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CHIP BREAKER STUDIES I

DESIGN AND PERFORMANCE OF GROUND CHIP BREAKERS

Content

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COLLEGE OF ENGINEERING
THE ENGINEERING EXPERIMENT STATION

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American Machinist

SPECIAL REPORT
NUMBER 360

balanced design will . . .

fit the Chip Breaker to the job

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Up to now, research work on chip-breaker design, sponsored by NMTBA, has been kept under wraps. A year or more ago, we asked Professor Henriksen, in charge of the project, to write us a Special Report, which we herewith publish. It differs considerably from the "general release" currently appearing elsewhere. Our design charts have straight rather than curved lines for greater accuracy and include a new concept, that of balanced chip-breaker design

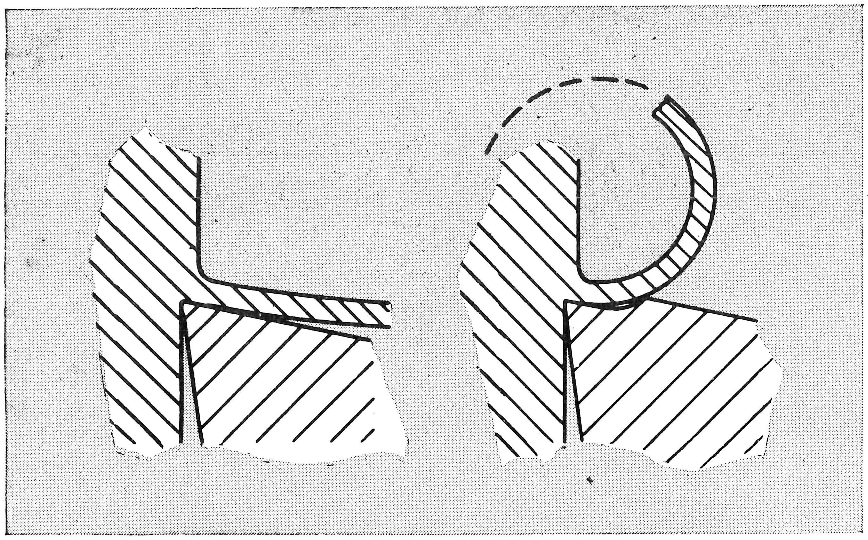


FIG. 1 . . Straight chip (plain tool) and curled chip (chip breaker tool)

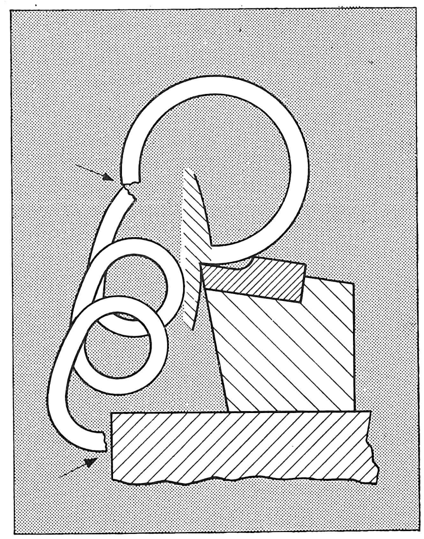


FIG. 2 . . The principal action of an ordinary chip breaker tool: The chip breaker curls the chip; the curling chip meets an obstacle (arrow); pressure builds up and the chip breaks (arrow).

Chip-breaker dimensions are critical

High-speed cutting of steel with carbide tools which have no chip breakers is troublesome for well-known reasons; but, unfortunately, it is by no means always trouble-free even if chip breakers are used, although the troubles may then sometimes take on a different character.

It is the old story of too little and too much—too little chip breaking leaves the chip in the snarling stage, just as from a plain tool with no chip breaker at all; too much chip breaking produces flying chips, which are a nuisance, if not an outright danger, to the operator, and likewise a danger to the tool itself.

Successful chip breaking requires a chip breaker of *balanced design;* that is, a chip breaker which curls and breaks the chip to the desired degree with minimum obstruction to chip flow.

To clarify the new term, "Balanced Chip-Breaker Design," the action of the chip breaker must first be analyzed. Such an analysis will reveal that the time-honored name, "chip breaker," is really a misnomer. Closer study will show that the chip breaker does not break the chip; its action is primarily that of curling or bending the chip (see Fig. 1), whereas the actual breaking is a secondary effect, which requires (a) that the flow of the curling chip meet an obstacle, and (b) that the chip have so much rigidity that a breaking pressure can build up (see Fig. 2).

The amount of curl that a chip undergoes as it passes over the chip breaker depends on chip-breaker dimensions, primarily on width w and height h. Most authorities dealing with chip breakers realize this fact to some extent and provide tables for chip-breaker width w in relation to feed, sometimes also to depth of cut.

In most cases it is recommended that width w be taken as a certain factor multiplied by the feed (with some modifications for various values of depth of cut).

The second chip-breaker dimension, height h, is usually treated rather vaguely, as is the question of any possible effect on chip breaking caused by variations in cutting speed, rake angle, properties of the work material, and the like. It is realized, however, in the existing tables that these other factors may have some effect; therefore, the common recommendation is to experiment to find the best — or perhaps just the workable—conditions.

The same situation was faced by the author in a large Copenhagen machine shop back in 1947-48; and this led to a series of experiments in the machine-tool laboratory of the Royal Technical University of Denmark, for the purpose of deter-

table 1 . . CONVERSION FROM RADIUS *B* TO WIDTH *w* AND HEIGHT *h*

(All dimensions in inches)

Height h	Radius B: 0.100	0.150	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000
	Width w										
0.015	0.053	0.065	0.076	0.094	0.108	0.121	0.133	0.144	0.154	0.164	0.173
0.020	0.060	0.075	0.087	0.108	0.125	0.140	0.154	0.166	0.178	0.188	0.199
0.025	0.066	0.083	0.097	0.120	0.139	0.156	0.171	0.185	0.198	0.211	0.222
0.030	0.071	0.090	0.105	0.131	0.152	0.171	0.187	0.203	0.217	0.230	0.243

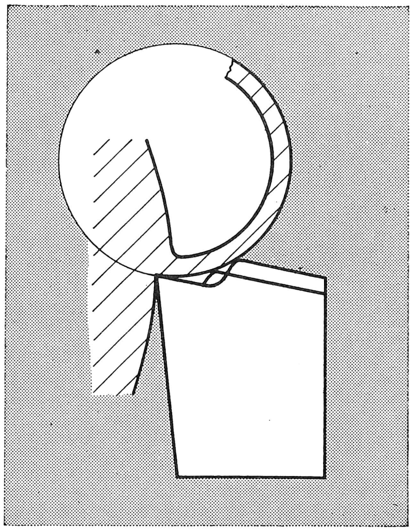


FIG. 3 . . The chip flow circle. Two chip breakers, of different widths and heights, but with the same size of the chip flow circle, will curl and break the chip in a similar manner

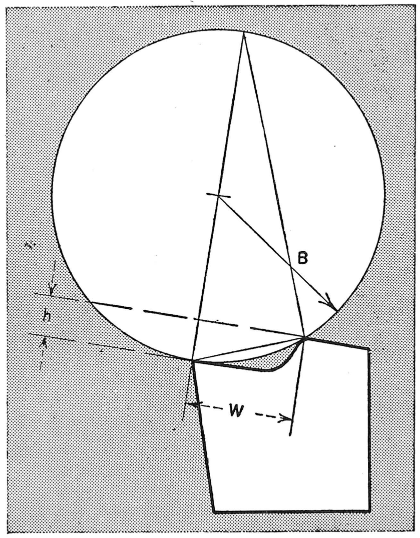


FIG. 4 . . Geometry of the chip-breaker profile, showing the relationship between width *w*, height *h*, and radius *B* in the chip-flow circle

in taming chips...

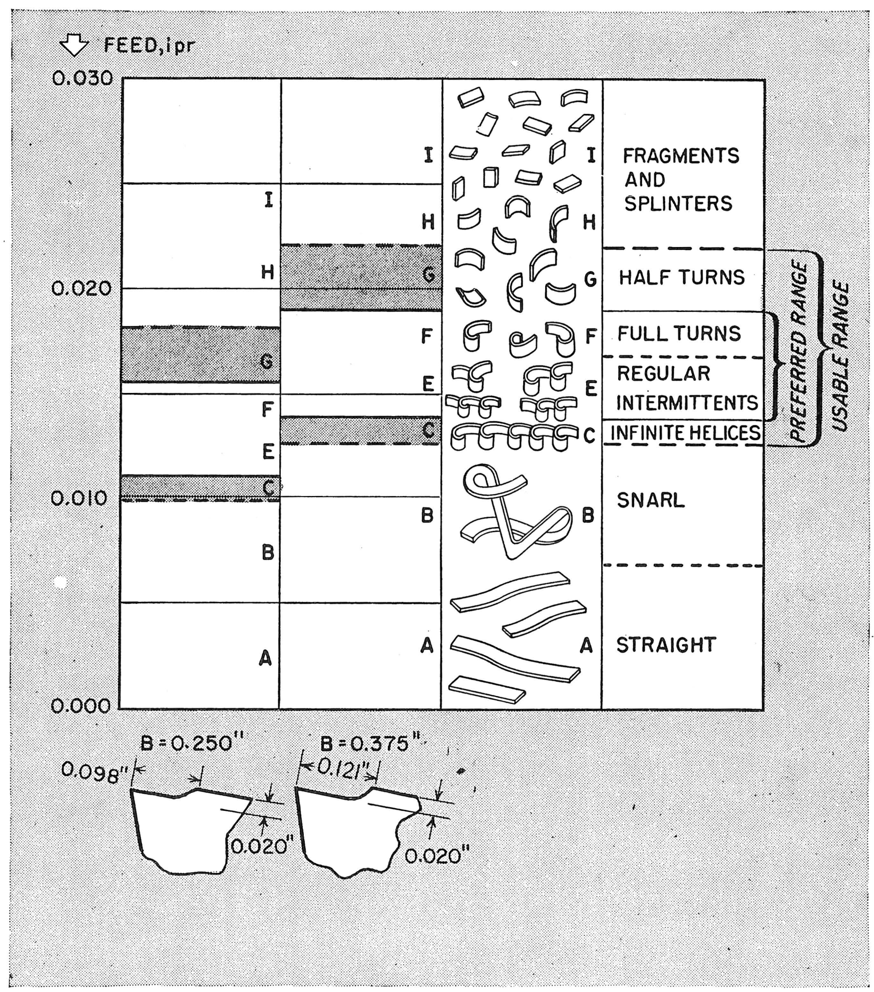


FIG. 5 . . Chip classification and types of chips produced by two chip breakers of different radius *B*

mining the effect of width *w* and height *h* *separately*. To begin with, the trends appeared to be quite obscure, but there was a striking similarity between the behavior of two particular chip breakers. Although of different width *w* and height *h*, these two chip breakers would always give practically identical performance; if one chip breaker would break the chip, the other would break the chip in practically the same fashion when applied under the same cutting conditions, and if one chip breaker would fail, the other would also fail.

When the two chip-breaker profiles are placed one on top of the other, Fig. 3, their significant relationship is revealed: the two chip breakers *determine the same chip-flow circle*. This fundamental observation was confirmed through subsequent tests, and establishes the general principle of chip-breaker action:

Two chip breakers, having the same size of chip-flow circle, will break the chip in (practically) *the same manner.*

The geometry of the chip breaker, and its chip-flow circle, is shown in Fig. 4. If the radius in the chip-flow circle is called *B* (for bending, because the chip breaker *bends* the chip), we have

$$B = \frac{w^2}{2h} + \frac{h}{2}$$

Corresponding values for *B*, *w* and *h* are given in Table I, and can also be taken from the diagram, Fig. 9.

Rigidity of the chip, as referred to above, is determined to some extent by its curl, but largely by its thickness, therefore by the feed. This very important relationship is clearly illustrated by this simple experiment, which can be made in any shop:

Make a cutting test on low- or medium-carbon steel at a cutting speed between 300 and 400 sfpm (to be kept as near as possible constant during the test) and with ⅛-in. depth of cut. The tool should have 0° side-cutting edge angle (no lead angle, straight turning tool) and chip-breaker dimensions should be approximately 0.125-in. width and 0.020-in. height. This

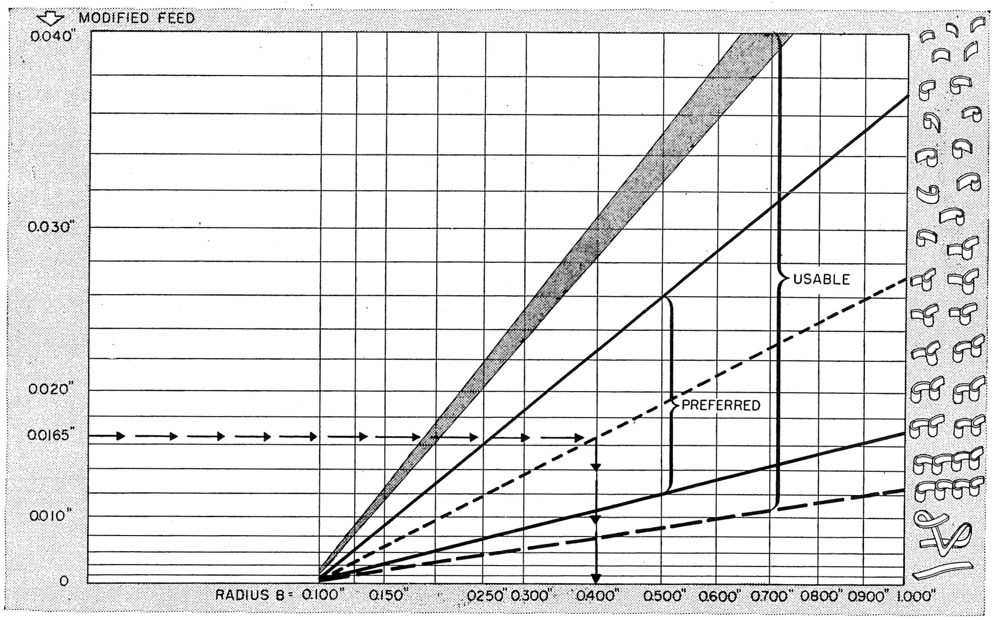


FIG. 6.. Chart for determination of radius *B* of a chip breaker in relation to feed, showing usable and preferred feed ranges. Free-cutting steel *B* 1112, 55,000-75,000 psi tensile strength, 35,000-50,000 psi yield point, 126-150 Bhn

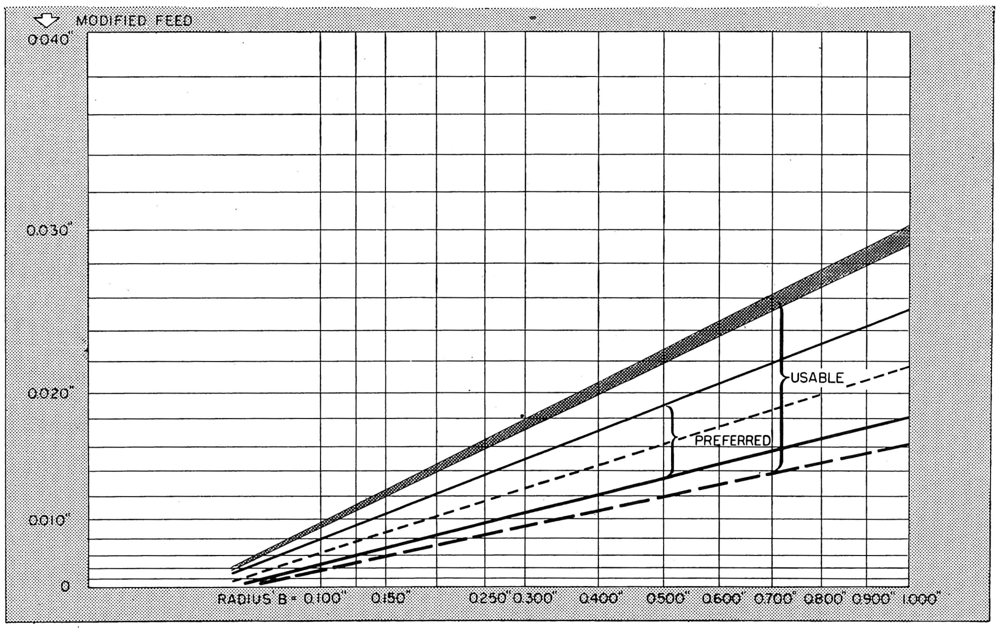


FIG 7.. Chart for determination of radius *B* of chip breaker in relation to feed, showing usable and preferred feed ranges. Plain carbon steel C 1015, 47,000-60,000 psi tensile strength, 30,000 - 40,000 psi yield point, 101-140 Bhn

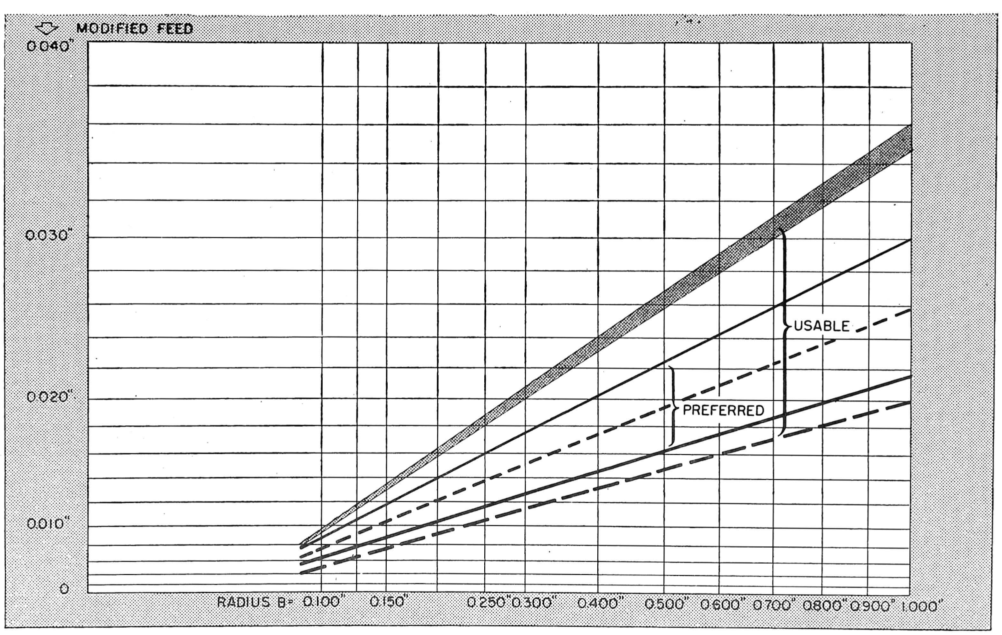


FIG. 8.. Chart for determination of radius *B* of a chip breaker in relation to feed, showing usable and preferred feed ranges. Alloy steel 4140, annealed, 85,000-105,000 psi tensile strength, 55,000 - 75,000 psi yield point, 170-223 Bhn

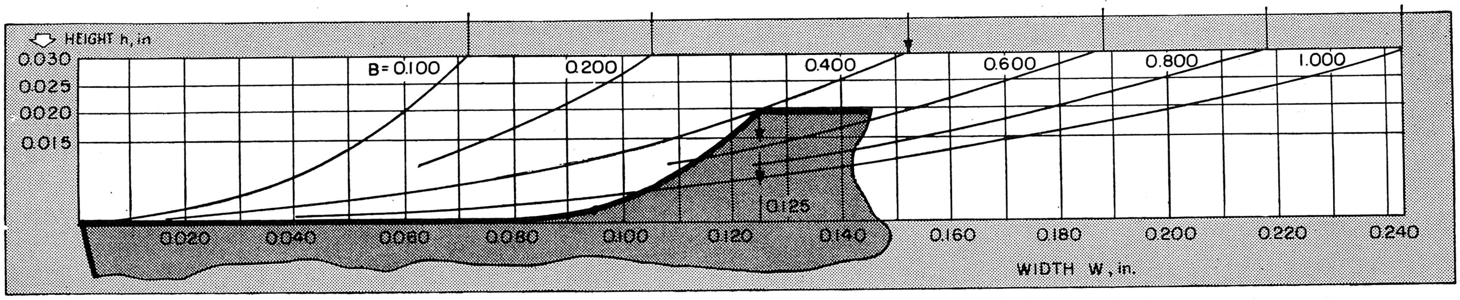


FIG. 9 . . Chart for conversion of radius *B* of chip breaker to width *w* and height *h*

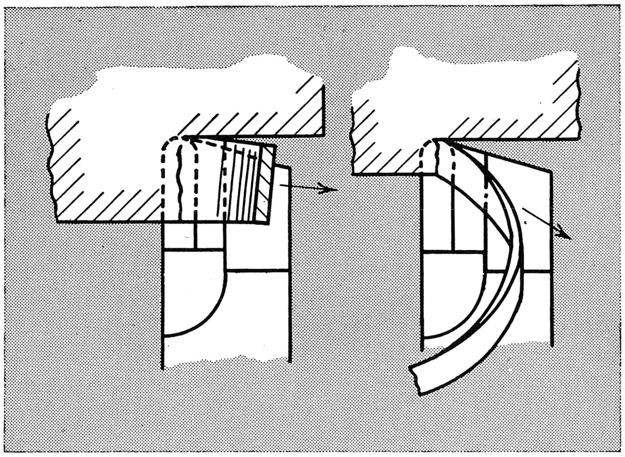


FIG. 10 . . A variation in the depth of cut changes the direction of chip flow and causes the chip to strike the chip breaker at a different angle

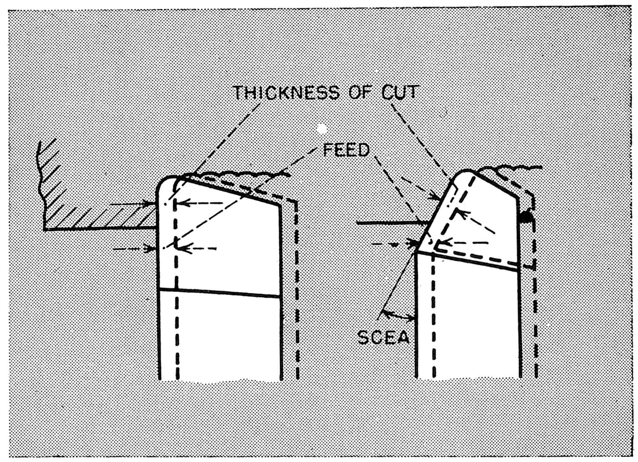


FIG. 11 . . Thickness of the cut is influenced by the side-cutting-edge angle on the tool

will result in a radius B of almost 0.400-in. (exactly 0.391 in.). Use a lathe with all fine feed steps; begin with a feed of 0.005-in. and increase the feed through all the steps to a value between 0.025 and 0.030 in. Collect typical samples of chips from each feed step, and arrange in order of increasing feed.

Such a test will give a picture like that in Fig. 5, in which chips from tests with two chip breakers of different radii B are shown in relation to the corresponding feeds. This illustrates, in a nutshell, the whole basic story of chip breaking, which is:

a. The radius B in the chip-flow circle, together with the feed, controls the degree of chip breaking.

b. Chip breaking is increased at increasing feeds and decreasing radii B.

c. *Any* type of chip can be produced by *any* chip breaker, but only within a limited range of feeds.

In Fig. 5 is also shown a system of chip classification, and it now remains to select the "satisfactory" or "acceptable" chip type or types. This, however, depends upon whether we are dealing with high-production conditions or with short-run or single jobs.

High production requires special tooling anyhow, and it is therefore economical to design each tool, including its chip breaker, for one purpose only. The most desirable type of chip is the one which is easiest to handle (the "shoveling" chip) and which, at the same time, does not sacrifice tool life. These conditions are simultaneously fulfilled by the "regular intermittents" and the "full turns" (including three-quarter turns). Feed ranges within which these two chip types are produced constitute, therefore, the "preferred range" of feeds. A middle line through the preferred range is the bull's-eye at which the design should be aimed. This is the middle-of-the-road course, where maximum safety is provided in either direction, to take care of unavoidable irregularities in properties of the material, quality and accuracy in chip-breaker grinding, condition of the cutting edge, and so on.

Production conditions in the job shop require versatile equipment in general, and therefore tools of a general-purpose character. In terms of chip breakers, it means the widest possible range of feeds, consistent with a tool life which is still acceptable, although shorter than required for high-production tools. For general-purpose tools we can, therefore, include the "infinite helix"; this is a chip type which is well under control and can be conveniently guided into the chip pan of the machine. We can also include a certain amount of half turns ("half moons"); as long as they appear in mixture with larger chips they are not too hard on the tool and can be accepted for short-run jobs. But when half turns appear in large quantity, and particularly when they gradually change to fragments and splinters, we have "over-breaking" of the chips and the tool is exposed to a heavy, vibrating load which very soon will have damaging effects.

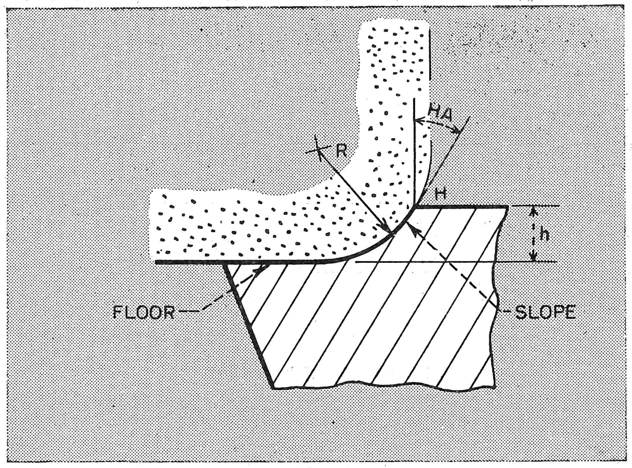


FIG. 13 . . Geometry of chip-breaker grinding

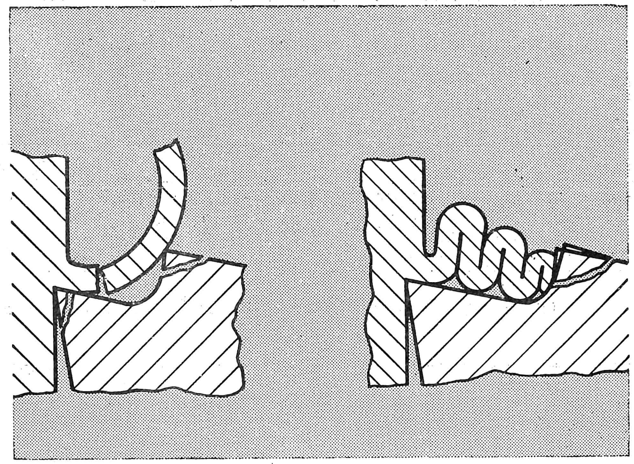


FIG. 14 . . The tool breaker . . .

This expansion of the range of acceptable chips results in a "usable range" of feeds, applicable to general-purpose tools, and normally up to twice as large as the preferred range recommended for high-production tools.

The preferred and usable ranges of feeds for three representative grades of steels were determined through the author's almost year-long research project at Cornell University, generously sponsored by the National Machine Tool Builders' Association and supported in various ways by other sections of American industry in the common interest of promoting the art of metal cutting.

Some of the results are condensed in Figs. 6, 7 and 8, covering free-cutting steel B 1112, plain carbon steel C 1015 and alloy steel 4140 annealed.

A glance at these graphs shows clearly the very wide variation in the response to chip breaking for the three steels. The preferred and usable ranges are up to 2½ times larger for the free-cutting steel than for the alloy steel, and the middle line in the *preferred* range for the free-cutting steel is entirely *outside* of the preferred range for the carbon steel; in fact it is almost as high as the upper limit for the *usable* range for the carbon steel.

It is, therefore, by no means advisable to attempt to transfer chip-breaker data indiscriminately from one material to another without careful investigation, and it is virtually impossible to formulate reliable chip-breaker rules covering a variety of materials. Each material, or group of related materials, must be treated separately.

A chip breaker that works fine on one material may utterly fail when used for a different material, even if feed and other cutting conditions are identically the same.

In addition to these important observations, the graphs provide the answers to these questions:

(a) Which types of chips can be expected with a given chip breaker and a certain feed?

(b) At what feed should a given chip breaker be used when a certain type of chip is desired?

(c) What size of radius B in the chip breaker is necessary at a given feed when a certain type of chip is desired?

Primarily the graphs determine radius B, but in conjunction with Fig. 9 their use can be extended to a direct reading of the corresponding values of width w and height h of the chip breaker.

Effects of the various cutting conditions and tool shapes, such as cutting speed, depth of cut, and

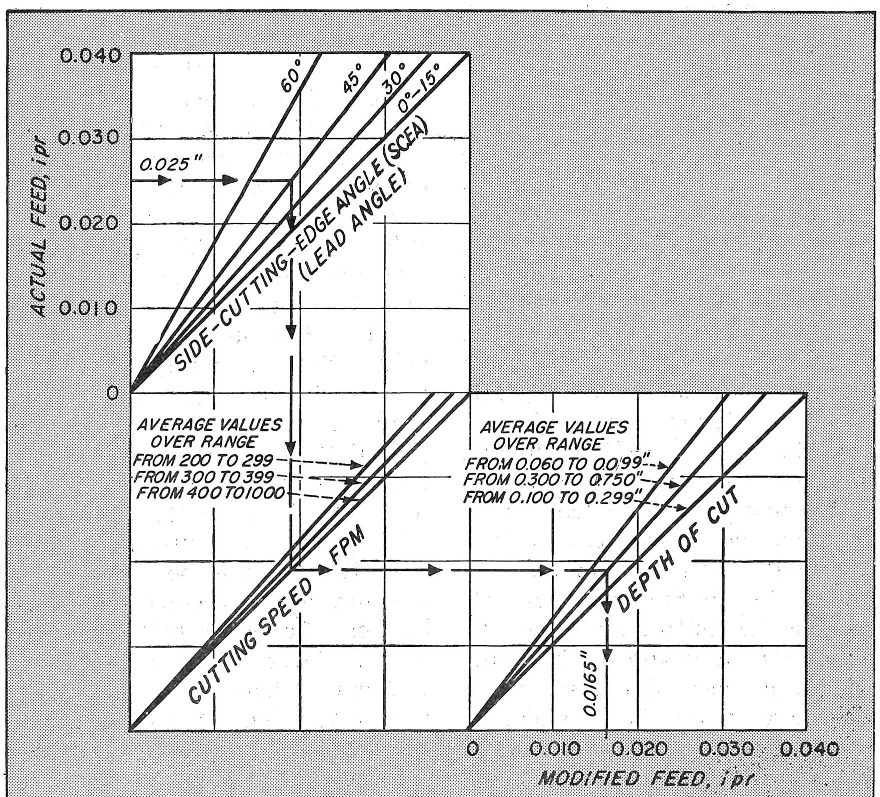
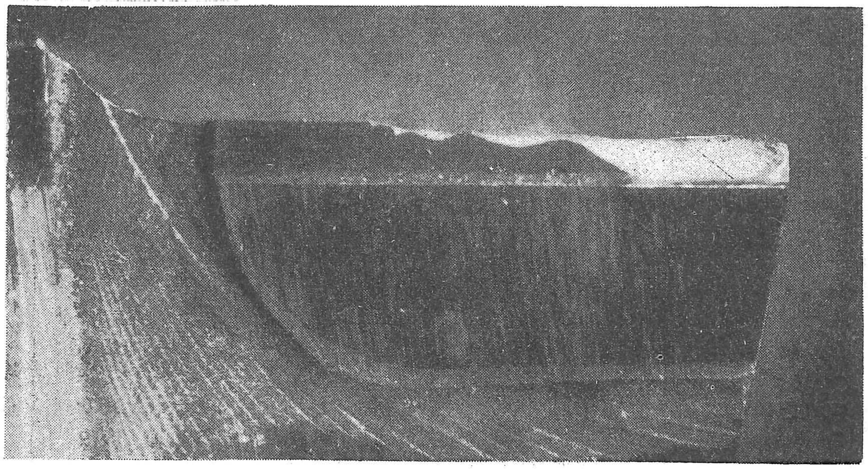


FIG. 12 . . Multiplication chart for conversion of actual feed to modified feed



. . . and its results, FIG. 15

table 2 . . LOWER AND UPPER LIMITS FOR CORNER RADIUS *R* ON GRINDING WHEEL

Chip Breaker Height *h*, In.	R_{min} to R_{max} In.
0.015	0.035 to 0.065
0.020	0.050 to 0.085
0.025	0.060 to 0.100
0.030	0.070 to 0.125

side-cutting-edge angle, can all be deduced from their effect on the thickness of the chip and the radius of the chip-flow circle. An increase in cutting speed tends to decrease chip thickness (besides it makes the chip more elastic, perhaps through metallurgical changes), a decrease in the depth of cut will change the direction of the chip flow and make the chip strike the chip breaker at a different angle, thereby increasing the effective radius in the chip-flow circle (Fig. 10), an increase in the side-cutting-edge angle will decrease the chip thickness (Fig. 11).

All these variations can be covered at the same time by using the graphs in Figs. 6, 7 and 8 with a "modified feed" instead of the real feed. The modified feed can be taken from Fig. 12 for a large variety of cutting conditions. Use of the graphs will be explained in a practical example.

Having now provided the means for designing the chip breaker for the correct degree of chip breaking, we shall direct our attention to the second factor in the balanced design, the chip flow with a minimum of obstruction.

This phase of chip-breaker design is intimately connected with the slope of the chip breaker and the size of heel angle *HA* (see Fig. 13). The function of the slope is to lift the chip from the floor of the chip breaker, carry it over the heel, and give it the permanent curl, all in a gentle and soft sweep. This is best accomplished when heel angle *HA* has a value between 35° and 50°. As the slope is formed as a fillet with radius *R* (not the same as radis *B*, but equal to the radius on the corner of the grinding wheel) this provides an equation for determination of *R*. The equation is

$$\sin HA = 1 - \frac{h}{R}$$

from which Table 2 is computed.

Direct practical conclusion to be drawn from this geometrical relationship is that the corner radius on the grinding wheel should be kept under control (check it regularly with a radius gage) and maintained within a lower and an upper limit. Periodic truing of the diamond wheel should be confined to the straightening of the wheel face and reduction of the corner radius to the lower limits given in Table 2. When regularly applied, this practice will result in a great saving in diamond, up to 50%, sometimes even more, as compared to the common, and very wasteful, truing of the wheel straight up to the corner.

Truing of the wheel to a sharp corner is also dangerous to the tool itself. With a more or less vertical wall at the back of the chip breaker, the gentle lifting effect of the slope is lost, the chip flow is interrupted, the chip breaker gets crowded (Fig. 14) and the tool point, or chip breaker, or both, are sheared off, all in less time than it takes to describe it.

This poor practice of truing the wheel to a sharp corner is much more widespread than one would expect. *It is probably responsible for more tools damaged or destroyed than any other error in tool grinding.* Nevertheless, it is described in technical literature, and it is practiced in the most modern and (otherwise) efficient shops. But whether it is done intentionally or unintentionally, the result is always the same (see Fig. 15): The chip breaker becomes a tool breaker.

PRACTICAL EXAMPLE

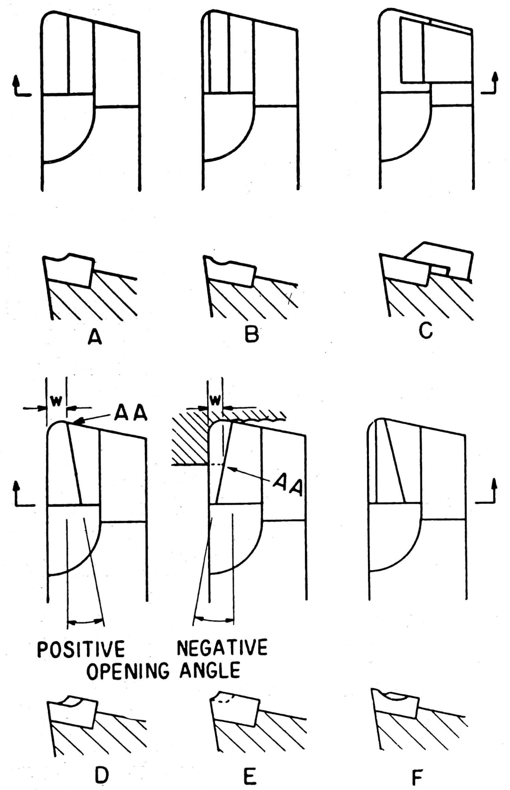
Given a free-cutting steel; to find chip-breaker dimensions for the tool.
Feed: 0.025-in. per revolution
Side-cutting-edge angle: 45°
Cutting speed: 500 sfpm
Depth of cut: 5/16 in. = 0.3125 in.
Solution:

Use graph in Fig. 12. Start at 0.025 ipr actual feed, go to the right, meet line for 45° SCEA, go down, meet line for 400-1000 sfpm cutting speed, go to the right, meet line for 0.300-0.750 in. depth of cut, go down, read 0.0165 ipr modified feed.

Use graph in Fig. 6 for free-cutting steel. Start at 0.0165 ipr modified feed, go to the right, meet middle line, go down, read 0.400 in. radius *B*.

Use graph in Fig. 9. Choose a chip-breaker height *h*, say 0.020 in. Start at *B* = 0.400 in., follow circle, meet line for 0.020 in. height, go down, read chip-breaker width *w* = 0.125 in.

Use Table No. 2. A chip-breaker height of 0.020 in. requires a corner radius *R* on the grinding wheel not less than 0.050 in. and not more than 0.085 in.



ALL CONVENTIONAL TYPES OF CHIP BREAKERS CAN BE CLASSIFIED AS FOLLOWS:

A . . Ground Chip Breakers—The chip breaker is ground into the body of the tool.

B . . Clamped Chip Breakers—The chip breaker is formed by a beveled block clamped on the face of the tool. (These are sometimes called mechanical chip breakers—an unfortunate terminology because there are devices which, more or less successfully, employ a mechanical motion for breaking the chips.)

Each of these types can be further classified as:

1 . . Parallel Chip Breakers—The heel of the chip breaker is parallel to the cutting edge of the tool.

2 . . Angular Chip Breakers—The heel forms an angle with the cutting edge.

The various combinations in general use are shown here. When properly applied, the rules, charts, and data previously mentioned can be used for all types of chip breakers.

Fig. 16 . . TYPES OF CHIP BREAKERS
(A) Ground parallel—step type
(B) Ground parallel—groove type
(C) Clamped parallel—step type
(D & E) Ground angular—step type
(F) Ground angular—groove type

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The author wishes to express his sincere thanks to the following for their generous support to his experimental work on chip breakers: National Machine Tool Builders' Association (financial support), Lodge & Shipley Company (lathe), Kennametal Inc, Wesson Company, Viking Tool Company, A S Batco (carbide tools), D A Stuart Oil Company (cutting oil), The Danish Steel Rolling Mill (work material).

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Wall chart with data from manual above.

American Machinist REFERENCE BOOK SHEET

How to Select Chip Breakers . . . I

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Any style of chip breaker should be based on the principle of the chip-flow circle (*AM*—April 26, 1954, p117). This is the characteristic relationship between width *w* and height *h* of the chip breaker. Consequently, with suitable modifications, all styles of chip breakers can be designed and dimensioned on the basis of the data given previously.

STYLES OF CHIP BREAKERS

A chip breaker can be either of the *ground type* (Figs. 1, 3, and 4) or of the *clamped type* (Fig. 2). A ground chip breaker is ground down into the carbide blank; a clamped chip breaker consists entirely of a block of a hard material, with a beveled edge, and clamped upon the face of the cutting tool.

A ground chip breaker is either of the *step type* (Figs. 1 and 4) or of the *groove type* (Fig. 3). The step-type chip breaker has a step or shelf with a *floor* and a *slope* (*AM*—Apr 26 '54, p122, Fig. 13). The cutting edge and the floor are located below the original cutting face. The floor represents a new cutting face and should be ground with the required rake angle. The slope should be designed for easy chip flow.

The groove-type chip breaker has simply a shallow groove ground into the cutting face, at some distance from the cutting edge. The height of the cutting edge is not affected by the chip breaker, and the rake angle is primarily determined by the original cutting face of the tool.

Any chip breaker can be either of the *parallel type* (Figs. 1, 2, and 3) or of the *angular type* (Fig. 4). With the parallel type the heel is parallel to the cutting edge. Consequently, the profile of the chip breaker and also width *w*, are constant throughout the length. With the angular chip breaker there is an *opening angle,* between the heel of the chip breaker and the edge of the cutting tool. The opening angle is *positive* when the chip breaker is wider at the back of the carbide blank, and it is *negative* when the chip breaker is wider at the tool point.

The angular chip breakers illustrated are of the ground step type. Clamped chip breakers are frequently made slightly angular. Groove-type chip breakers can be made angular if desired. This practice does not seem to be common in the United States.

CHIP-BREAKER LIMITATIONS

When properly dimensioned, the ground, parallel, step-type chip breaker can be made to work successfully in any combination of cutting conditions. But this type is not a *universal* chip breaker, and it has other limitations. The chief disad-

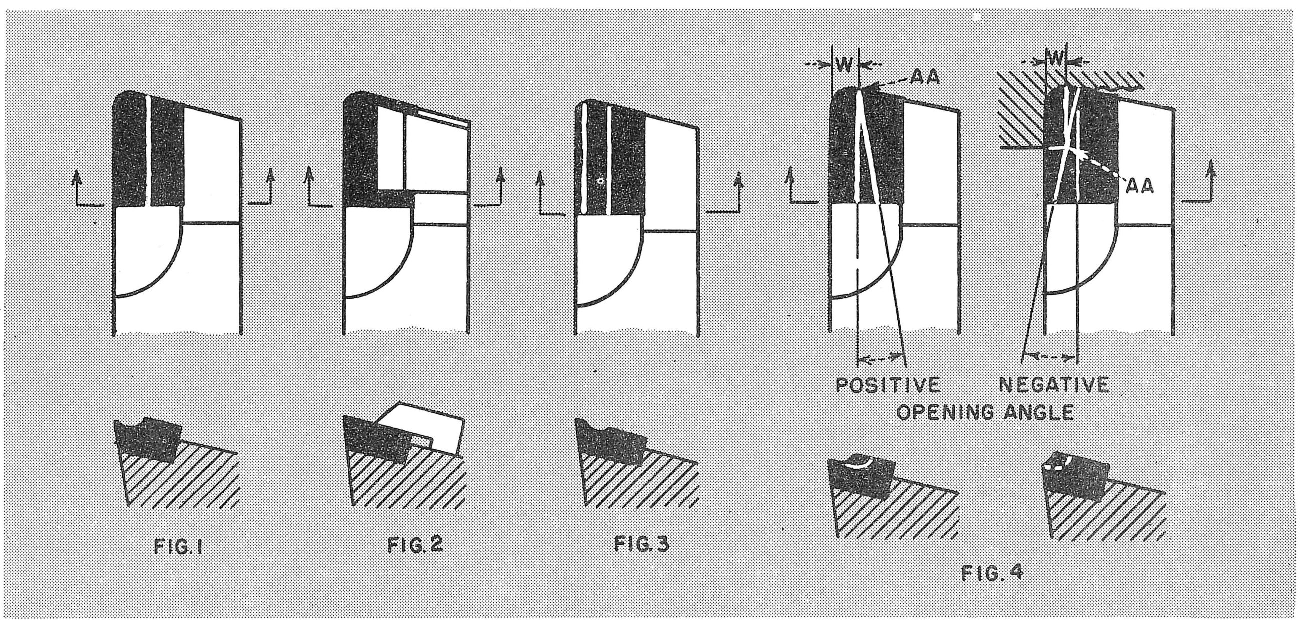

FIG. 1 . . . A ground chip breaker of the parallel, step type. **FIG. 2** . . . A clamped chip breaker of the parallel type. **FIG. 3** . . . A groove-type chip breaker of the ground, parallel type. **FIG. 4** . . . Angular chip breakers with positive and negative opening angle; ground step type

How to Select Chip Breakers . . . II

vantage is the relatively high grinding cost, in terms of carbide and diamond-wheel material. In the initial grinding, a strip of carbide from 0.015 to 0.030 in. thick is sacrificed. Sharpening on the cutting edge decreases the width of the chip breaker. After a few sharpenings, the chip breaker must be reground to its original dimensions.

Unless the carbide blank is raised above the tool shank, or a relief groove is provided behind the blank, the grinding wheel will cut into the shank material (Fig. 5), and load and glaze.

Another disadvantage of this chip breaker is lack of flexibility. Each chip breaker has a fairly limited field of application. If used otherwise, the dimensions must be changed by grinding.

ANGULAR-TYPE CHIP BREAKERS

Because any angular chip breaker has a varying width, it is necessary to define its *"effective width."*

The effective width is "the width that curls the chip," and that, again, is the *minimum width in contact with the chip*. For the positive angular chip breaker the minimum width is obviously the width at the tool point (Fig. 4, left), indicated by arrow *AA*. For the negative angular chip breaker the effective width is the width at the surface of the workpiece (Fig. 4, right), arrow *AA*. The effective width should be used in all computations based upon the charts and tables in the previous article.

The effective width for the positive angular chip breaker is constant, and is determined by the way the tool is ground. This chip breaker can therefore be used with the same degree of chip-breaking performance for varying depth of cut, within the same limits as the parallel type. On the other hand, the effective width of the negative angular chip breaker depends upon the depth of cut. This type of chip breaker should, therefore, be used for long runs on constant depth of cut; the chip breaker being specifically designed not only for the feed, but also for the depth of cut in the particular cutting operation.

Factory-ground chip breakers with a positive opening angle are available in the form of carbide inserts for clamping into a toolholder (Figs. 6 and 7). The effective width is easily adjusted by grinding off either the side-cutting-edge or the end-cutting-edge. This type of tool is well suited to roughing cuts, particularly, but not necessarily, on uneven surfaces, such as forgings. Incidentally, the factory-ground chip breaker has the further advantage that it eliminates the need for the chip-breaker-grinding operation.

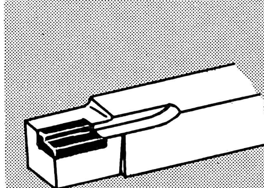

FIG. 5

FIG. 6

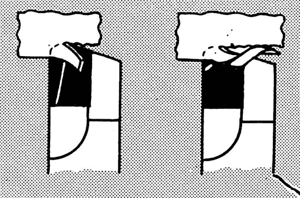

FIG. 8

FIG. 5 . . . Undesirable design of a carbide tool. Chip-breaker grinding wheel cuts into shank material. **FIG. 6** . . . Carbide insert, with factory-ground chip breaker of the positive angular type. Effective width W is measured at the tool point. **FIG. 8** . . . Two angular chip breakers with different negative opening angles. When the opening angle is too large, the chip may hit the finished surface and cause damage

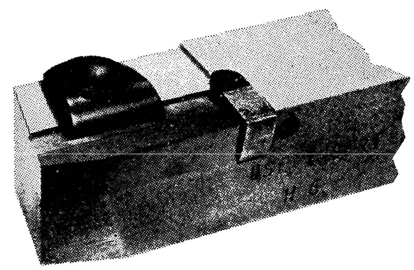

FIG 7 . . . Toolholder (Kennametal BRH-16) with insert (style HS) with factory-ground chip breaker of the angular type. ***(Courtesy, Kennametal, Inc, Latrobe, Pa)***

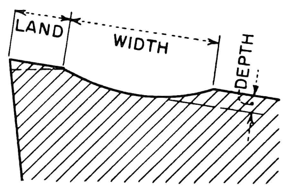

FIG. 9

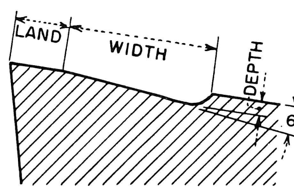

FIG. 10

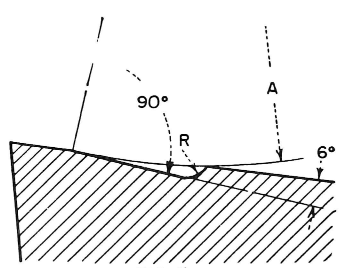

FIG. 11

FIG. 9 . . . Elements of a groove-type chip breaker with round groove. **FIG. 10** . . . Elements of a groove- type chip breaker with tilted V-groove. **FIG. 11** . . . Geometry of a groove-type chip breaker

The negative-angular chip breaker is useful on fine cuts that are difficult in chip breaking, because the device has a strong tendency to direct the flowing chip back against the unmachined surface of the workpiece. This action assists in breaking the chip. Good results are usually obtained with opening angles from –8° to –15° and up to –25°. An angle as high as –45° is not recommended,

How to Select Chip Breakers . . . III

because this may swing the chip over against the finished surface (Fig. 8). One advantage of the negative opening angle is that it provides a runout path for the grinding wheel.

GROOVE-TYPE CHIP BREAKERS

Essentially there are two types of grooves, the round groove and the tilted V-groove (Figs. 9 and 10). The round groove is cut by a narrow wheel, usually not more than 1/16 in. wide; the width of the groove can be regulated by swinging the plane of the wheel from 5° to 15° out of the direction of table travel. The tilted V-groove is cut by an ordinary chip-breaker wheel, with the tool tilted an additional angle; the usual recommendation is 6°. The rake angle on the chip-breaker floor is thereby increased by the same amount.

Various recommendations for dimensions of groove-type chip breakers can be consolidated as follows:

Land—0.015 to 0.030 in. or 1 to 1½ times the feed

Width—1/16 to 3/32 in. or 2 to 4 times the feed

Depth—0.005 to 0.010 in.

Sometimes a 2° to 5° negative rake is recommended on the land, to strengthen the cutting edge, which is somewhat weakened by the unavoidable undercut of the groove.

To design the groove-type chip breaker on the basis of the chip-flow circle, use this procedure:

Draw the profile of the cutting edge and the planned chip breaker in large scale (Fig. 11). Construct the inscribed circle in the groove. If the radius in this circle is found to be A, then the chip-flow circle radius B can be taken approximately as

$$B = 1.75\ A$$

The charts and data from the previous article can be applied with this radius.

Choose the fillet radius R (in the case of the tilted V-groove) in accordance with the rules given previously, in order to facilitate a smooth chip flow.

The undercutting effect of the groove tends to weaken the cutting edge. This chip-breaker type therefore works best at medium feeds. Within its range, its action is less drastic than the step type, so that it tends to produce helical chips rather than broken chips.

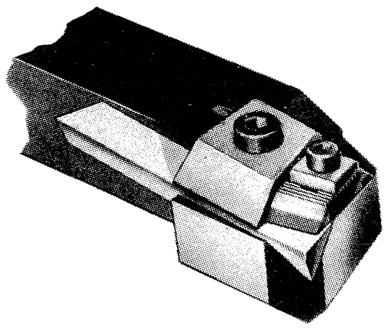

FIG. 12 . . . Toolholder with triangular toolbit and adjustable clamped chip breaker. *(Courtesy Everede Tool Co, Chicago 39)*

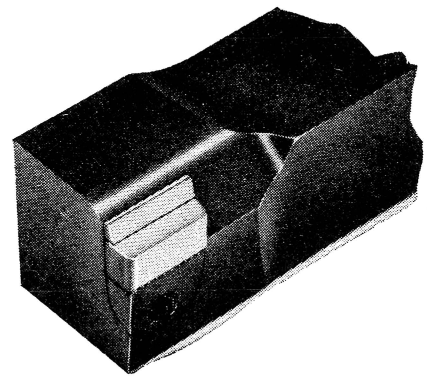

FIG. 13 . . . Holder for straight turning tool ("S-70-RKVB") with adjustable clamped chip breaker. *(Courtesy The Viking Tool Co, Shelton, Conn)*

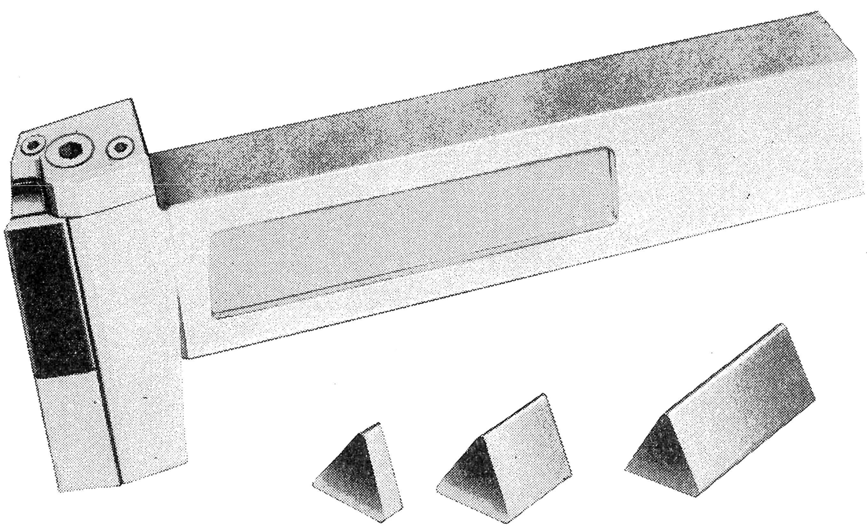

FIG. 14 . . . Toolholder for indexing insert (V-R vertical) with permanently clamped chip breaker, and three insert lengths. *(Courtesy The Vascoloy-Ramet Corp, Waukegan, Ill)*

The principal advantage claimed for the groove-type breaker is low grinding cost, because the depth is only 0.005 to 0.010 in. It is practical to use a small (3-in. dia.) metal-bonded wheel, operating with fast traverse and a small feed (0.0003 in.) for each pass.

CLAMPED CHIP BREAKERS

A clamped chip breaker must possess these characteristics:

(a) Rigid clamping, so that it is not moved out of position by chip pressure.

(b) Tight fit against the face of the cutting tool, so there is no opening to catch the chip.

(c) Adjustable to varying widths, if desired.

Several models of clamped chip breakers are available on the American market today. Some of these have the advantage of being adjustable. They represent the closest approximation, as of today, to the ideal universal chip breaker, because the effective dimensions can be set to desired cutting conditions. Others sacrifice adjustability, but attain a higher degree of safety and avoidance of improper use.

CHIP BREAKING - A STUDY OF THREE-DIMENSIONAL CHIP FLOW

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Paper No. 53-S-9, presented at the ASME Spring Meeting, Columbus, Ohio, April 28-30, 1953.

Abstract

The chip breaking process is analyzed and it is shown that the process is completely determined by the radius in the chip flow circle of the tool, a parabola-like relation between this radius and the Chip Breaking Feed, and a hyperbola-like relation involving the depth of cut, all for a given material and a given cutting speed.

Introduction

In the era of the high speed steel tools the chips, in general, did not present any serious problem, and very few references to the subject of chip breaking are found in literature from that period, the most prominent, and one of the first, being a description of the chip patterns produced by the Klopstock tool (1)*.

The application of sintered carbide tools made a higher speed range available to the metal working industry, and the continuous chip became the rule, rather than the exception; coming off the tool with high speed and temperature and with edges that are sharp as a knife edge and sometimes toothed like a saw blade they present a danger to the operator, and when they curl around the tool and the work piece their removal slow down production. Bulky chips are a nuisance to the clean-up man and have less commercial value than well broken chips.

Broken chips and chip breaking.

The character of the chips can be expressed by the Bulk Ratio R

$$R = \frac{\text{Volume of Chips}}{\text{Volume of Solid Material}}$$

where

R = 50 for entirely unbroken chips,

R = 15 for tightly curled chips,

R = 3 for well broken chips.

Milling machine chips may often have R = 3; a 15 HP lathe may produce over 60 cu.ft. of unbroken chips in one hour of continuous operation.

The conventional way of solving this chip problem is by using a chip breaker tool. The basic form is the ground, parallel type chip breaker, see Figure 1 with proposed nomenclature. Other forms are the groove type and the clamped chip breaker. All of them can be of the parallel type or the angular (non-parallel) type. Only the ground, parallel type chip breaker will be considered in this analysis.

*Numbers in parenthesis refer to the Bibliography at the end of the paper.

It is a paradox, but true, that the chip breaker does not break the chips. Its action is primarily that of forming, bending and deflecting the chip, imposing upon it a considerable increase in curvature and thereby producing a curling chip, which is ultimately guided forcibly against an obstruction whereby it breaks, mostly at very regular intervals. So far, a more fitting name for this device would be "chip former", and the equivalent of this word has apparently been adopted in the German language. In English, the word chip breaker seems to have come to stay.

Chip classification.

Any systematical study of chip breaking requires necessarily a chip classification. The following system has been adopted by the author;

A. Straight (or slightly curved) chips,
B. Snarling chips,
C. Infinite helical chips,
D. Irregular intermittant helical chips (with more than one turn),
E. Regular intermittant helical chips (with more than one turn),
F. Full turns (approximately circular single turns),
G. Half turns (approximately, sometimes very accurately, semi-circular pieces),
H. Fragments and splinters (less than half turns).

This classification assumes silently that (apart from straight and snarling chips) the chip will form a helix. Another possibility exists: that the chip forms a flat spiral. This case is less frequent, and whenever it occurs, the chip will break at intervals, no infinite chip of this type being formed, hence it is conveniently included under E.

When a series of cutting operations are being performed in such a menner that the feed is increased in small increments the chip patterns obtained will normally follow the classification. Sometimes one or two types may appear only sporadically or not at all: for example it often happens that the B-type (snarling chip) will change to the E-type (regular intermittant) for a slight increase in feed, by-passing the C- and D-type. Neither is it uncommon that the chip will change from the C-type to the F-type for just one small increment in the feed. Other exceptions have been found occasionally, but the author never found any reversal of the sequence of his eight classification types. It is therefore concluded that they represent the natural development in ordinary chip breaking.

At present industry has no standardized requirements or definitions of satisfactory chip breaking. It is obvious that the A-type and the B-type are the undesirable types; they represent completely unbroken and truly objectionable chips. The C-type is, strictly speaking, also an unbroken chip. However, it represents the first type where the tool has imposed a controlled flow on the chip, and it is definitely a vast improvement over the A- and the B-type. In many cases it would be acceptable, and in some cases, such as for box turning tools, it is even preferable over finer broken chips, because it has less tendency to get into the rollers.

Chip breaking, in the proper sense of the word, is present as soon as the C-type has disappeared and the D- or E-type (or a higher type) has appeared. A further advanced stage of chip breaking is found, when the F-type enters the picture, while the arrival of the G-type marks the beginning of "overbreaking". When the H-type chips begin to fly through the air the chip breaking has become excessive.

For most practical applications the range D, E and F will normally be satisfactory, and the "ideal" chip is a short E-type, approaching the F-type. As to the upper limit for permissible or desirable chip breaking opinions in industry and engineering seem to be somewhat divided. Some prefer not to go beyond the F-type, and some want a mixture of the F-type and the G-type: some even like to see a large share of the G-type in the chips because this type is the most convenient for removal and handling.

The author's recommendation for the upper limit of chip breaking is a chip type between the F-type and the G-type, in other words, an abbreviated F-type. The author also advises definitely against cutting with an appreciable amount of G-chips, because this type of chip normally appears under flow conditions where it has a tendency to strike and damage the edge just outside of and behind the cutting zone.

Taking all these considerations into account it is possible to simplify the chip classification as follows:

<u>No chip breaking</u>, as long as A- and B-chips appear,

<u>Initial chip breaking</u>, when A- and B-chips have disappeared, and the C-chip is being formed,

<u>Complete chip breaking</u>, when the C-chip has disappeared, and D- and/or E-chips are produced,

<u>Advanced chip breaking</u>, when F-chips (or a higher type) have superceded the E-chips.

In graphs and charts, relating to chip breaking, it will usually be possible to determine curves for the three significant stages, initial, complete and advanced chip breaking, see Figure 3. The recommended range of cutting conditions will then be represented by the area between the curves for complete chip breaking and for advanced chip breaking. By this choice there will be provided a safety margin to either side; to the side of No Chip Breaking the safety margin will be the range of Initial Chip Breaking, to the opposite side it will be the range until G-chips appear in quantity. The safety margins may be of varying width, sometimes they are even very narrow. See Figure 3.

Curves of this nature will show immediately what chip breaker dimensions are required for a certain job, and under what cutting conditions a certain chip breaker will work satisfactory or, at least, be acceptable. Referring again to Figure 3, cutting condition A (for example a certain feed, speed and depth of cut in a given material) will call for a chip breaker dimension C, and with this chip breaker it will give ideal chips, while cutting condition B will give ideal chips with chip breaker dimension D. The range of cutting conditions for satisfactory performance of chip breaker D is quite wide, although it does <u>not</u> include cutting condition A, whereas the satisfactory performance range for chip breaker C is narrow.

The degree of chip breaking at any given operation may be influenced by a large number of factors, such as material in work piece, and tool, cutting speed, feed and depth of cut, tool angles and tool shape, chip breaker form and dimensions, edge conditions, wet or dry cutting. Each of these factors may have influence, sometimes insignificant, sometimes very important. Of all the factors relating to the tool itself, it is essentially width and height of the chip breaker which determines the result, while of the operating factors the feed is the dominating one.

Analysis of chip flow through the chip breaker.

Chip breaker width and height, taken separately, are of no importance per se; the determining factor is the radius ρ_T (T stands for Tool) in the circle which can be inscribed in the chip breaker; this circle is called the chip flow circle and there is a definite and well defined relation between ρ_T and the feed at which a certain degree of chip breaking occurs, this feed being termed the chip breaking feed CBF.

We will analyze the action of a ground, parallel type chip breaker.

If the cut is taken with a plain tool (no chip breaker) we would in the general case get a chip with a slight curvature or no curvature at all. If a chip breaker is used the chip is bent plastically and leaves the tool with a considerable curvature defined by radius R_o, see Figure 4. We will ignore the possible effect of weight, inertia and air resistance, and R_o will be constant as long as the chip does not meet any obstruction.

There is a considerable pressure, including a friction, between the chip and the heel, so that the various radii of the chip within the chip breaker will be less than R_o, the difference being due to elastic deformation and therefore small compared with the plastic deformation which resulted in the permanent curvature R_o. We will, therefore, as an approximation, look at it as if we have a constant radius ρ_T (the chip flow circle radius) inside the chip breaker, and another radius R_o beyond the chip breaker, $\rho_T < R_o$.

ρ_T is a function of the geometry of the chip breaker

$$\rho_T = 1/2 \left(\frac{w^2}{h} + h \right)$$

where w and h are width and height of the chip breaker.

If the chip forms a helix with a small pitch, just slightly larger than the depth of cut, it may in many cases clear the shoulder of the work piece, but when it proceeds (see Fig. 5) it will hit the relief side of the tool, because $R_o > \rho_T$, a little below the cutting edge, and a force P will begin to build up, as the cutting process continues to feed the chip out of the chip breaker. A bending stress will be produced in the chip, having its maximum at A.

The analysis of this case is based upon the formula for the open elastic ring, see Figure 6. A set of forces P, P will produce an opening δ , determined by (2)

$$\delta = 3\pi \frac{PR_o^3}{EI} ,$$

where I is the moment of inertia of the cross section of the chip, and where δ is small. However in many cases break does not occur before the circle has expanded to a radius R considerably larger than R_o and in this case an integration is required to get the result. We get

$$P = \frac{1}{3} EI \left(\frac{1}{R_o^2} - \frac{1}{R^2} \right)$$

This result assumes that the chip retains circular shape, which is an approximation only.

Under the same assumption the bending stress at A is determined by

$$\sigma = \frac{M}{Z} = \frac{2PR}{Z} = \frac{1}{3} Et \frac{R^2-R_o^2}{RR_o^2}$$

or

$$\sigma = \frac{1}{3} Et \frac{R^2 - \rho_T^2}{R \rho_T^2}$$

by using t for the chip thickness and ignoring the difference between R_o and ρ_T. When σ reaches the ultimate stress for the chip material break will occur at A. When the break occurs without previous plastic bending, as assumed, the length of the broken chip will be πR and it will spring back to curvature R_o and its total angle will be $\pi \frac{R}{R_o}$, see Figure 8A. If $R = 2R_o$ we will get just the F-type , the full turn.

Generally, within the assumptions, the degree of chip breaking can be expressed by the ratio

$$c = \frac{R}{\rho_T}$$

which gives

$$t = \frac{3\sigma}{E} \frac{c}{c^2-1} \rho_T$$

or, if we put

$$t = \alpha f$$

$$f = \frac{3\sigma}{\alpha E} \frac{c}{c^2-1} \rho_T$$

which means, so far, a linear relation between the chip flow circle radius and the feed.

This simple procedure has been given as a simplified example of the analytical method of approach. Actually there are many complicating factors, such as: There may be friction at point B, see Figure 7B, so that A will shift its position, or the free end of the chip may be caught by some projection on the tool surface. The ultimate bending strength σ for the chip material may in all probability not be constant, but may be influenced by the work hardening of the material, by residual stresses in the chip and by its surface roughness. Finally the chip thickness may change with ρ_T.

The mechanism of chip breaking described here is far from the only one possible. There may be plastic deformation at A before break; in this case the broken chip may look as shown on Figure 8B. The chip may curl more, before break occurs, see Figure 9: it may obtain a curvature where there is lack of stability, or it may hit the tool after several turns have been formed: it may hit the work piece, or it may hit nothing at all, but curl freely until vibrations or the weight of the chip coil makes it break off. Without going into details it can be said that these factors, generally, are of such a nature that they will attempt to slightly increase the breaking tendency at the larger values of ρ_T, in other words, at larger ρ_T breaking will occur for lower values of f than indicated by the linear equation just found, and vice versa for smaller ρ_T. The relation will therefore be expressed by a parabola-like curve rather than by a straight line, see Figure 10.

This result has found its confirmation by tests. Figure 11 shows the relation between the chip flow circle radius ρ_T and the chip breaking feed CBF for steel AISI 4140, annealed, at a cutting speed of approx. 500 FPM, at 0.125" depth of cut, and with a rake angle of + 10° and a side cutting edge angle of 0°.

The observations were taken for a variety of values of width and height of the chip breakers, ranging from w = 0.095" to w = 0.205", from h = 0.0075" to h= 0.113" and $\frac{w}{h}$ from 1.0 to 13.44, and no significance was found relating to variation of w and h separately, nor to their ratio.

The curves are parabola, and the relation between chip flow circle radius ρ_T and chip breaking feed CBF can therefore be expressed by the equation

$$\rho_T = \text{constant} \times (\text{CBF})^2.$$

It is of interest to see that the plotted points indicate a curve which goes to zero at a small distance from the point of origin. This is easily explained by the fact that the chip flow circle does not start right at the edge, but at a distance from the edge, so the effective width of the chip breaker is actually a little less then w, see Figure 12. This small deviation from the assumptions has, of course, only a significant effect on the smaller values of w and ρ_T.

Analysis of Effect of Depth of Cut

For heavy cuts the effect on the Chip Breaking Feed, of a smaller change in the depth of cut is usually negligible; as the depth of cut is essentially reduced, chip breaking becomes more difficult, that is, CBF goes up.

This can be explained as an effect of a variation in the direction of the chip flow over the face of the tool, (see Figure 13). With a large depth of cut the direction of chip flow will be approximately perpendicular to the cutting edge. With less and less depth of cut, the direction of chip flow will change, due to the effect of the nose radius.

Assume a chip breaker with width w, height h and

$$\rho_T = 1/2 \left(\frac{w^2}{h} + h\right) = \text{approx. } \frac{w^2}{2h}$$

Assume further chip flow in a direction under an angle θ with the tool edge, then the effective width of the chip breaker is

$$w_e = \frac{w}{\sin \theta}$$

and the effective radius ρ_{TE} in the chip flow circle in this direction is

$$\rho_{TE} = \frac{w_e^2}{2h} = \frac{\rho_T}{\sin^2 \theta}$$

Assume the radius-relation for perpendicular flow is

$$\rho_T = \alpha (\text{CBF})^2$$

and for flow in the direction under angle θ the relation is

$$\rho_{TE} = \alpha (\text{CBF})_1^2$$

then

$$(\text{CBF})_1 = \frac{\text{CBF}}{\sin\theta}$$

The variation in $(CBF)_1$ as effected by a change in depth of cut, should therefore be as the variation of $\frac{1}{\sin\theta}$.

A method for determination of θ was proposed by Friedrich (3) and some applications made by Littman and Newmann (4). By this method the author found the values given in Table No. 1. When plotted over $\frac{d}{r}$, where r is the nose radius of the tool, they give a hyperbola-like curve, see Fig. 14.

In Figure 15 is shown an experimental curve for Chip Breaking Feed, also plotted over the ratio $\frac{d}{r}$. The agreement seems very satisfactory.

Conclusion

1. The chip breaking process can be analyzed by a study of the chip flow in the three directions in space.

2. For large depths of cut the significant factor is the flow in a plane perpendicular to the tool face.

3. The determining factors are, in this case, the radius ρ_T in the chip flow circle, and the feed.

4. There is a specific relation between the chip flow circle radius ρ_T and the Chip Breaking Feed CBF. This relation is with good approximation a parabola.

5. For small depths of cut the direction of the chip flow across the tool face also becomes significant for the chip breaking. This direction can be determined by known methods.

6. The determining factors for the direction of the chip flow across the tool face is the ratio between depth of cut and tool nose radius.

7. When Chip Breaking Feed CBF is plotted over the ratio $\frac{d}{r}$ a hyperbola-like curve is the result.

8. For a given material, and a given depth of cut, chip breaking is completely determined by

   (a) the chip flow circle radius
   (b) the parabola-like curve for the relation CBF-chip flow circle radius.
   (c) the hyperbola-like curve over the ratio $\frac{d}{r}$.

Acknowledgements

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TABLE NO. 1

The function $\frac{1}{\sin\theta}$ for various values of depth of cut d and tool nose radius r.

$r=\frac{1}{16}''$				$r=\frac{1}{8}''$			
d	$\frac{d}{r}$	θ	$\frac{1}{\sin\theta}$	d	$\frac{d}{r}$	θ	$\frac{1}{\sin\theta}$
$\frac{1}{16}''$	1	50.8°	1.29	$\frac{1}{16}''$	1/2	33.9°	1.79
$\frac{1}{8}''$	2	71.4°	1.053	$\frac{1}{8}''$	1	53.7°	1.24
$\frac{3}{16}''$	3	78.0°	1.021	$\frac{3}{16}''$	1 1/2	62.7°	1.12
$\frac{1}{4}''$	4	81.2°	1.01	$\frac{1}{4}''$	2	66.5°	1.09

* * * * * * * * * * *

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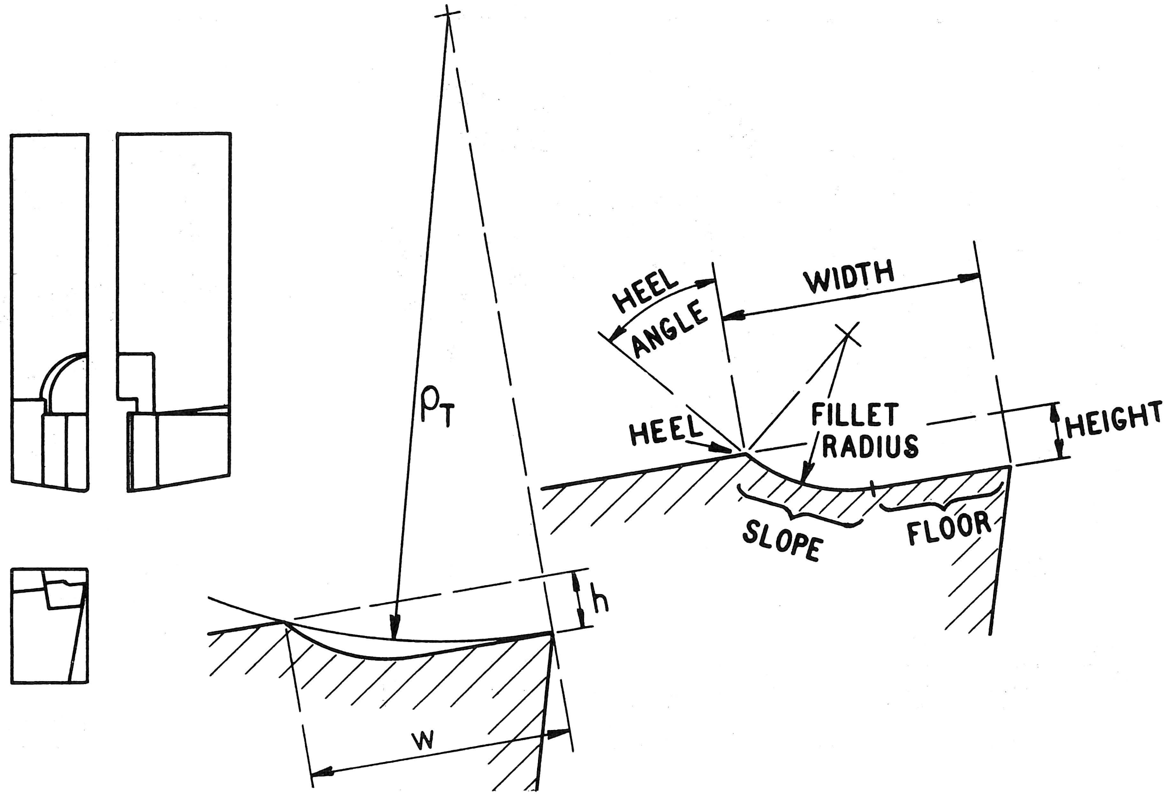

Figure 1. Lathe Tool with Ground, Parallel, Step Type of Chip Breaker. Elements of the Chip Breaker.

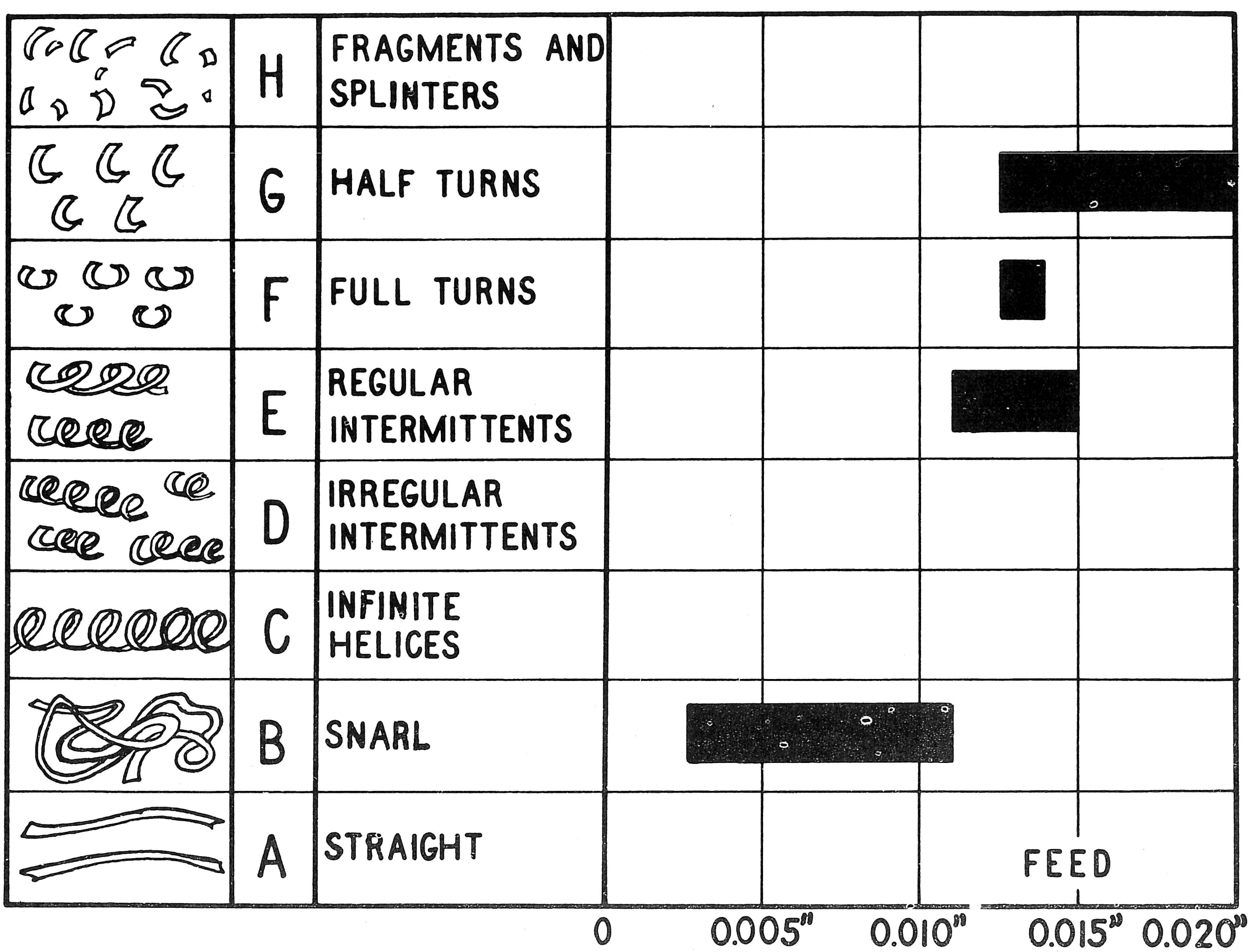

Figure 2. Chip Classification. Relation between Feed and Types of Chips. Black Areas Indicate where Chips Occur.

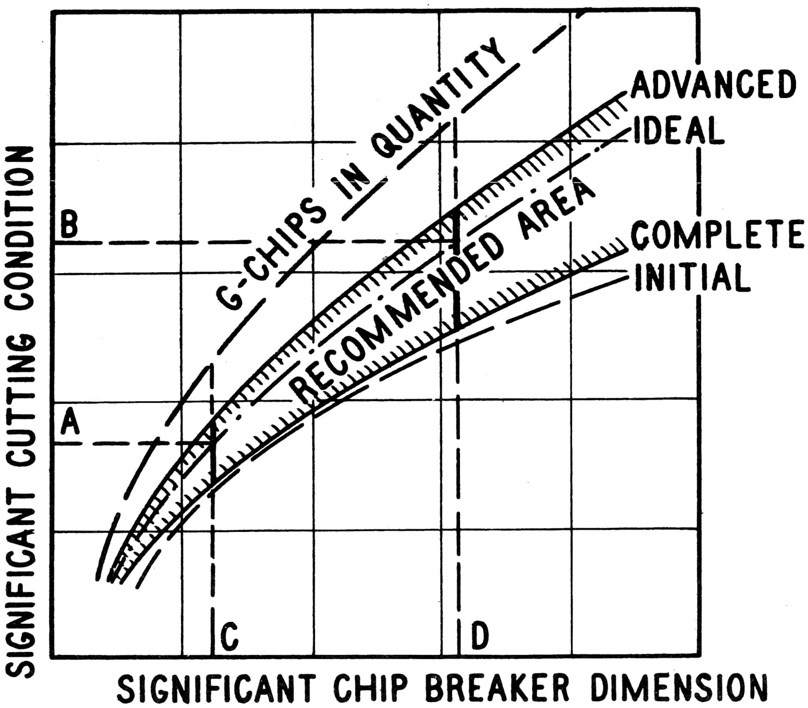

Figure 3. Principal Chart for Chip Breaking.

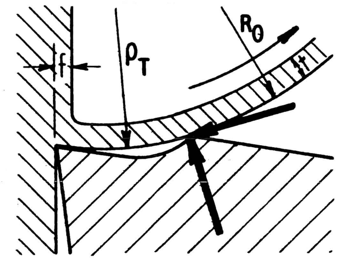

Figure 4. Flow of Chip over the Chip Breaker.

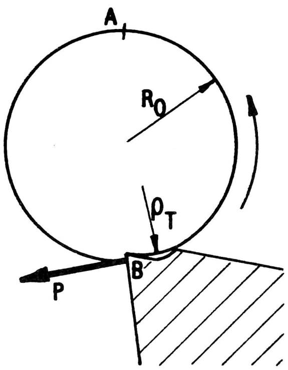

Figure 5. Basic First Stage in Chip Breaking.

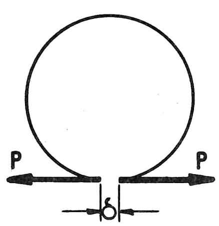

Figure 6. Open Elastic Ring with Load and Deformation.

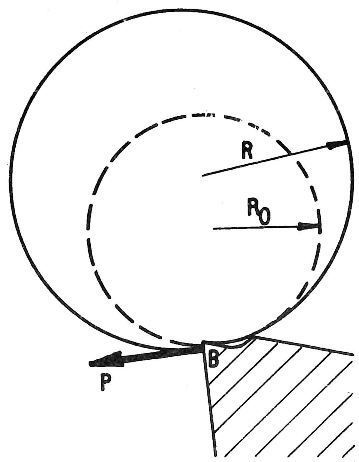

Figure 7A. Chip Ring with Large Deformation before Break.

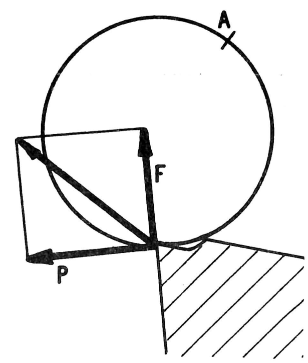

Figure 7B. Normal and Frictional Force on Free End of Chip at Point of Impact with Tool.

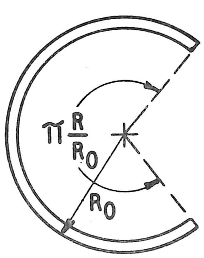

Figure 8A. Broken Chip after Spring-Back.

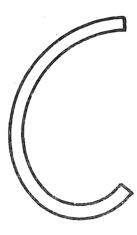

Figure 8B. Broken Chip after Plastic Deformation.

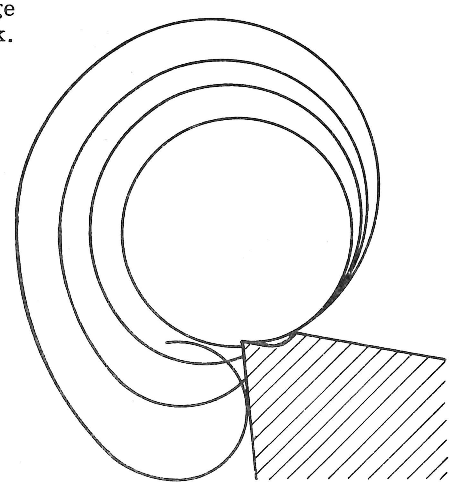

Figure 9. Stages in Chip Deformation.

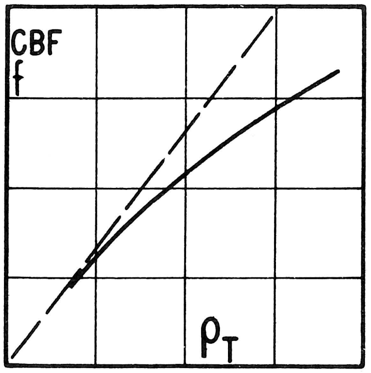

Figure 10. The Basic Relationship for Chip Breaking.

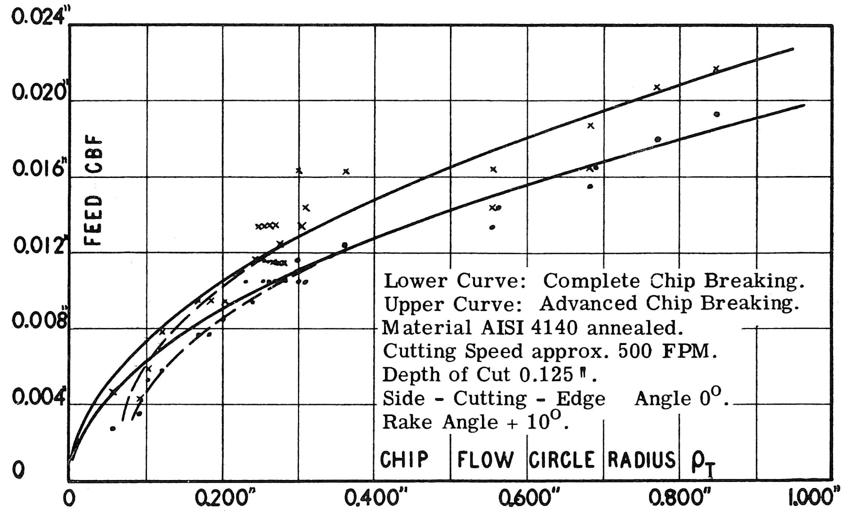

Figure 11. Chip Breaking in Relation to Feed.

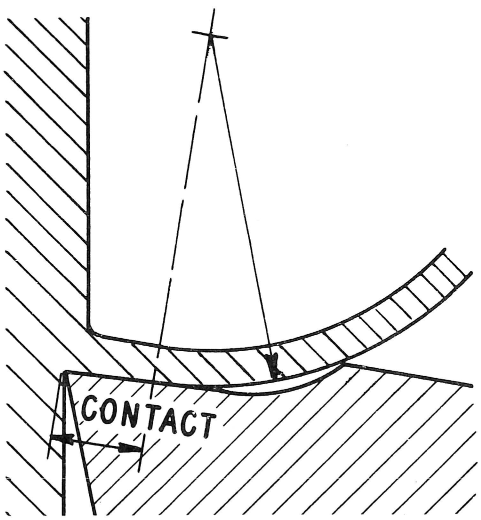

Figure 12. Condition of Contact between Chip and Tool.

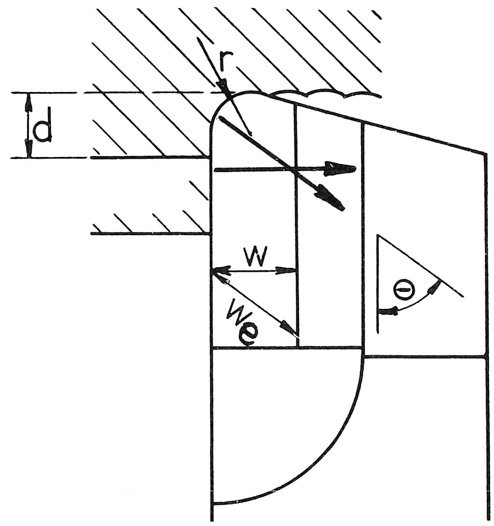

Figure 13. Variation in Direction of Chip Flow for different Depths of cut.

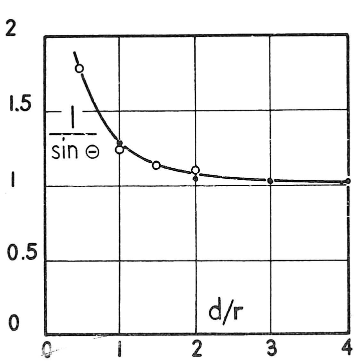

Figure 14. Variation of the Function 1/sin θ with Ratio d/r.

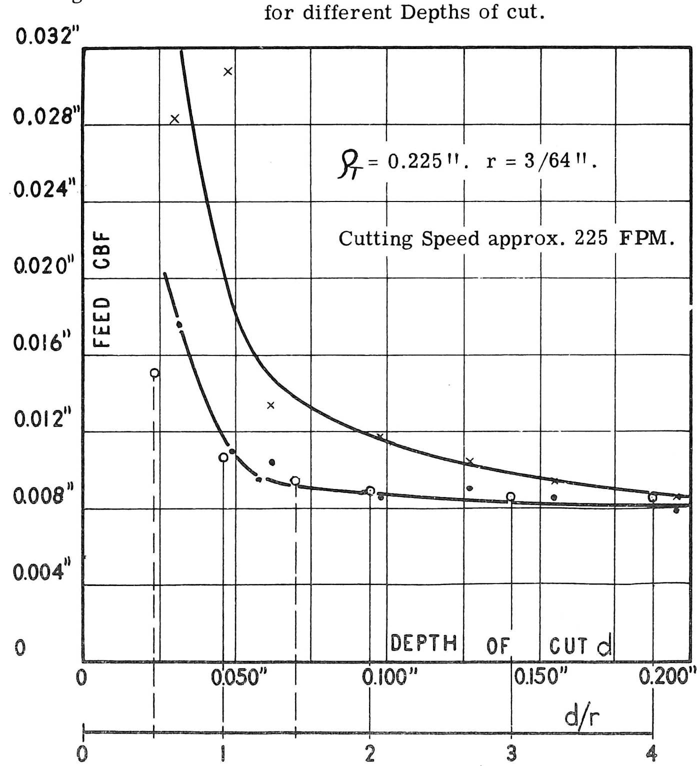

Figure 15. Chip Breaking in Relation to Depth of Cut. Material and Tool Angles as For Figure 11.

SMALL BUSINESS ADMINISTRATION

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No. 36

ECONOMICAL CHIP BREAKERS FOR MACHINING STEEL

By *Erik K. Henriksen,* University of Missouri, Columbia, Missouri

The chip breaker is a device developed as a result of the introduction of new tool materials, such as sintered carbides and cast alloys, which permit cutting speeds from 3 to 10 times higher than were formerly possible.

In the era of high-speed steel tools, chips presented no difficulty. With carbides and cast alloys, however, chip control and chip handling have become problems. The amount (by weight and by volume) of chips is larger, they move faster, and their temperature is much higher. Further, since they have extremely sharp and toothed edges, they have frequently been the cause of severe accidents, producing cuts and burns that are difficult to heal.

In addition, and these are the most troublesome features of the chips, they are tough, stringy, and do not curl, but either shoot straight out from the tool, or are captured by the tool holder and wrap themselves around tool and work, thus obstructing the flow of coolant, so that the tool alternately becomes overheated and quenched. In short, they are a danger to the tool, a menace to the operator, and a source of trouble for the janitor. Long and

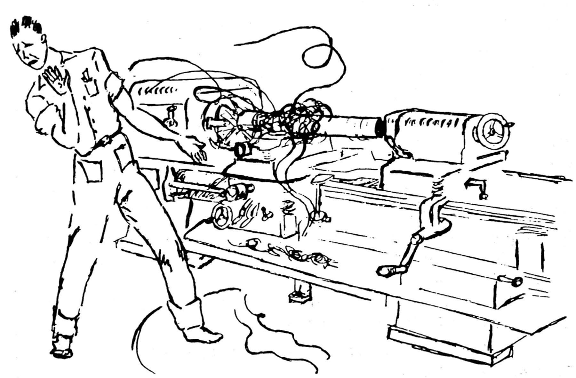

Figure 1.--The menace. (Courtesy Wm. J. Stracke.)

snarling chips are equally objectionable from the viewpoints of safety and of economy. With snarling and stringy chips, the cutting oil is only partly recovered in the chip extractor ("chip wringer"), and the efficiency and capacity of the chip crusher (disintegrator) is reduced. The commercial scrap value of chips also is influenced by their size; at present, scrap in the form of "shoveling chips" is worth approximately \$3.00 to \$6.00 more than "long chips."

The handling, storage, and shipping costs are increased manyfold by long, stringy, and snarling chips. Table No. 1 may serve as a guide for estimating the necessary capacity of tote boxes, conveyors, and shipping containers for chips.

Table 1.—VOLUME OF CHIPS OF VARIOUS TYPES AND MATERIALS

	Type of chip					
	Straight	Snarling	Infinite helices	Partly broken	Well broken	Milling machine chips
Material	Volume in cubic feet per ton					
Steel....	200-400	120-200	50-120	20-50	12-20	12-14
Titanium	450-900	250-450	100-250	45-100	25-45	25-30
Aluminum	600-1200	350-600	150-350	60-150	35-60	35-42
Magnesium	900-1800	500-900	200-500	90-200	50-90	50-60

CHIP CONTROL

The remedy for the troubles discussed in the foregoing section is to curl the chip. Primarily, this has the effect of getting the chip flow under control, thereby making it possible to direct the chip flow in such a manner that the curling chip breaks up in fairly regular pieces of almost any desired length.

The principle of the chip breaker action was clearly illustrated by the author's early work on this problem. Demonstrations of carbide tools in a Copenhagen machine shop disclosed the need for more specific information on chip breaker design than was available in literature at that time (1947-48), and consequently the author made a series of tests in the Machine Tool Laboratory of the Royal Technical University of Denmark.

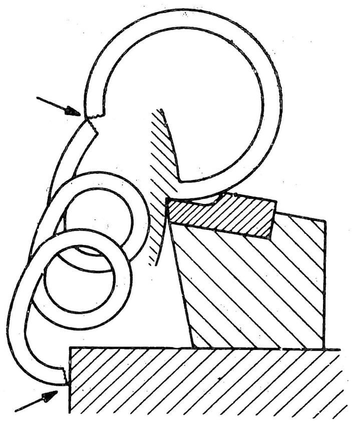

Figure 2.—The remedy. Cross section of tool with ground chip breaker, showing how curling chip hits obstacle (arrow) and breaks (arrow).

PRELIMINARY OBSERVATIONS

It was first assumed that the width or the height, or both, of a chip breaker would determine its action and performance; however, it was found that two particular chip breakers always gave very similar results, although their dimensions were entirely different. If the one chip breaker, at a certain speed, feed, and depth of cut, would break the chips satisfactorily, the other one would do the same and produce very similar chips; and if the one chip breaker would fail to break the chips, the other one would fail likewise. A large-scale drawing, with the two chip breaker profiles superimposed, provided the answer: *Both chip breakers determined the same circle of chip flow* (see Fig. 3). Once this simple principle was established, it was confirmed in subsequent tests without exception.

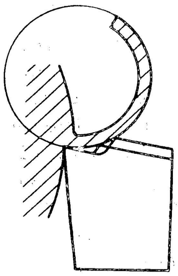

Figure 3.—Principle of the chip flow circle. Same chip flow circle on two chip breakers of different width and height.

FACTORS WHICH DETERMINE BREAKER DESIGN

Simple geometry (see Fig. 4) leads to the following relation between the width w, and height h, of the chip breaker, and the radius B in the chip flow circle (B for Bending,

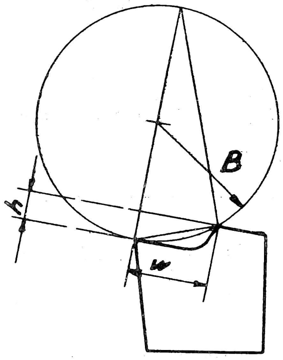

Figure 4.—Geometry of the chip flow circle.

since the chip breaker bends and curls the chip, whereas the actual breaking is a secondary effect):

$$B = \frac{w^2}{2h} + \frac{h}{2}$$

Corresponding values of B, w and h can be taken from Table No. 3 or from Fig. 5. For practical shop use and in order to measure directly from the drawing, it is recommended to reproduce the figure to scale 1/32" = 0.001" or 1/16" = 0.001". This is also a convenience in shops where chip breakers are inspected in an optical comparator.

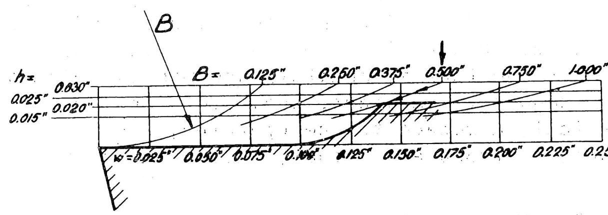

Figure 5.—Chart for conversion of chip breaker dimensions.

Feed is the major factor in determining the correct value of radius B. The following simple test will demonstrate this, and at the same time give a clear picture of the possibilities and limitations of a given chip breaker.

Prepare a tool with a side-cutting-edge angle of 0° (a "no-lead-angle" tool), and with chip breaker dimensions w = 0.121" and h = 0.020", which gives B = 0.375" (see Table No. 3 or Fig. 5). Run the test on a low or medium carbon steel with a cutting speed of approximately 400 feet per minute and 1/8" depth of cut. Start with a feed of 0.005" and increase the feed in steps until or beyond 0.025". Collect typical samples of chips from each step, and line the chips up with the corresponding feed.

The results of such a test, made with two different chip breakers, are shown in Figure 6, together with a classification of the chips produced.

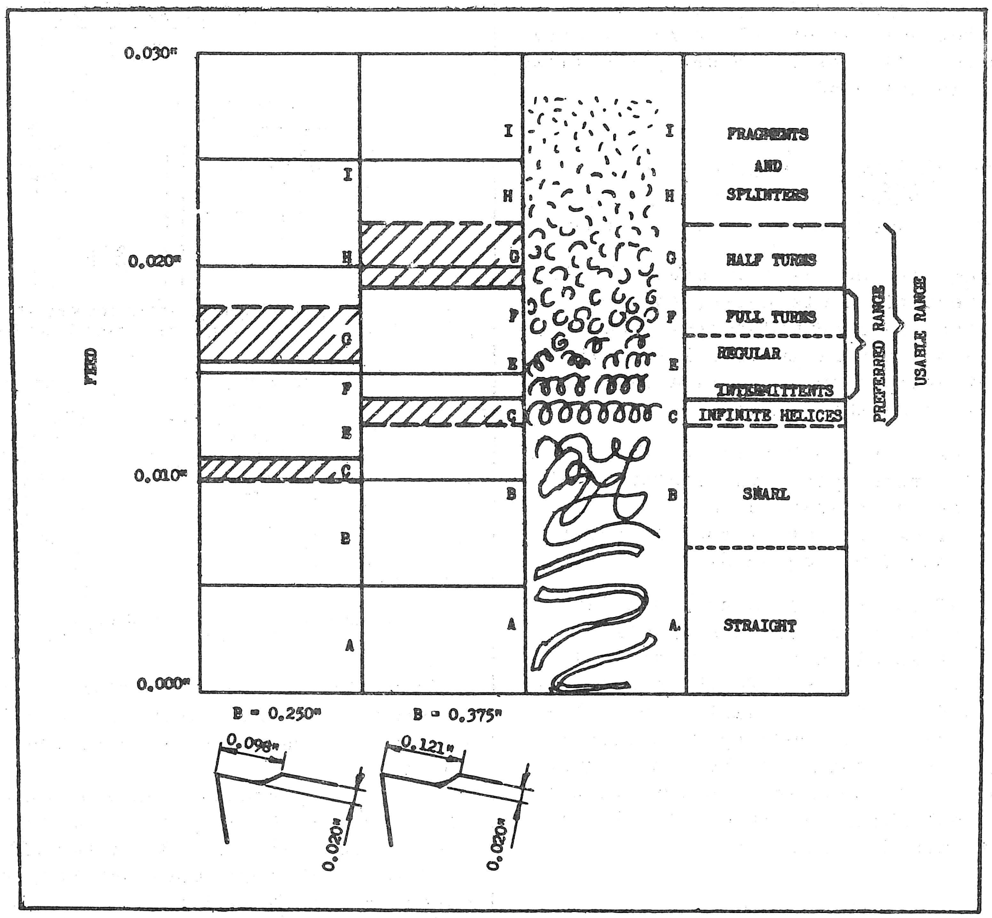

Figure 6.—Chip classification for two chip breakers of different radius B.

Simple as it is, this little experiment shows in a nutshell the whole basic story of chip breaking, and from it the following conclusions can be drawn:

(a) The degree of chip breaking depends upon the feed and the Radius B in the chip flow circle;

(b) A given chip breaker can be made to produce any type of chip by varying the feed at which it is used;

(c) An increase in feed gives stronger chip breaking;

(d) A decrease in feed gives weaker chip breaking;

(e) A certain type of chip is produced within a certain limited range of feeds;

(f) A "tighter" chip breaker (smaller chip flow circle radius B) will produce a certain type of chip within a lower feed range than a more "open" chip breaker (larger chip flow circle B); in other words a tighter chip breaker has a stronger chip-breaking action.

The preferred types of chips are the regular intermittents and the full turns (including three-quarter turns). These chips are of the "shoveling size"; they are convenient and safe to handle; they do not increase the tool load to any considerable extent, and consequently they do not endanger economical tool life. Mass production tools should always have their chip breakers designed to produce this type of broken chips.

Job Shop Tools.—In shops for small lot and single job production, the cutting tools must be of a general purpose character and cannot be designed for such narrow limits of feed; therefore it becomes desirable to expand the range of application of each chip breaker. The infinite helix, although unbroken, is frequently an acceptable chip, because it is well under control and can easily be guided into the chip pan of the machine. The half turns ("half moons") are convenient to handle, and as long as they appear in mixture with larger chips they do not reduce tool life more than is acceptable on short-run jobs.

For general purpose tools, therefore, there is a "usable range" of feeds (shown on Figure 6) which, normally, is up to twice as large as the "preferred range."

The upper limit for chip breaking is signified by the formation of "overbroken" chips: half turns in larger quantities, fragments, splinters, and "tight chips" (Figure 7). These are three-quarter or full turns, partly folded together with one sharp bend, sometimes with a crack in the bend.

Figure 7.—"Tight" (overbroken) chips, a danger signal.

Overbreaking of the chips creates vibration and a characteristic acute noise, and increases the tool load considerably. The result is a sharp decrease in tool life. The appearance of overbroken chips is a serious danger signal since they signify:

(a) that the chip breaker is too tight for the feed, and a more open chip breaker should be selected for the operation, or

(b) that a large crater is worn in the tool, and the tool should be reground.

Cratering of the tool is also indicated by a *very* closely curled chip, looking almost like a flexible metal tube. The chip pattern may be vacillating back and forth between the "tube chip" and the full or half turns. The chip has an unpleasant tendency to strike the cutting edge just outside of the cut (Figure 8) and nick it. As soon as this type of chip appears the tool should be reground and the chip breaker opened up slightly.

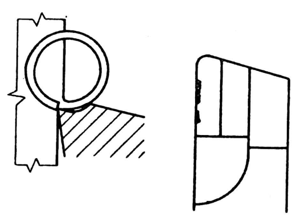

Figure 8.—Damage to cutting edge by tubular chip.

INFLUENCE OF CUTTING CONDITIONS

Cutting conditions, other than feed, influence the chip breaking in the following way:

When a tool is ground with a side-cutting-edge angle (SCEA, lead angle), the thickness of the cut becomes less than the feed (Figure 9). This has the same effect as a reduced feed, i.e., the chip breaking is weaker.

In a cut of a substantial depth, the chip flow will be practically perpendicular to the the cutting edge and, normally, perpendicular to the chip breaker. With a decrease in the depth of cut the chip flow will change its direction (Figure 10), and the chip will strike the chip breaker at a reduced angle. This has the same effect as widening the chip breaker, and will therefore weaken the chip breaking.

Actual chip thickness is somewhat greater than the thickness of the cut, due to metal

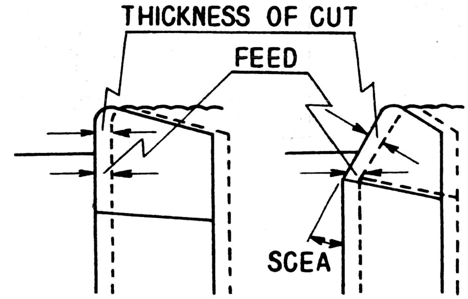

Figure 9.—Side-cutting-edge angle reduces thickenss of cut in relation to feed. Formula: Thickness of cut = feed x cos SCEA.

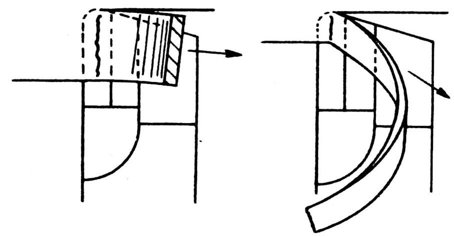

Figure 10.—Variation of depth of cut changes direction of chip flow.

deformation in the shear plane ahead of the cutting edge. The variation in chip thickness depends, among other factors, upon the cutting speed.

At cutting speeds from 400 FPM and up the thickness of the chip can, for our purpose, be considered constant. Below 400 FPM the chip becomes thicker and more brittle, which gives stronger chip breaking.

Within normal practical limits a change in rake angle does not seem to have any effect on the chip breaking.

The various cutting conditions listed above can all be taken care of by determining the chip breaker dimensions on the basis of a "modified feed" instead of the real feed. The modified feed is computed from the real feed by means of the multipliers from Table No. 2, or by using the wind-mill diagram in Fig. 11. The complete method will be explained later in connection with a numerical example.

Table 2.—MULTIPLIERS FOR COMPUTING MODIFIED FEED

For side-cutting-edge angle	Small 0°-15°	Medium 30°	Medium 45°	Large 60°
multiply feed by	1	0.875	0.76	0.56
For cutting speed	Low 200-299 FPM	Medium 300-399 FPM		High 400-1000 FPM
multiply feed by	1.113	1.05		1
For depth of cut	Small 0.060"-0.099"	Average 0.100"-0.299"		Large 0.300"-0.750"
multiply feed by	0.77	1		0.87

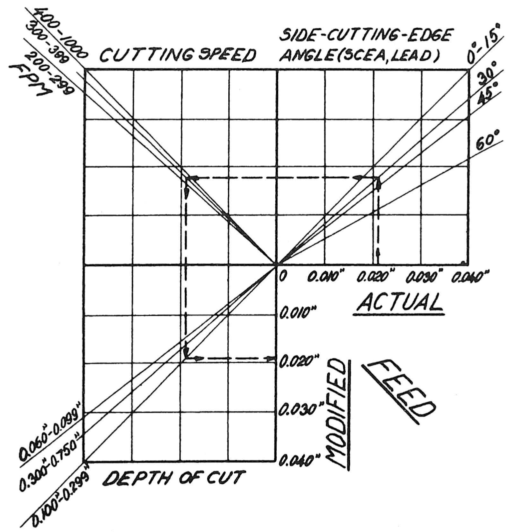

Figure 11.—Multipliers for conversion of "actual feed" to "modified feed."

Effects of Different Materials

Materials respond differently to chip breaking. This was confirmed by the author's experimental work at Cornell University sponsored by The National Machine Tool Builders' Association, on three representative grades of steel. The results are summarized on the graphs, Figures 12, 13, and 14, and tabulated in Table No. 3.

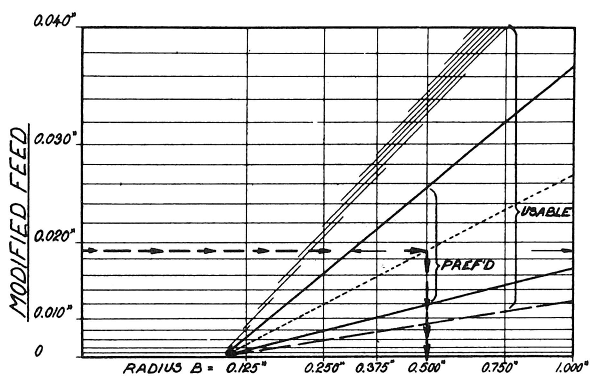

Figure 12.—"Preferred" and "Usable" feed ranges as related to radius B of chip breaker. Free-cutting Steel, B-1112: 55,000-75,000 psi Tensile Strength, 35,000-50,000 psi Yield Point, 126-150 BHN.

In the graphs and the table the preferred and the usable ranges of feed are plotted and listed in relation to the various values of

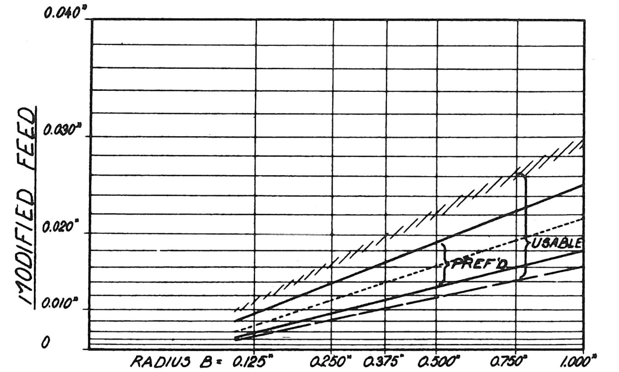

Figure 13.—"Preferred" and "Usable" feed ranges as related to radius B of chip breaker. Plain Carbon Steel, C 1015: 47,000-60,000 psi Tensile Strength, 30,000-40,000 psi Yield Point, 101-140 BHN.

the chip flow circle radius B of the chip breaker (compare also Figure 6). A vertical line for a fixed value of B shows the feeds for which this particular chip breaker can be used. A horizontal line for a fixed value of the feed shows which sizes of chip breakers can be used with this feed. A dotted middle line is drawn through each of the areas for preferred chip breaking. This line represents the "middle of the road" conditions for chip breaking, because it provides the largest possible margin of safety in either direction, with respect to the unavoidable variations, errors in chip breaker dimensions, changes in the conditions of the cutting edge, and so on.

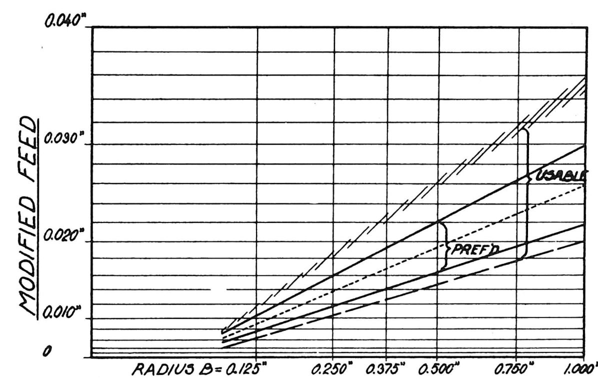

Figure 14.—"Preferred" and "Usable" feed ranges as related to radius B of chip breaker. Alloy Steel, annealed, 4140: 85,000-105,000 psi Tensile Strength, 55,000-75,000 psi Yield Point, 170-223 BHN.

Dimensions of Chip Breakers

Reasonable dimensions of the chip breaker in proportion to the over-all size of the cut-

Table 3.—CHIP BREAKER DIMENSIONS WITH CORRESPONDING PREFERRED AND USABLE FEED RANGES

Radius B	Chip-breaker Width w	Chip-breaker Height h	Feed ranges for— Free-cutting steel B 1112	Feed ranges for— Low-carbon steel C 1015	Feed ranges for— Alloy steel 4140
0.125"	0.059" 0.068" 0.075" 0.081"	0.015" 0.020" 0.025" 0.030"	PREFERRED 0.003"-0.006" 0.002"-0.009" USABLE	PREFERRED 0.006"-0.009" 0.005"-0.011" USABLE	PREFERRED 0.007"-0.010" 0.006"-0.012" USABLE
0.250"	0.085" 0.098" 0.109" 0.119"	0.015" 0.020" 0.025" 0.030"	PREFERRED 0.008"-0.016" 0.006"-0.021" USABLE	PREFERRED 0.009"-0.014" 0.008"-0.016" USABLE	PREFERRED 0.012"-0.016" 0.010"-0.018" USABLE
0.375"	0.105" 0.121" 0.135" 0.147"	0.015" 0.020" 0.025" 0.030"	PREFERRED 0.010"-0.021" 0.008"-0.028" USABLE	PREFERRED 0.011"-0.017" 0.010"-0.020" USABLE	PREFERRED 0.014"-0.019" 0.013"-0.023" USABLE
0.500"	0.121" 0.140" 0.156" 0.171"	0.015" 0.020" 0.025" 0.030"	PREFERRED 0.012"-0.026" 0.009"-0.034" USABLE	PREFERRED 0.013"-0.019" 0.012"-0.022" USABLE	PREFERRED 0.016"-0.026" 0.015"-0.022" USABLE
0.750"	0.149" 0.172" 0.192" 0.210"	0.015" 0.020" 0.025" 0.030"	PREFERRED 0.015"-0.032" 0.011"-0.042" USABLE	PREFERRED 0.016"-0.023" 0.014"-0.027" USABLE	PREFERRED 0.019"-0.027" 0.018"-0.032" USABLE
1.000"	0.173" 0.199" 0.222" 0.243"	0.015" 0.020" 0.025" 0.030"	PREFERRED 0.017"-0.037" 0.012"-0.050" USABLE	PREFERRED 0.018"-0.025 0.016"-0.030" USABLE	PREFERRED 0.022"-0.030" 0.020"-0.035" USABLE

ting tool are obtained, when the height h of the chip breaker is taken from Table No. 4.

Once the height h is selected it determines not only the width w, that is necessary in order to arrive at the desired Radius B for breaking the chip, but also the fillet radius R, that is necessary for smooth chip flow.

The fillet radius R is the same as the radius on the corner of the grinding wheel, and in combination with the height h it determines the heel angle HA (See Figure 15), which in turn is responsible for the smooth flow of the chip over the heel H of the chip breaker. If the fillet radius R is too small, then the heel angle becomes too small, i.e., the slope of the chip breaker becomes too steep, and the result is overbreaking of the chip, crowding

Table 4.—CHIP BREAKER HEIGHT IN RELATION TO SIZE OF TOOL SHANK

Height of tool shank...	Less than 3/4"	3/4"-7/8"	More than 7/8"
Height of chip breaker......	0.015"-0.020"	0.020"-0.025"	0.025"-0.030"

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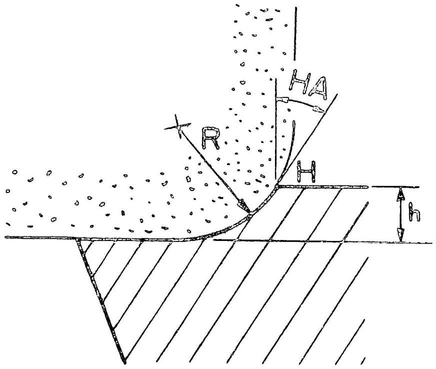


Figure 15.—Grinding the chip breaker. Formula: $\sin HA = 1 - \frac{h}{R}$

of the chip breaker, and almost instantaneously a completely ruined tool (See Figure 16).

This particular cause of chip breaker failure is probably the most common of them all, and probably *more tools are destroyed this way than by any other error in the design and grinding of chip breakers.*

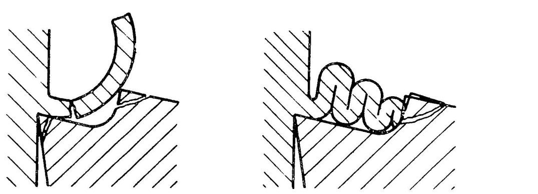


Figure 16.—An incorrect chip breaker becomes a tool breaker.

For good chip flow and efficient chip breaking at the same time, the heel angle HA, Fig. 15, should be between 35° and 50°, and this is accomplished when the fillet radius R is kept between the limits given in Table No. 5. The corner radius on the grinding wheel can be checked accurately enough by means of a radius gage.

Table 5.—RECOMMENDED LIMITS FOR FILLET RADIUS R AND CORNER RADIUS ON GRINDING WHEEL

Chip breaker height........h..	0.015"	0.020"
Limits for fillet radius...R..	0.035"-0.065"	0.050"-0.085"
Chip breaker height........h..	0.025"	0.030"
Limits for fillet radius...R..	0.060"-0.100"	0.070"-0.125"

Diamond Wheels

It is very fortunate that the conditions for smooth chip flow coincide with some measures for saving diamond wheel material.

A diamond wheel should *not* be dressed down to a sharp corner. When the wheel is worn to the upper limit of the corner radius it should be dressed down only so far that the periphery is straight, and the lower limit of the corner radius can be reproduced. The saving of diamond wheel material by this method is close to 50 percent or more.

Factory-ground and Clamped Chip Breakers

Other methods for saving diamond material are the use of factory-ground chip breakers (Figures 17 and 18), and clamped chip breakers (Figures 20 and 21).

The factory-ground chip breaker in Figures 17 and 18 is of the angular type, that is, the heel of the chip breaker is no longer parallel with the cutting edge. The effective width w of the chip breaker is measured at the tip of the tool, and can be increased or decreased by grinding off the end-cutting-edge or the side-cutting-edge, respectively.

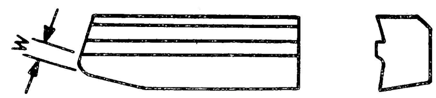


Figure 17.—Carbide tip with factory-ground angular chip breaker. (Courtesy Kennametal Inc., Latrobe, Pa.)

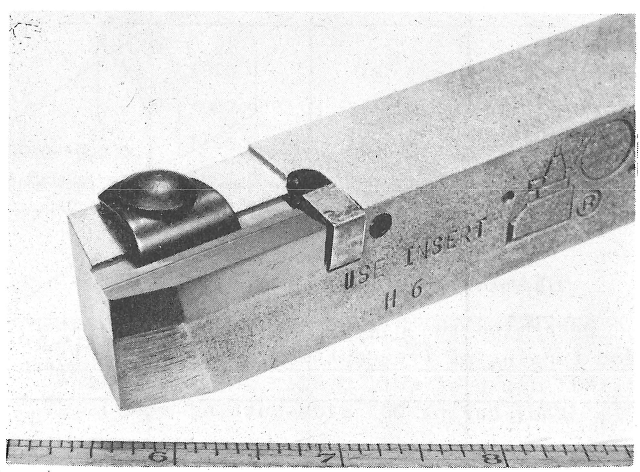
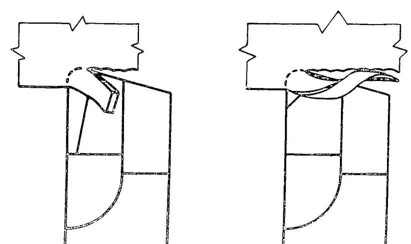


Figure 18.—Kennemetal BRH-16 holder with HS insert incorporating permanent chip breaker ("factory-ground"). (Courtesy Kennametal Inc.)

A different type of angular chip breaker, with the opening in the opposite direction, is shown in Figure 19A. This type does not have



A B

Figure 19.—Angular chip breaker used for fine cuts.

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the same advantage as the one in Figure 17, but is recommended for fine cuts, where the parallel type may fail. The angle should not be larger than 8° - 15°; otherwise, the chip may be thrown off to the right and damage the finished surface (See Figure 19B).

The clamped chip breaker (sometimes called a "mechanical" chip breaker), as shown in Figures 20 and 21, has no groove ground into the tool. It consists of a beveled block, adjustable in relation to the cutting edge, and *very* securely clamped, so that it cannot be moved out of position by the pressure from the chip. Furthermore, there should be no gap between the block and the tool face. For high-speed cutting of steel the front of the block must be carbide or cast alloy. Any softer material will wear out rapidly.

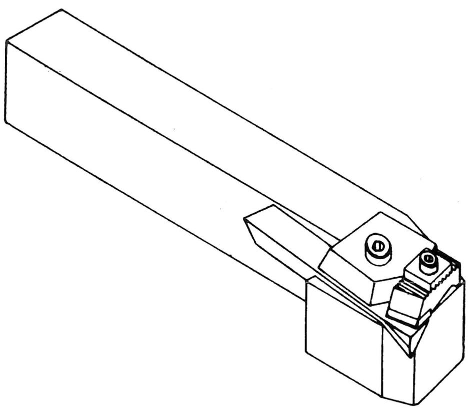

Figure 20.—Everede BX-L tool holder with triangular tool bit and adjustable clamped chip breaker. (Courtesy Everede Tool Company, Chicago, Ill.)

EXAMPLE OF CHIP BREAKER DESIGN

Determine the dimensions of a chip breaker for turning of free-cutting steel at 350 FPM, 0.150" depth of cut, 0.021" feed and with a 3/4" tool having 30° side-cutting-edge angle.

Step 1A. Use Table No. 2. The data given above determine the following single multipliers:

30° SCEA...............	0.875
350 FPM cutting speed..	1.05
0.150" depth of cut....	1
Total multiplier.......	0.875 × 1.05 × 1 = 0.92
Modified feed..........	0.021 × 0.92 = 0.019"

or **Step 1B.** Use Figure 11. Start at 0.021" actual feed, go up, meet line for 30° SCEA, go to the left, meet line for 300-399 FPM, go down, meet line for 0.100"-0.299" depth of cut, go to the right. Read 0.019" modified feed.

Step 2A. Use Table No. 3. Go down through column for free-cutting steel. The modified feed of 0.019" is found within the preferred range for the following values of radius B: 0.375", 0.500", 0.750", and 1.000"; but 0.500" is the best choice, since the feed of 0.019" is in the middle of the corresponding preferred range 0.012"-0.026".

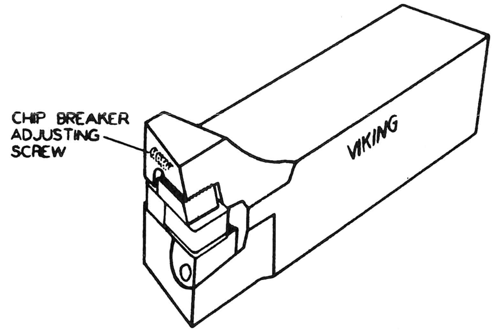

Figure 21.—Viking Type RK-BV straight turning tool with adjustable clamped chip breaker. (Courtesy The Viking Tool Co., Shelton, Conn.)

Or **Step 2B.** Use Figure 12. Start at 0.019" on the vertical axis. Go to the right. Enter "preferred range" at approximately B = 0.300", and meet the middle line at B = 0.500".

Any chip breaker with radius B from 0.300" to a little over 1.000" will do the job, but the one with B = 0.500" is the best choice.

Step 3. Use Table No. 4. For a 3/4" tool the height h can be taken at 0.020".

Step 4A. Use Table No. 3 again. Enter at B = 0.500". A height h of 0.020" requires a width w of 0.140".

or **Step 4B.** Use Fig. 5. Follow curve for B = 0.500". Meet h = 0.020" at approximately w = 0.140".

Step 5. Use Table No. 5. A height h of 0.020" requires that the corner radius on the grinding wheel should be between 0.050" and 0.085".

Solution: Chip breaker height....... 0.020"
Chip breaker width........ 0.140"
Radius on grinding wheel.. 0.050" - 0.085"

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Sources of additional useful data on the operations discussed in this Aid are contained in a carefully selected bibliography. Copies of this free bibliography may be obtained upon request directed to the Managerial Assistance Division, Small Business Administration, Washington 25, D. C. Ask for Bibliography TA 35 B.

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