum diameter, *D*, the cut-down below the center, *C*, the width of the cut-off tool, *W*, and the size of tapped hole, *B*, as shown in Fig. 17, are tabulated in Table II, for the various sizes of Brown & Sharpe automatic screw machines.

Calculating the Diameter of Circular Tools

Locating the cutting edge of the tool below the center changes the form produced on the work. On account of this, the actual difference of diameters on the piece of work cannot be used for the measurements on the forming tool. If the dimension *A*, shown in Fig. 17, on the piece to be formed, is transferred to the form tool and then the tool cut below the horizontal center line, as shown at *C*, it would make the dimension *A* on the piece greater than required. Therefore, it is evident that a certain amount must be subtracted from the dimension *A* on the work to find dimension *a* on the circular tool. A general formula may be deduced by the aid of geometry, by which the various diameters on the forming tool can be determined, when the largest or smallest diameter of the tool, the amount that the cutting edge is below the center, and the diameter on the piece to be formed, are known.

TABLE II. DIMENSIONS REQUIRED FOR DESIGNING FORMING TOOLS FOR B. & S. AUTOMATIC SCREW MACHINES (See Fig. 17 for Notation Used)

No. of Machine	D	C	B	W
00	$1\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{8}$-16	$\frac{1}{4}$
0	$2\frac{1}{4}$	$\frac{5}{32}$	$\frac{1}{2}$-14	$\frac{5}{16}$
2	3	$\frac{1}{4}$	$\frac{5}{8}$-12	$\frac{3}{8}$

Let R = largest radius of tool in inches,
A = difference in radii of steps on the work,
C = amount cutting edge is below the center in inches,
r = required radius in inches.

Then:

$$r = \sqrt{(\sqrt{R^2 - C^2} - A)^2 + C^2} \qquad (1)$$

If the smaller radius r is given and the larger radius R is required, the formula would be:

$$R = \sqrt{(\sqrt{r^2 - C^2} + A)^2 + C^2} \qquad (2)$$

Assume that it is required to make a circular form tool to be used on the No. 0 Brown & Sharpe automatic screw machine for forming the piece shown in the lower view in Fig. 17, the diameters *G* and *H* to be formed by the tool. By referring to Table II it will be seen that the largest diameter should be 2¼ inches, and that the cutting edge is 5/32 inch below the horizontal center line. Half the diameter

E, Fig. 17 (or radius *r*), is then found from Formula (1), by inserting the given values.

$R = 1\,1/8$; $C = 5/32$; assume that $A = 1/8$.

Then

$$r = \sqrt{\left(\sqrt{(1\tfrac{1}{8})^2 - (\tfrac{5}{32})^2} - \tfrac{1}{8}\right)^2 + (\tfrac{5}{32})^2} =$$

$$\sqrt{\left(\sqrt{\tfrac{1271}{1024}} - \tfrac{1}{8}\right)^2 + \tfrac{25}{1024}} = 1.0014 \text{ inch.}$$

The value of *r* is thus found to be 1.0014 inch and diameter *E* will then be 2 times this or 2.0028 inches instead of 2 inches exactly, as would have been the case if the cutting edge had been on the center line. The formula may seem rather complicated, but when applied to circular tools used on the Brown & Sharpe automatic screw machines it can be simplified by inserting the values for *R* and *C*, these being constant for each size of machine. The formula would then take the following form:

No. 00 Brown & Sharpe automatic screw machine:

$$r = \sqrt{(0.866 - A)^2 + 0.0156} \qquad (3)$$

No. 0 Brown & Sharpe automatic screw machine:

$$r = \sqrt{(1.114 - A)^2 + 0.0244} \qquad (4)$$

No. 2 Brown & Sharpe automatic screw machine:

$$r = \sqrt{(1.479 - A)^2 + 0.0625} \qquad (5)$$

Top Rake

Most circular form tools are made without top rake, that is, they have the cutting edge in a horizontal plane when cutting, as shown in Fig. 17; tools made in this manner are best suited for cutting brass, but do not work entirely satisfactorily on tougher and harder metals, as the chip, instead of being cut away, is scraped off, this action destroying the cutting edge very fast. Form tools for steel should, therefore, be provided with top rake, as shown in Fig. 18. The amount of top rake that should properly be used on circular tools for different materials varies from 0 to 18 degrees. Under general conditions the following angles are suggested as most suitable:

Material	Angle of Top Rake, Degrees
Rod brass	0
Drill rod and tool steel	8 to 10
Gun-screw iron	12
Machine steel	15
Norway iron	18

When top rake is ground on a circular form tool, as shown in Fig. 18, the calculations for the diameters must be accordingly changed. In Fig. 18 the case is shown exaggerated in order to be able to show clearly the various dimensions involved. To find the diameters of a form tool made in this manner, proceed as follows:

First find radius R_1 which would be the actual radius if the tool were merely cut down the required amount *C* below the center of the tool, but had no top rake. Then the radius R_2 of the tool, required when top rake is given, must be found. In order to explain the procedure clearly we will assume a practical example. Let $R = 1\frac{1}{8}$ inch, $C = 5/32$ inch, D (see Fig. 18) = 9/16 inch, $D_1 = 5/16$ inch. Then $A = 1/8$ inch.

First find R_1 by means of Formula (1) or (4):

$$R_1 = \sqrt{(1.114 - 0.125)^2 + 0.0244} = 1.00126 \text{ inch.}$$

The next step will be to find dimension B:

$$B = \sqrt{R^2 - C^2} - A = 1.114 - 0.125 = 0.989 \text{ inch.}$$

The next step is to find dimension h and as the tool is to cut machine steel, angle θ is 15 degrees.

Then:

$$h = A \times \tan 15 \text{ deg.} = \tfrac{1}{8} \times 0.26794 = 0.03349.$$

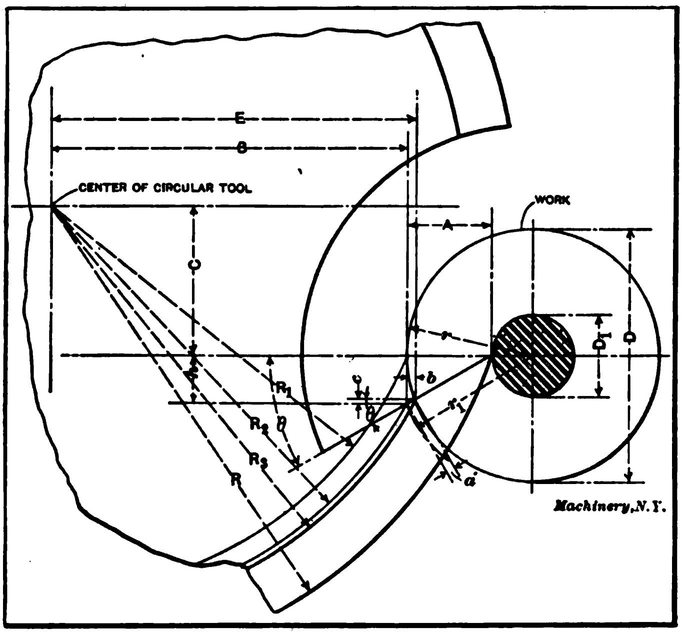


Fig. 18. Diagram for Calculating Form Tools having Top Rake

This gives us the distance from the center of the work to the point where radius R_2 intersects the face of the cutting edge. Now R_2 may be found:

$$R_2 = \sqrt{B^2 + (C + h)^2} = \sqrt{0.989^2 + 0.18974^2} = 1.007 \text{ inch.}$$

Radius R_2 would be a fairly approximate dimension for the tool when the diameters of the tool and work are nearly of the same size, and when the angle θ is comparatively small. As the difference between the diameters of the tool and work increases, the diameter of the work being small in comparison with the diameter of the tool, it is necessary to find the theoretically correct radius R_3. To do this first find r_1:

$$r_1 = \sqrt{r^2 + h^2} = \sqrt{(9/32)^2 + 0.0335^2} = 0.2832 \text{ inch.}$$

We have further that $a = r_1 - r$, and $b = a \times \cos\theta$. Also $c = a \times \sin\theta$. Then $E = B + b$. Having obtained these dimensions we have:

$$R_3 = \sqrt{(C + h - c)^2 + E^2}.$$

Inserting the actual values in the formulas just given, we have:

$$a = 0.2832 - \frac{9}{32} = 0.00195,$$

$$b = 0.00195 \times \cos 15^\circ = 0.00188,$$

$$c = 0.00195 \times \sin 15^\circ = 0.00051,$$

$$E = 0.989 + 0.00188 = 0.99088,$$

$$R_3 = \sqrt{0.18923^2 + 0.99088^2} = 1.0088 \text{ inch.}$$

The found value of R_3 is the required radius of the tool. This radius is about 0.0075 inch greater than the radius R_1. The procedure may appear difficult at first sight, but a few examples in practice will make the user familiar with it.

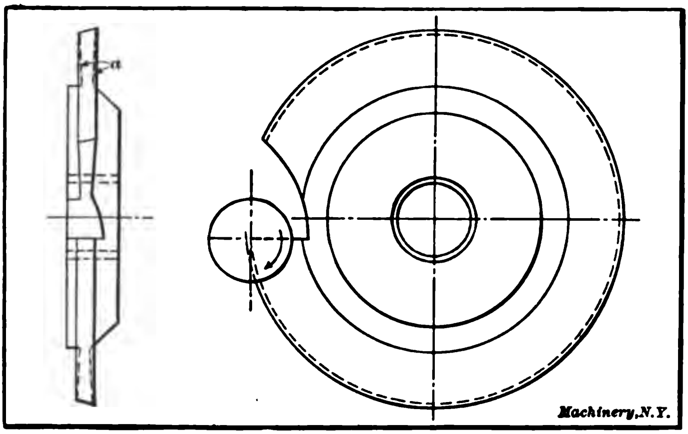


Fig. 19. Side Clearance on Circular Tools

While the angle of top rake as given is suitable for cutting the material specified, the distance C as given in Table II for the various machines is only suitable when cutting brass and drill rod and does not give sufficient peripheral clearance when cutting Norway iron and soft machine steel. The arrangement shown at C in Fig. 9 should be adopted when these materials are cut, as the centers of both the form and cut-off tools can then be raised as compared with the usual arrangement. This raising of the center is accomplished by putting packing strips of the required thickness under the tool-holder blocks.

Side Clearance on Circular Tools

The question of side clearance is a subject which few authorities seem to agree upon. Some advocate a great deal of side clearance, others only a slight amount, and still others, no clearance at all; in fact, some go as far as to say that a cut-off tool should be about 0.0015 inch narrower at the point than at the back. The greatest trouble with tools heating up and welding is not to be attributed to insufficient side clearance only, but to the quality of oil or other cooling lubricant used. It has been demonstrated that if a poor grade of oil is used and the tools made without side clearance, welding will surely occur; but take the same tools and use a good quality of lard oil, and the tools will run for days without welding. The writer admits that there are some cases in which side clearance is necessary, but the clearance should not be given as shown at *a*, Fig. 19, as this is not side clearance, but merely provision for pockets for the fine chips to lodge in, while the revolving stock forces the chips in and also tries to draw them out; and when a chip is drawn out, it leaves a rough finish on the end of the piece, and sometimes breaks the tool.

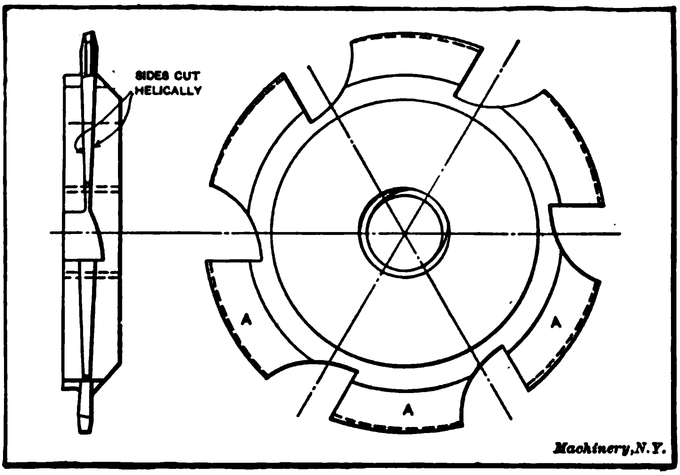


Fig. 20. Cut-off Tool with Side Clearance

When side clearance is necessary, and when the width of the slot is not important, a tool as shown in Fig. 20, where each section *A* of the tool is finished helically on each side, provides for excellent clearance. This tool is specially adapted for cutting vulcanite or fiber. It can also be used to advantage in cutting a very soft grade of iron. All the sections are ground, and when one becomes dull the following section is brought into position, and so on, until the tool requires grinding again. When a tool is made without side clearance, it should be ground smooth on the sides, as any high spots on the face of the sides would cause heating and welding. A good grade of lard oil should also be used if good results are to be expected. When pieces as shown at *A*, Fig. 21, are being made, the tools should be made without side clearance, and the faces ground and lapped as indicated. The form tool should be made in sections and straddle the thin portion of the piece; it should remain in position on the work until the angle on the edge of the cut-off tool is well into the stock as shown at *b*.

CHAPTER III

SPEEDS AND FEEDS FOR FORMING TOOLS

The conditions under which different classes of work are made and the kinds of materials used vary to such an extent that it is impossible to give any definite rules for the speed of the spindle or the feed of the tools, and whatever is said here is only by way of suggestion. The maximum speeds obtainable on the various Brown & Sharpe automatic screw machines are as follows: On the No. 00 machine the maximum spindle speed is 2400 R.P.M. and the maximum diameter of stock that can be turned is 5/16 inch; this gives a maximum surface speed of 197 feet per minute. On the No. 0 machine the maximum spindle speed is 1800 R.P.M. and the maximum diameter that can be turned is ⅝ inch, giving a maximum surface speed of 294 feet per minute. On the No. 2 machine, the maximum spindle speed is 1200 R.P.M. and the maximum diameter that can be turned is ⅞ inch, giving a maximum surface speed of 275 feet per minute. It can be easily seen that the greatest surface speed (294 feet per minute) is rather high for ordinary carbon steel tools even when working on

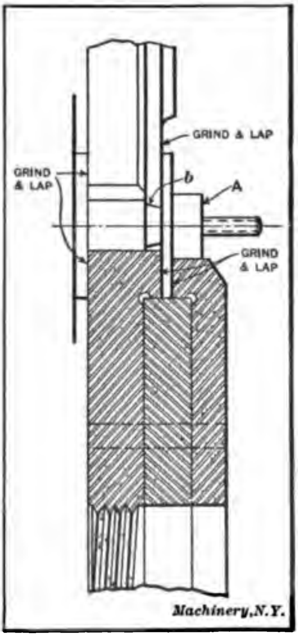


Fig. 21. Circular Form Tool without Side Clearance

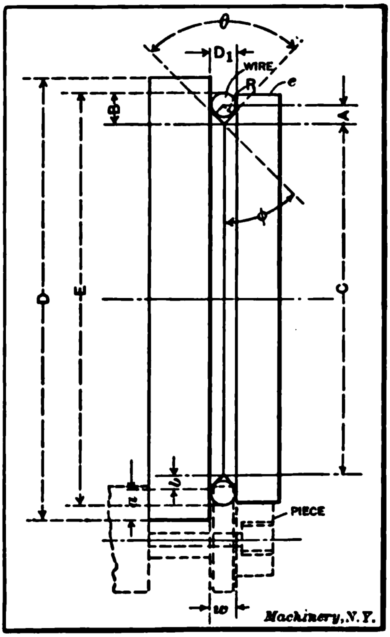


Fig. 22. Wire Method employed for Measuring Circular Form Tools

TABLE III. FEEDS PER REVOLUTION FOR FORMING TOOLS

Width of Form	Smallest Diameter of Form												
	1/16	3/32	1/8	5/32	3/16	7/32	1/4	5/16	3/8	1/2	5/8	3/4	7/8
1/16	0.0007	0.00075	0.0008	0.0009	0.001	0.0011	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012	0.0012
3/32	0.00065	0.0007	0.0008	0.0009	0.001	0.001	0.0013	0.0014	0.0015	0.0017	0.0019	0.002	0.0021
1/8	0.0005	0.00055	0.00075	0.00085	0.001	0.00095	0.0012	0.0014	0.0016	0.002	0.0023	0.0025	0.0025
3/16		0.0003	0.0007	0.0008	0.00095	0.00095	0.0011	0.0015	0.0016	0.0018	0.0019	0.0021	0.0022
7/32			0.0005	0.00075	0.0009	0.0009	0.0011	0.0013	0.0015	0.0017	0.0018	0.002	0.0021
1/4			0.00025	0.0007	0.0009	0.0009	0.001	0.0012	0.0015	0.0016	0.0017	0.0018	0.002
5/16				0.0005	0.00085	0.00085	0.001	0.0011	0.0013	0.0015	0.0016	0.0017	0.0018
3/8				0.00025	0.0008	0.00085	0.00095	0.001	0.0012	0.0012	0.0014	0.0016	0.0017
1/2					0.0008	0.0008	0.00095	0.00095	0.001	0.0011	0.0013	0.0015	0.0016
5/8					0.0003	0.0005	0.0009	0.0009	0.00095	0.001	0.0012	0.0014	0.0015
3/4						0.0002	0.0008	0.00085	0.0009	0.00095	0.0011	0.0013	0.0014
7/8							0.0005	0.0006	0.00085	0.00095	0.001	0.0012	0.0013
1							0.0002	0.0005	0.0008	0.00085	0.00095	0.001	0.0012

brass rod. Hence, if the highest speeds obtainable on the various machines mentioned are to be taken advantage of, a suitable grade of cutting steel must be used. This matter will be discussed later.

The following surface speeds can be used when the tools are made from Bohler's Styrian steel:

Material	Surface Speed, Feet per Minute
Brass rod	200-300
Gun-screw iron	100-125
Norway iron and machine steel	80-95
Drill rod and tool steel	60-75

A good supply of lard oil should be provided, and the tools kept in good condition.

Feeds

In all cases, the feed is governed by the surface speed, the smallest diameter being formed, and the width of the form tool. Feeds for forming tools are given in Table III. The widths covered here range from 1/16 to 1 inch, and the smallest diameters formed from 1/16 to 7/8 inch. It will be seen that a tool about 1/8 inch wide is, in general, adapted to take the coarsest feed. Tools from 3/32 to 3/16 inch (such as are commonly used for cutting-off purposes) admit of coarser feeds, as a rule, than either wider or narrower tools. Thus the feed decreases as the tool decreases in thickness to 1/16 inch, except for small diameters, and increases from 3/32 to 3/16 inch. From 1/4 inch up, the feed must again be decreased to give satisfactory results. For cutting-off purposes the feed varies from 0.0008 to 0.0025 inch, depending on the nature of the material, the surface speed, and the width of the tool. The feeds for machine steel, gun-screw iron and Norway iron should be less than the feed used for brass. The feed used in cutting off Shelby steel tubing should not exceed 0.001 inch per revolution; a surface speed as high as 125 feet per minute can be used with good results, when using tools made from Styrian special steel.

Cooling and Lubricating Mediums

A proper cooling and lubricating medium is essential, if good results are to be expected. As previously stated, if a proper cooling and lubricating medium is not used, welding and excessive heating of the tools and work will result. There are various compounds on the market, some of them giving good results on certain classes of work, depending on the conditions under which they are used. Oil is used to advantage in cutting internal and external threads, where friction plays a very important part, but when cutting threads at high speeds, a cooling material largely composed of water is sometimes used. Oil will not conduct away the heat generated at high cutting speeds as rapidly as some of the special cooling compounds, because oil is more sluggish in penetrating to the point of the tool, where the chip is being cut or torn from the work. The writer would, however, advise that a good grade of lard oil be used on screw machines in preference to all other compounds or other poorer grades of screw cutting oil for the following reasons: 1. The speeds used are comparatively low. 2. A good supply can be furnished to the cutting edges of the tools. 3. Circular tools can be used without side clearance and yet give satisfactory results. 4. Good lard oil does not gum up the machines or cause rusting of the operating parts, as would be the case if cooling mediums composed of water and compounds were used. The lard oil used should be thin and not sluggish.

CHAPTER IV

MAKING CIRCULAR FORMING TOOLS

The conditions under which the work is produced should determine the steel to be used in making the circular tools, *i. e.*, if the piece to be made is of a very difficult shape, requiring sharp or thin projections on the tool, a grade of steel should be used which would not require a high heat to harden, as the thin projections are liable to become burnt or cracked while hardening. A brand of steel which has been found to give good satisfaction in such cases is Bohler's Gold Label Styrian steel; this steel holds a fine edge satisfactorily and also gives a very smooth finish to the work; it is especially adapted for cutting brass. Care should be exercised in hardening this steel, as it hardens at a very low heat. Various other grades of special carbon and high-speed steel are used on screw machines, among which are the following: Jessops steel, Novo high-speed steel, Blue-chip steel and Saben steel. Some of these kinds, especially Novo, give good results when high cutting speeds and feeds are used. Novo steel is frequently used for cutting machine steel and Norway iron, as it will stand a higher speed and a coarser feed than Styrian steel, but when a high finish is required, Styrian steel should be used in preference.

Methods of Making Circular Tools

In designing circular tools, the methods of making them should be carefully considered, and when possible, the contour of the tool should be as simple as the requirements will permit. There are various methods employed in making circular tools of irregular shape, among them being the transfer scheme, the templet system, the use of master tools, and of individual turning tools. For work requiring a fair amount of accuracy, the first two methods are not reliable. The master tool system is sometimes advisable when very difficult shapes are to be produced and when a large number of tools of the same shape are required. The writer considers that where a few tools are required, the individual turning-tool method is the cheapest and best, and that direct measurements are more reliable than either the transfer scheme or templet system.

The Transfer Method

To illustrate what is meant by the transfer scheme, refer to Fig. 23; here a circular tool and setting gage are shown on the arbor *A*. The steps 1, 2, 3, 4, on the setting gage correspond with the various diameters required on the circular tool The setting gage is turned to micrometer measurements, and then copper plated with blue vitriol. To transfer the sizes from the setting gage to the circular tool, the master tools for the various shapes are brought in until they touch the setting gage, and the reading on the micrometer collar on the feed-screw is noted. The master tool is then brought into position on the circular tool and fed in the depth required, as indicated on the micrometer collar. The succeeding operations are continued in like manner until the desired shape on the tool is obtained. As previously stated, where a fair amount of accuracy is required, this scheme is not advisable, for the reason that if the feed-screw or slide has any lost motion, as is generally the case, the same pressure could not be brought to bear on the gage, when setting the master tool, as would be exerted on the circular tool when cutting to the indicated depth; then the circular tool would be larger in diameter than the setting gage.

Templets

Some authorities advocate making templets which conform to the contour of the piece to be made. Considerable skill is required to file complicated templets accurately, as any error which might occur would be doubled in the diameters of the product. It is just as easy to measure a circular tool, as it is to measure a templet, and in the first case the error would be less, as the measurement does not require to be transferred. The writer considers that when accurate tools are required, templets should be avoided and direct measurements used instead.

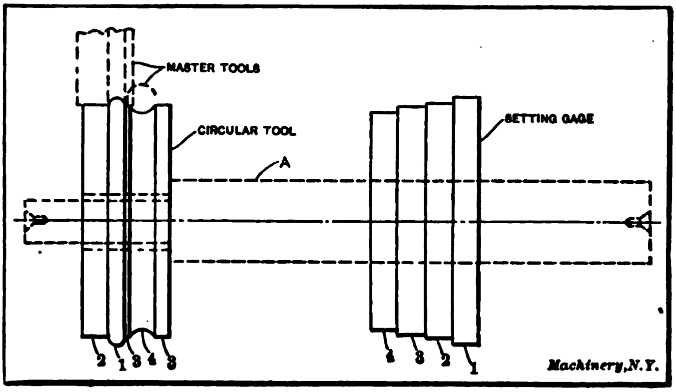


Fig. 28. Transfer Method for Making Circular Form Tools

Master Tools

Master tools are unnecessary, unless a large number of circular tools of the same shape are required. When master tools are being made, the differences in diameters due to the cutting down below center should be calculated, and the tool made so that it can be set on the center of the work when cutting the circular form tool, instead of setting the master tool below the center the required amount, as is advocated by some authorities. It is bad practice to set the edge of a tool much below the center of the work, as it produces chattering, and the material is removed by a scraping action instead of being cut. In the majority of cases, it is preferable to make a circular master tool rather than a dove-tail tool, as the former is more easily measured and made.

Individual Turning Tools

The individual turning tool method, in conjunction with direct measurements, is preferable to all others, when only a small number of similar-shaped tools are required. In Fig. 24 is shown a tool-holder *A* and tool *B* for forming the radii for oval head screws and other shapes of a similar character, special tools being inserted in the tool holder *A*, as required. When using this tool for forming circular cut-off tools, as shown in Fig. 11, the distance *a* is set equal to the radius of the tools *B*, minus the amount that the center is ahead of the edge of the circular tool. The radius of the tool *B* is, of course, made equal to the radius required on the circular tool. The operating parts of this tool holder are clearly illustrated in Fig. 24.

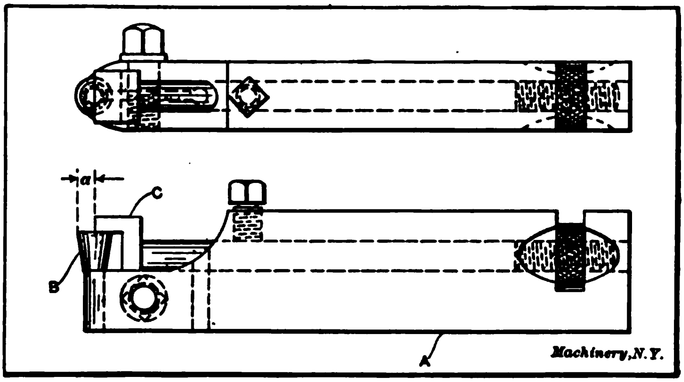


Fig. 24. Holder for Special Turning Tools

The operations for making a circular tool for a round-head screw are shown at *A*, *B*, *C*, and *D*, Fig. 25. The first operation *A* consists in taking a cut (about 0.005 inch) partly across the circumference, making the distance *a* equal to the dimension *D*, shown in Fig. 11. Then a light cut is taken along the side as at *B*, making the distance *b* equal to the dimension *X*. The tool shown in Fig. 24 is then set square with the face-plate or at right angles to the centers, and the tool fed in until the gage *C* touches the largest diameter of the tool, leaving the shape of the tool as shown at *C*, Fig. 25. A square nose tool is then set tangentially to the radius, forming the angle θ, as shown in Fig. 11. This square nose tool removes the material left after the operation at *C*, Fig. 25, and leaves the tool as shown at *D*. The individual turning tools used are concave tools, round or convex tools, square nose tools, and parting tools.

Measuring Difficult Shapes

When making circular tools of irregular contour, shapes difficult to measure are sometimes encountered. There are various tools and methods employed for this. An appliance to be used in connection with a micrometer for measuring deep slots and grooves is shown in Fig. 26. The special measuring pieces *A* are fitted to the anvil and spindle of the micrometer, and when the measurement is taken, the distances *B* are subtracted, giving the actual diameter of the tool. The pieces *A* can be made so that tools of very difficult shapes can be measured with accuracy. When a form tool straddles a piece, the sharp corners produced by the tool rubbing against the sides are frequently objectionable and require to be removed. A form tool similar to that shown in Fig. 22 is sometimes used for this purpose. Making a tool of this description produces a form difficult to measure accurately, but by adopting the wire method, the measuring of the tool is somewhat simplified. In Fig. 22,

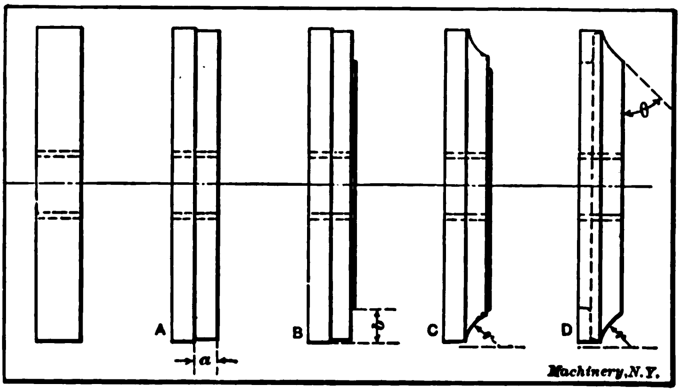


Fig. 25. Making Cut-off Tools for Spherical Work

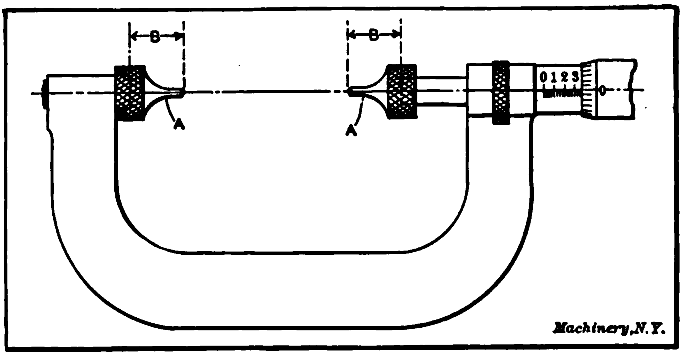


Fig. 26. Micrometer Arranged for Measuring Form Tools of Difficult Shapes

Let D = the largest diameter of the tool,
a = distance from outer edge of largest diameter of tool to bottom of chamfer, on the piece,
w = the width of piece to be chamfered,

ϕ = angle that chamfer makes with vertical line of tool,
b = distance from bottom of chamfer to apex or root of triangle,
C = the root diameter of tool,
R = the radius of wire,
A = distance from center of wire to apex or root of triangle,
E = the diameter over wires.

Then $b = \frac{w}{2} \times \cot \phi$; $C = D - 2\,(a + b)$

$$A = \frac{R}{\sin \phi}; \quad B = A + R; \quad E = C + 2B.$$

The dimension E can be calculated when the tool is designed, and put on the drawing, also giving the size of wire to be used. When the wires are below the part e, the pieces A shown in Fig. 26 can be used for finding dimension E.

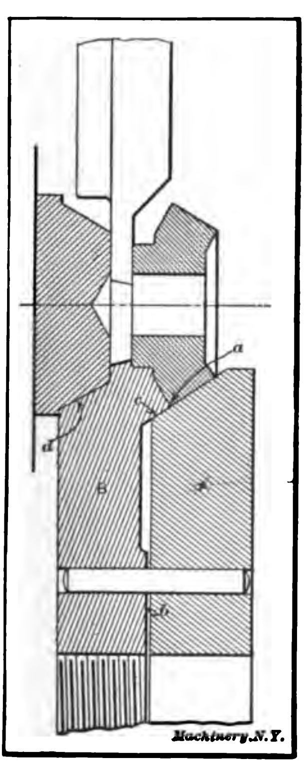


Fig. 27. Forming Tool for Bevel Gear Blanks

As an interesting example of the making of forming tools, the following case of making forming tools for forming the outside angular surfaces of small bevel gears on automatic screw machines may be cited. The forming tool can best be made as shown in Fig. 27. It consists of two sections A and B, doweled together. Two fillister head screws, not shown in the illustration, are also used for clamping the sections together. When grinding the two sections, a slight clearance of about 0.002 inch is allowed between the parallel faces at b; then, when the tool is fastened in the tool-holder, the clamping screw will entirely close up any space at point a. When grinding the inside face c of section B, the angle should be somewhat less than the corresponding angle on part A, so that the sections will fit very tightly at a. The angular surface at d takes a roughing cut on the next piece. The face of the section A, when cut down below the center, would theoretically be slightly concave, but the amount would be so slight that it would be imperceptible, and of no account in practice. When an absolutely true taper is required, a circular forming tool cut down below the center should not be used, but instead a taper turning box tool or a taper turning attachment, operated from the cross-slide. A so-called dove-tail forming tool is also sometimes found convenient.

APPENDIX

CALCULATION OF CIRCULAR FORMING TOOLS

When a large number of circular forming tools are to be designed, it involves a great deal of labor to compute the different diameters separately. The usual method is as follows (see Fig. 28):

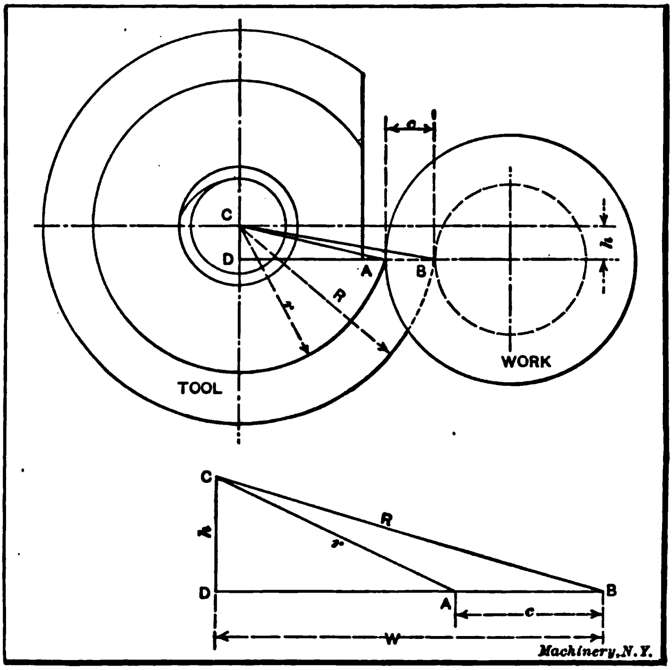


Fig. 28. Notation used in Formulas for Forming Tool Calculations

First find the value of W in the right-angle triangle BCD:

$$W = \sqrt{R^2 - h^2}$$

in which

R = radius of largest diameter of circular tool,

h = distance which the center of the tool is set either above or below the center line of the work.

Now, find the value of r in the right-angled triangle ACD:

$$r = \sqrt{(W - c)^2 + h^2}$$

in which

c = one-half the difference between the required diameters of the work,

r = the required radius of the circular tool.

This method is quite long and cannot be materially shortened by using a table of squares. Therefore, anything that can be done to aid in computing the different diameters of circular forming tools will no doubt be appreciated. The purpose of this chapter is to show how to compute tables giving the diameters of circular tools corresponding to differences of one-thousandth inch in the radius of the work. Such tables are given on pages 34 to 37, inclusive.

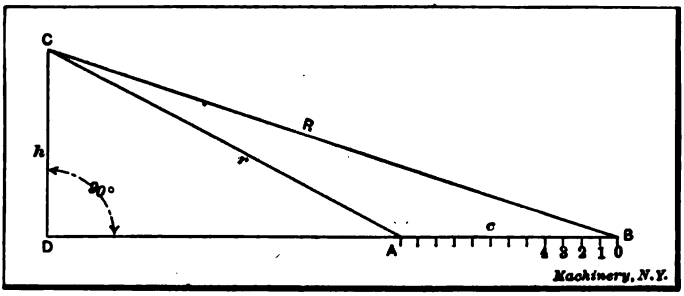


Fig. 29. Notation used in Formulas for Calculating Table IV

In Table II, Chapter II, are given the dimensions required for designing circular forming tools for Brown & Sharpe automatic screw machines. (See Fig. 17 for notation used.) For the purpose of illustration, a table of diameters for circular forming tools for the No. 2 machine will be computed. The method can be applied universally, however, provided the tools have no top rake. The conditions of the problem are shown diagrammatically in Fig. 29. The notation is the same as that used in Fig. 28.

TABLE IV. VALUES OF r FOR DIFFERENT VALUES OF n

n	r	Difference between Radii for n = 50	Corresponding Difference for n = 1	2 r	Double Difference (n = 1)
0	1.500000			3.000000	
		0.049277	0.0009855		0.001971
50	1.450723			2.901446	
		0.049225	0.0009845		0.001969
100	1.401498			2.802996	
		0.049169	0.0009834		0.001967
150	1.352329			2.704658	
		0.049105	0.0009821		0.001964
200	1.303224			2.606448	
		0.049035	0.0009807		0.001961
250	1.254189			2.508278	
		0.048955	0.0009791		0.001958
300	1.205234			2.400468	
		0.048866	0.0009773		0.001955
350	1.156368			2.312736	
		0.048765	0.0009753		0.001951
400	1.107603			2.215206	
		0.048650	0.0009730		0.001946
450	1.058953			2.117906	
		0.048517	0.0009703		0.001941
500	1.010436			2.020872	

Let

n = the numbers 1, 2, 3, 4, etc., successively,

$c = 0.001\,n$.

TABLE V. CALCULATING CIRCULAR FORMING TOOLS

Length c on Tool	Number of B. & S. Auto. Screw Machine			Length c on Tool	Number of B. & S. Auto. Screw Machine		
	No. 00	No. 0	No. 2		No. 00	No. 0	No. 2
0.001	1.7480	2.2480	2.9980	0.051	1.6491	2.1490	2.8995
0.002	1.7460	2.2460	2.9961	0.052	1.6471	2.1470	2.8975
0.003	1.7441	2.2441	2.9941	0.053	1.6452	2.1451	2.8955
0.004	1.7421	2.2421	2.9921	0.054	1.6432	2.1431	2.8936
0.005	1.7401	2.2401	2.9901	0.055	1.6412	2.1411	2.8916
0.006	1.7381	2.2381	2.9882	0.056	1.6392	2.1391	2.8896
0.007	1.7362	2.2361	2.9862	0.057	1.6373	2.1372	2.8877
0.008	1.7342	2.2341	2.9842	0.058	1.6353	2.1352	2.8857
0.009	1.7322	2.2321	2.9823	0.059	1.6333	2.1332	2.8837
0.010	1.7302	2.2302	2.9803	0.060	1.6313	2.1312	2.8818
0.011	1.7282	2.2282	2.9783	0.061	1.6294	2.1293	2.8798
0.012	1.7263	2.2262	2.9763	0.062	1.6274	2.1273	2.8778
0.013	1.7243	2.2243	2.9744	1/16	1.6264	2.1263	2.8768
0.014	1.7223	2.2222	2.9724	0.063	1.6254	2.1253	2.8759
0.015	1.7203	2.2203	2.9704	0.064	1.6234	2.1233	2.8739
1/64	1.7191	2.2191	2.9692	0.065	1.6215	2.1213	2.8719
0.016	1.7184	2.2183	2.9685	0.066	1.6195	2.1194	2.8699
0.017	1.7164	2.2163	2.9665	0.067	1.6175	2.1174	2.8680
0.018	1.7144	2.2143	2.9645	0.068	1.6155	2.1154	2.8660
0.019	1.7124	2.2123	2.9625	0.069	1.6136	2.1134	2.8640
0.020	1.7104	2.2004	2.9606	0.070	1.6116	2.1115	2.8621
0.021	1.7085	2.2084	2.9586	0.071	1.6096	2.1095	2.8601
0.022	1.7065	2.2064	2.9566	0.072	1.6076	2.1075	2.8581
0.023	1.7045	2.2045	2.9547	0.073	1.6057	2.1055	2.8561
0.024	1.7025	2.2025	2.9527	0.074	1.6037	2.1035	2.8542
0.025	1.7005	2.2005	2.9507	0.075	1.6017	2.1016	2.8522
0.026	1.6986	2.1985	2.9488	0.076	1.5997	2.0996	2.8503
0.027	1.6966	2.1965	2.9468	0.077	1.5978	2.0976	2.8483
0.028	1.6946	2.1945	2.9448	0.078	1.5958	2.0956	2.8463
0.029	1.6926	2.1925	2.9428	5/64	1.5955	2.0954	2.8461
0.030	1.6907	2.1906	2.9409	0.079	1.5938	2.0937	2.8443
0.031	1.6887	2.1886	2.9389	0.080	1.5918	2.0917	2.8424
1/32	1.6882	2.1881	2.9384	0.081	1.5899	2.0897	2.8404
0.032	1.6867	2.1866	2.9369	0.082	1.5879	2.0877	2.8384
0.033	1.6847	2.1847	2.9350	0.083	1.5859	2.0857	2.8365
0.034	1.6827	2.1827	2.9330	0.084	1.5839	2.0838	2.8345
0.035	1.6808	2.1807	2.9310	0.085	1.5820	2.0818	2.8325
0.036	1.6788	2.1787	2.9290	0.086	1.5800	2.0798	2.8306
0.037	1.6768	2.1767	2.9271	0.087	1.5780	2.0778	2.8286
0.038	1.6748	2.1747	2.9251	0.088	1.5760	2.0759	2.8266
0.039	1.6729	2.1727	2.9231	0.089	1.5740	2.0739	2.8247
0.040	1.6709	2.1708	2.9211	0.090	1.5721	2.0719	2.8227
0.041	1.6689	2.1688	2.9192	0.091	1.5701	2.0699	2.8207
0.042	1.6669	2.1668	2.9172	0.092	1.5681	2.0679	2.8187
0.043	1.6649	2.1649	2.9152	0.093	1.5661	2.0660	2.8168
0.044	1.6630	2.1629	2.9133	3/32	1.5647	2.0645	2.8153
0.045	1.6610	2.1609	2.9113	0.094	1.5642	2.0640	2.8148
0.046	1.6590	2.1589	2.9093	0.095	1.5622	2.0620	2.8128
3/64	1.6578	2.1572	2.9076	0.096	1.5602	2.0600	2.8109
0.047	1.6570	2.1569	2.9073	0.097	1.5582	2.0581	2.8089
0.048	1.6550	2.1549	2.9054	0.098	1.5563	2.0561	2.8069
0.049	1.6531	2.1529	2.9034	0.099	1.5543	2.0541	2.8050
0.050	1.6511	2.1510	2.9014	0.100	1.5523	2.0521	2.8030

TABLE VI. CALCULATING CIRCULAR FORMING TOOLS

Length c on Tool	Number of B. & S. Auto. Screw Machine			Length c on Tool	Number of B. & S. Auto. Screw Machine		
	No. 00	No. 0	No. 2		No. 00	No. 0	No. 2
0.100	1.5523	2.0521	2.8030	0.151	1.4517	1.9514	2.7027
0.101	1.5503	2.0502	2.8010	0.152	1.4498	1.9494	2.7007
0.102	1.5484	2.0482	2.7991	0.153	1.4478	1.9474	2.6988
0.103	1.5464	2.0462	2.7971	0.154	1.4458	1.9455	2.6968
0.104	1.5444	2.0442	2.7951	0.155	1.4439	1.9435	2.6948
0.105	1.5425	2.0423	2.7932	0.156	1.4419	1.9415	2.6929
0.106	1.5405	2.0403	2.7912	$\frac{5}{32}$	1.4414	1.9410	2.6924
0.107	1.5385	2.0383	2.7892	0.157	1.4399	1.9395	2.6909
0.108	1.5365	2.0363	2.7873	0.158	1.4380	1.9376	2.6889
0.109	1.5346	2.0343	2.7853	0.159	1.4360	1.9356	2.6870
$\frac{7}{64}$	1.5338	2.0336	2.7846	0.160	1.4340	1.9336	2.6850
0.110	1.5326	2.0324	2.7833	0.161	1.4321	1.9317	2.6830
0.111	1.5306	2.0304	2.7814	0.162	1.4301	1.9297	2.6811
0.112	1.5287	2.0284	2.7794	0.163	1.4281	1.9277	2.6791
0.113	1.5267	2.0264	2.7774	0.164	1.4262	1.9257	2.6772
0.114	1.5247	2.0245	2.7755	0.165	1.4242	1.9238	2.6752
0.115	1.5227	2.0225	2.7735	0.166	1.4222	1.9218	2.6732
0.116	1.5208	2.0205	2.7715	0.167	1.4203	1.9198	2.6713
0.117	1.5188	2.0185	2.7696	0.168	1.4183	1.9178	2.6693
0.118	1.5168	2.0166	2.7676	0.169	1.4163	1.9159	2.6673
0.119	1.5148	2.0146	2.7656	0.170	1.4144	1.9139	2.6654
0.120	1.5129	2.0126	2.7637	0.171	1.4124	1.9119	2.6634
0.121	1.5109	2.0106	2.7617	$\frac{11}{64}$	1.4107	1.9103	2.6617
0.122	1.5089	2.0087	2.7597	0.172	1.4104	1.9099	2.6614
0.123	1.5070	2.0067	2.7578	0.173	1.4084	1.9080	2.6595
0.124	1.5050	2.0047	2.7558	0.174	1.4065	1.9060	2.6575
0.125	1.5030	2.0027	2.7538	0.175	1.4045	1.9040	2.6556
0.126	1.5010	2.0008	2.7519	0.176	1.4025	1.9021	2.6536
0.127	1.4991	1.9988	2.7499	0.177	1.4006	1.9001	2.6516
0.128	1.4971	1.9968	2.7479	0.178	1.3986	1.8981	2.6497
0.129	1.4951	1.9948	2.7460	0.179	1.3966	1.8961	2.6477
0.130	1.4932	1.9929	2.7440	0.180	1.3947	1.8942	2.6457
0.131	1.4912	1.9909	2.7420	0.181	1.3927	1.8922	2.6438
0.132	1.4893	1.9889	2.7401	0.182	1.3907	1.8902	2.6418
0.133	1.4873	1.9869	2.7381	0.183	1.3888	1.8883	2.6398
0.134	1.4853	1.9850	2.7361	0.184	1.3868	1.8863	2.6379
0.135	1.4833	1.9830	2.7342	0.185	1.3848	1.8843	2.6359
0.136	1.4813	1.9810	2.7322	0.186	1.3829	1.8823	2.6339
0.137	1.4794	1.9790	2.7302	0.187	1.3809	1.8804	2.6320
0.138	1.4774	1.9771	2.7282	$\frac{3}{16}$	1.3799	1.8794	2.6310
0.139	1.4754	1.9751	2.7263	0.188	1.3789	1.8784	2.6300
0.140	1.4734	1.9731	2.7243	0.189	1.3770	1.8764	2.6281
$\frac{9}{64}$	1.4723	1.9719	2.7231	0.190	1.3750	1.8744	2.6261
0.141	1.4715	1.9711	2.7224	0.191	1.3730	1.8725	2.6241
0.142	1.4695	1.9692	2.7204	0.192	1.3711	1.8705	2.6222
0.143	1.4675	1.9672	2.7184	0.193	1.3691	1.8685	2.6202
0.144	1.4655	1.9652	2.7165	0.194	1.3671	1.8665	2.6182
0.145	1.4636	1.9632	2.7145	0.195	1.3652	1.8646	2.6163
0.146	1.4616	1.9613	2.7125	0.196	1.3632	1.8626	2.6143
0.147	1.4596	1.9593	2.7106	0.197	1.3612	1.8606	2.6123
0.148	1.4577	1.9573	2.7086	0.198	1.3592	1.8587	2.6104
0.149	1.4557	1.9553	2.7066	0.199	1.3573	1.8567	2.6084
0.150	1.4537	1.9534	2.7047	0.200	1.3553	1.8547	2.6064

TABLE VII. CALCULATING CIRCULAR FORMING TOOLS

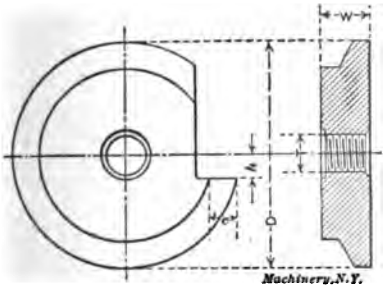
Length c on Tool	No. of B. & S. Machine		Length c on Tool	No. of B. & S. Machine		Length c on Tool	No. 2 B. & S. Machine	Length c on Tool	No. 2 B. & S. Machine
	No. 0	No. 2		No. 0	No. 2				
0.201	1.8527	2.6045	0.251	1.7543	2.5064	0.301	2.4085	0.351	2.3108
0.202	1.8508	2.6025	0.252	1.7523	2.5045	0.302	2.4066	0.352	2.3088
0.203	1.8488	2.6006	0.253	1.7503	2.5025	0.303	2.4046	0.353	2.3069
13/64	1.8486	2.6003	0.254	1.7484	2.5005	0.304	2.4026	0.354	2.3049
0.204	1.8468	2.5986	0.255	1.7464	2.4986	0.305	2.4007	0.355	2.3030
0.205	1.8449	2.5966	0.256	1.7444	2.4966	0.306	2.3987	0.356	2.3010
0.206	1.8429	2.5947	0.257	1.7425	2.4947	0.307	2.3968	0.357	2.2991
0.207	1.8409	2.5927	0.258	1.7405	2.4927	0.308	2.3948	0.358	2.2971
0.208	1.8390	2.5908	0.259	1.7385	2.4908	0.309	2.3929	0.359	2.2952
0.209	1.8370	2.5888	0.260	1.7366	2.4888	0.310	2.3909	23/64	2.2945
0.210	1.8350	2.5868	0.261	1.7346	2.4868	0.311	2.3890	0.360	2.2932
0.211	1.8330	2.5849	0.262	1.7326	2.4849	0.312	2.3870	0.361	2.2913
0.212	1.8311	2.5829	0.263	1.7306	2.4829	5/16	2.3860	0.362	2.2893
0.213	1.8291	2.5809	0.264	1.7287	2.4810	0.313	2.3851	0.363	2.2874
0.214	1.8271	2.5790	0.265	1.7267	2.4790	0.314	2.3831	0.364	2.2854
0.215	1.8252	2.5770	17/64	1.7255	2.4778	0.315	2.3811	0.365	2.2835
0.216	1.8232	2.5751	0.266	1.7248	2.4770	0.316	2.3792	0.366	2.2815
0.217	1.8212	2.5731	0.267	1.7228	2.4751	0.317	2.3772	0.367	2.2796
0.218	1.8193	2.5711	0.268	1.7208	2.4731	0.318	2.3753	0.368	2.2776
7/32	1.8178	2.5697	0.269	1.7189	2.4712	0.319	2.3733	0.369	2.2757
0.219	1.8173	2.5692	0.270	1.7169	2.4692	0.320	2.3714	0.370	2.2737
0.220	1.8153	2.5672	0.271	1.7149	2.4673	0.321	2.3694	0.371	2.2718
0.221	1.8133	2.5653	0.272	1.7130	2.4653	0.322	2.3675	0.372	2.2698
0.222	1.8114	2.5633	0.273	1.7110	2.4633	0.323	2.3655	0.373	2.2679
0.223	1.8094	2.5613	0.274	1.7090	2.4614	0.324	2.3636	0.374	2.2659
0.224	1.8074	2.5594	0.275	1.7071	2.4594	0.325	2.3616	0.375	2.2640
0.225	1.8055	2.5574	0.276	1.7051	2.4575	0.326	2.3596	0.376	2.2620
0.226	1.8035	2.5555	0.277	1.7031	2.4555	0.327	2.3577	0.377	2.2601
0.227	1.8015	2.5535	0.278	1.7012	2.4535	0.328	2.3557	0.378	2.2581
0.228	1.7996	2.5515	0.279	1.6992	2.4516	21/64	2.3555	0.379	2.2562
0.229	1.7976	2.5496	0.280	1.6972	2.4496	0.329	2.3538	0.380	2.2542
0.230	1.7956	2.5476	0.281	1.6953	2.4477	0.330	2.3518	0.381	2.2523
0.231	1.7936	2.5456	9/32	1.6943	2.4472	0.331	2.3499	0.382	2.2503
0.232	1.7917	2.5437	0.282	1.6933	2.4457	0.332	2.3479	0.383	2.2484
0.233	1.7897	2.5417	0.283	1.6913	2.4438	0.333	2.3460	0.384	2.2464
0.234	1.7877	2.5398	0.284	1.6894	2.4418	0.334	2.3440	0.385	2.2445
15/64	1.7870	2.5390	0.285	1.6874	2.4398	0.335	2.3421	0.386	2.2425
0.235	1.7858	2.5378	0.286	1.6854	2.4378	0.336	2.3401	0.387	2.2406
0.236	1.7838	2.5358	0.287	1.6835	2.4359	0.337	2.3381	0.388	2.2386
0.237	1.7818	2.5339	0.288	1.6815	2.4340	0.338	2.3362	0.389	2.2367
0.238	1.7799	2.5319	0.289	1.6795	2.4320	0.339	2.3342	0.390	2.2347
0.239	1.7779	2.5300	0.290	1.6776	2.4300	0.340	2.3323	25/64	2.2335
0.240	1.7759	2.5280	0.291	1.6756	2.4281	0.341	2.3303	0.391	2.2328
0.241	1.7739	2.5260	0.292	1.6736	2.4261	0.342	2.3284	0.392	2.2308
0.242	1.7720	2.5241	0.293	1.6717	2.4242	0.343	2.3264	0.393	2.2289
0.243	1.7700	2.5221	0.294	1.6697	2.4222	11/32	2.3250	0.394	2.2269
0.244	1.7680	2.5201	0.295	1.6677	2.4203	0.344	2.3245	0.395	2.2250
0.245	1.7661	2.5182	0.296	1.6658	2.4183	0.345	2.3225	0.396	2.2230
0.246	1.7641	2.5162	19/64	1.6641	2.4166	0.346	2.3206	0.397	2.2211
0.247	1.7621	2.5143	0.297	1.6638	2.4163	0.347	2.3186	0.398	2.2191
0.248	1.7602	2.5123	0.298	1.6618	2.4144	0.348	2.3166	0.399	2.2172
0.249	1.7582	2.5104	0.299	1.6599	2.4124	0.349	2.3147	0.400	2.2152
0.250	1.7562	2.5084	0.300	1.6579	2.4105	0.350	2.3127	0.401	2.2133

TABLE VIII. CALCULATING CIRCULAR FORMING TOOLS

Length c on Tool	No. 2 B. & S. Machine	Length c on Tool	No. 2 B. & S. Machine	Length c on Tool	No. 2 B. & S. Machine	Length c on Tool	No. 2 B. & S. Machine	Length c on Tool	No. 2 B. & S. Machine
0.402	2.2113	0.422	2.1724	0.443	2.1315	0.464	2.0907	31/64	2.0505
0.403	2.2094	0.423	2.1704	0.444	2.1296	0.465	2.0888	0.485	2.0500
0.404	2.2074	0.424	2.1685	0.445	2.1276	0.466	2.0868	0.486	2.0480
0.405	2.2055	0.425	2.1666	0.446	2.1257	0.467	2.0849	0.487	2.0461
0.406	2.2035	0.426	2.1646	0.447	2.1237	0.468	2.0830	0.488	2.0441
13/32	2.2030	0.427	2.1627	0.448	2.1218	15/32	2.0815	0.489	2.0422
0.407	2.2016	0.428	2.1607	0.449	2.1199	0.469	2.0810	0.490	2.0403
0.408	2.1996	0.429	2.1588	0.450	2.1179	0.470	2.0791	0.491	2.0383
0.409	2.1977	0.430	2.1568	0.451	2.1160	0.471	2.0771	0.492	2.0364
0.410	2.1957	0.431	2.1549	0.452	2.1140	0.472	2.0752	0.493	2.0344
0.411	2.1938	0.432	2.1529	0.453	2.1121	0.473	2.0733	0.494	2.0325
0.412	2.1919	0.433	2.1510	29/64	2.1118	0.474	2.0713	0.495	2.0306
0.413	2.1899	0.434	2.1490	0.454	2.1101	0.475	2.0694	0.496	2.0286
0.414	2.1880	0.435	2.1471	0.455	2.1082	0.476	2.0674	0.497	2.0267
0.415	2.1860	0.436	2.1452	0.456	2.1063	0.477	2.0655	0.498	2.0247
0.416	2.1841	0.437	2.1432	0.457	2.1043	0.478	2.0636	0.499	2.0228
0.417	2.1821	7/16	2.1422	0.458	2.1024	0.479	2.0616	0.500	2.0209
0.418	2.1802	0.438	2.1413	0.459	2.1004	0.480	2.0597	.....	......
0.419	2.1782	0.439	2.1393	0.460	2.0985	0.481	2.0577	.....	......
0.420	2.1763	0.440	2.1374	0.461	2.0966	0.482	2.0558	.....	......
0.421	2.1743	0.441	2.1354	0.462	2.0946	0.483	2.0538	.....	......
27/64	2.1726	0.442	2.1335	0.463	2.0927	0.484	2.0519	.....	......

METHOD OF USING TABLES

The accompanying tables have been compiled to facilitate the calculation of circular forming tools for Brown & Sharpe automatic screw machines. The maximum diameter *D* (see illustration) of forming tools for these machines should be: For No. 00 machine, 1¾ inch; for No. 0 machine, 2¼ inches; for No. 2 machine, 3 inches. To find the other diameters of the tool for any piece to be formed, proceed as follows: Subtract the smallest diameter of the work from that diameter of the work which is to be formed by the required tool-diameter; divide the remainder by 2; locate the quotient obtained in the column headed "Length *c* on Tool," and opposite the figure thus located and in the column headed by the number of the machine used, read off directly the diameter to which the tool is to be made. (The quotient obtained, and which is located in the column headed "Length *c* on Tool" is the length *c* as shown in the illustration).



GENERAL DIMENSIONS OF FORMING TOOLS FOR B. & S. AUTOMATIC SCREW MACHINES

(See illustration for notation.)

Number of Machine	D	h	T	W
00	1¾	1/8	3/8—16	1/4
0	2¼	5/32	1/2—14	5/16
2	3	1/4	5/8—12	3/8

Example: A piece of work is to be formed on a No. 0 machine to two diameters, one being ¼ inch and one 0.550 inch; find the diameters of the tool.

The maximum tool diameter is 2¼ inches. This will be the diameter which will cut the ¼ inch diameter of the work. To find the other diameter, proceed according to the rule given.

0.550 — ¼ = 0.300; 0.300 ÷ 2 = 0.150.

In Table II, opposite 0.150, we find that the required tool diameter is 1.9534 inch.

From Fig. 29 we have:

$$\sin CBD = \frac{h}{R}.$$

From Table II we have $h = C = \frac{1}{4}$, and $R = \frac{1}{2} D = 1\frac{1}{2}$, and hence:

$$\sin CBD = \frac{1}{6}$$

$$\cos CBD = \sqrt{1 - \sin^2 CBD} = \sqrt{\frac{35}{36}} = 0.9860133$$

From the "law of cosines" in trigonometry, we obtain:

$$r = \sqrt{R^2 + c^2 - 2 R c \times \cos CBD}$$

Substituting the known values, we have:

$$r = \sqrt{2.25 + 0.000001\, n^2 - 0.0029580399\, n}.$$

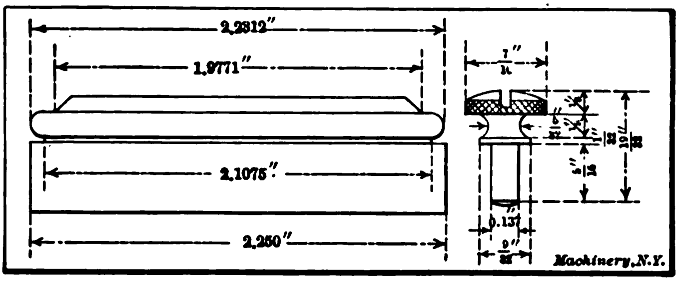


Fig. 30. Dimensions of Work and Tool in the Practical Example Given

To shorten the numerical work we can now calculate r for $n = 50$, $n = 100$, $n = 150$, etc., which is equivalent to considering the distance AB, Fig. 29, divided into a number of equal divisions, each 0.001 inch long, and computing the radius r for $AB = 0.050$, $AB = 0.100$, etc. By trial it can be determined that the values of r for other values of n can be interpolated between those calculated, so that the interpolated values will be correct to four decimal places. Hence, by computing the values of r, as stated, by the formula just given, we obtain the values in Table IV. The fourth column in this table gives the differences of radii corresponding to a difference of 0.001 inch in the length of line AB. By multiplying the values of r and the differences for 0.001 inch, by 2, we obtain the diameter and diametral differences directly, as shown in the last two columns. The tables on pages 34 to 37 are computed by simply subtracting these diametral differences, as given in Table IV, from each preceding diameter, as indicated below.

For

$n = 0$, $2r = 3.000000$

$n = 1$, $2r = 3.000000 - 0.001971 = 2.998029$

$n = 2$, $2r = 2.998029 - 0.001971 = 2.996058$

and so forth to $n = 49$.

For

$n = 50$, $2r = 2.901446$

$n = 51$, $2r = 2.901446 - 0.001969 = 2.899477$

$n = 52$, $2r = 2.899477 - 0.001969 = 2.897508$

and so forth to $n = 99$. In this way the calculations are continued until the table is completed.

The following example will illustrate the practical application of Tables V to VIII. Assume that we wish to design a circular forming tool to turn the piece shown in Fig. 30, on a No. 0 Brown & Sharpe automatic screw machine. Let the largest diameter of the circular tool correspond with the smallest diameter on the piece. Then find one-half the difference between the required diameters of the work as follows:

$$\frac{\frac{5}{32} - 0.137}{2} = \frac{0.156 - 0.137}{2} = \frac{0.019}{2} = 0.0095 \text{ inch}$$

$$\frac{\frac{9}{32} - 0.137}{2} = \frac{0.281 - 0.137}{2} = \frac{0.144}{2} = 0.072 \text{ inch}$$

$$\frac{\left(\frac{7}{16} - 0.024\right) - 0.137}{2} = \frac{0.276}{2} = 0.138 \text{ inch}$$

From Table V, we find opposite 0.0095,* in the column headed No. 0 the value 2.2312, which is the diameter to which to turn the circular tool to produce the 5/32 inch diameter on the work when the largest diameter of the circular tool turns the smallest diameter on the work to 0.137 inch diameter. The other diameters are found opposite 0.072 and 0.138, in the column headed No. 0; they are 2.1075 inches and 1.9771 inch, respectively.

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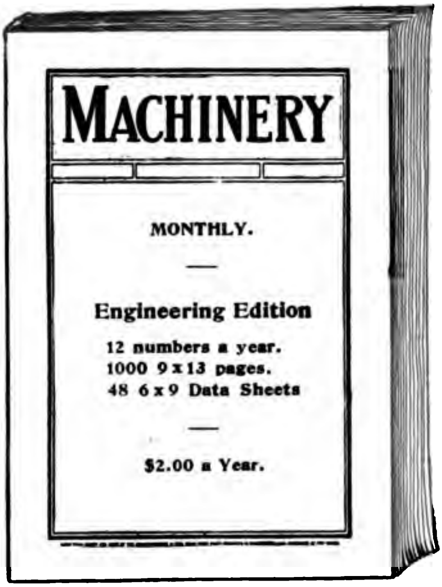
* The table only reads to thousandths of an inch, but values corresponding to ten-thousandths inch can be found by interpolating.



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