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ECONOMIC TRADEOFFS IN DEBURRING

PDO 6984405, Topical Report

L. K. Gillespie, Project Leader

Published September 1976

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Prepared for the United States Energy
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Bendix Kansas City Division

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Topical Report

Technical Communications Bendix Kansas City Division

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The reliability of small precision mechanisms depends on the production of burr-free, sharp-edged parts. An investigation was conducted to determine how these requirements could best be maintained. The study included investigating the capabilities of the 24 major deburring processes and finding other techniques for minimizing burr-related problems and assuring sharp-edged parts. It has been concluded that four approaches can be used to provide the required quality: prevent burrs from forming; minimize burr size by proper machining conditions; design parts to minimize deburring problems; and improve existing deburring techniques by defining and increasing capabilities.

WPC-dvh

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SUMMARY

Component parts of small precision mechanisms typically require nearly sharp edges to assure reliable operation. A burr-free condition also is needed to minimize the chance of a loose burr jamming of the mechanism. In the past, the reliable removal of machining burrs and the assurance of part-edge sharpness have dictated that deburring be done only by hand, which is inherently time-consuming and operator-variable.

Small burrs are easily removed by many deburring processes. Because the repeatability of burr removal and the time required for removal are directly related to burr size, this study was initiated to determine how repeatable deburring could be achieved in minimum time. To meet this objective, the capabilities of the 24 major deburring processes and other techniques for minimizing deburring problems were analyzed. This report presents the results of those analyses.

Specifically, this report summarizes how machining conditions affect burr size and describes burr prevention approaches and the effect of burr size on deburring processes. Manufacturing and design approaches used in minimizing burr problems are described, and the economics of changing machining and deburring conditions are summarized. Burr standards are discussed as are areas deserving additional study.

DISCUSSION

SCOPE AND PURPOSE

The objective of this study was to define conditions which minimize deburring costs. Specifically, this study identifies the economics of the most widely used deburring processes, defines specific deburring approaches which should be used whenever possible, identifies tradeoffs between metal cutting rates and deburring time, and illustrates machining practices which minimize deburring costs.

PRIOR WORK

This is the first Bendix Kansas City report to describe in depth the economics of alternative approaches to deburring. Previous reports[1-5] presented some of the facets of the deburring problem which are described in this report.

The technical capabilities of several deburring processes have been reported in related investigations.[6-23] Several theories of burr formation have been described,[24-27] and empirical studies of burrs produced by machining operations have been reported.[8,24,28-35] In addition, three bibliographies describing burr related literature have been prepared,[36-38] the problems of measuring burrs have been described,[39-41] and international trends in deburring have been reported.[42-43]

ACTIVITY

All conventional machining operations produce some burrs. The size of these burrs depends on the tool geometries used, the speeds and feeds, and the workpiece material properties. The cost of removing the burrs is directly related to burr size and location. In many instances the cost of removing the burrs from precision miniature parts approaches the cost of machining because of close tolerances, minute part sizes, and large burr sizes. An understanding of how deburring costs vary with burr size and how machining conditions influence burr size is necessary to minimize total fabrication costs.

This report summarizes all the results obtained in this study as they relate to selecting the most economical production conditions.

How To Use This Report

If the sizes of burrs on a part are known, consult the companion to this report[23] to determine deburring process which will remove the burrs while maintaining part dimensions, edge radii, and surface finish. To calculate economics or determine ways to reduce deburring effort, consult the appropriate sections in this report.

If burr sizes are not known, consult the section titled *Burr Size as a Function of Machining Conditions* then go to the companion report to select appropriate deburring processes. To determine costs or other approaches to reducing costs, consult the additional sections of this report.

If the reader desires only to determine specific approaches to minimize deburring costs, then only this report needs to be reviewed.

If detailed information is required on any process, the reader should consult the references listed in this or the companion report.

Throughout this report, the emphasis is on deburring precision miniature metal pieceparts, although the results can be applied equally to non-precision parts. Examples of the types of features often encountered on the precision miniature parts at Bendix are described in Table 1. Some of the pins which must be deburred are so small that 12,000 will fit into a thimble.

The second feature to note in reading this report is that any deburring process can remove any burr. In selecting a deburring process, it is essential to know all the following facts:

- The size of burr to be removed (thickness and height);
- The amount of stock loss which can be tolerated from the deburring process;
- The surface finish which is required; and
- The required edge condition (how large a radius or chamfer is allowable or required).

Part size, material, and burr location are also important criteria in many processes. These facts will allow one to determine which processes can be used. (Reference 23 describes the capabilities of all 24 major deburring techniques based on these parameters. No other reference published to date presents such comparative information.) At this point, the economics can be calculated and if none are suitable, an evaluation of tradeoffs can be made.

Table 1. Piecepart Requirements Significant in Deburring Effects

Requirement	Problem
Usual Piecepart Material for Miniature Components:	
Aluminum	Extremely Pliable
Beryllium Copper	Usually Very Tough
Stainless Steel	Very Tough
Very Small Parts	Cause handling problem; very small holes, undercuts, slots, and other features present problems because of feature size alone
Toleranced Edge Break	Deburr process must deburr and generate a given dimension, for example, 0.05 to 0.13 mm edge break
Burr-Free Under 16X Magnification	Finished parts must be burr-free; 95 percent burr-free is <u>not</u> acceptable. Many burrs <u>are</u> small, but they still must be removed
Low Volume and Short Lead Times	Makes special design, single-purpose machines impractical
Deep, Intersecting Features	Design makes burr inaccessible
Fine Surface Finishes and Precision Tolerances	Deburr process may affect adjacent surface finishes or precision tolerances

The third feature to note is that, unless otherwise indicated, deburring implies the removal of all material projecting past the theoretical intersection of the surfaces bounding the burr. It is also assumed that some form of smooth blend is required since chamfering typically produces small burrs which must also be removed. *For this report, a burr is defined as all material extending past the theoretical intersection of two adjacent surfaces where such material was the result of plastic deformation by a chip-making cutting tool.* Recast material from EDM, dross from torch cutting, flash, metal displaced from friction welded joints, plating nodules, and die-formed flanges are not burrs by this definition. Despite this, many of the comments made in this report will also be applicable to these burr-like protrusions.

Burr Size as a Function of Machining Conditions

Burrs form by three basic mechanisms as indicated in Table 2. Burr-like protrusions form by a number of other mechanisms.

Poisson Burr

The Poisson Burr occurs whenever the cutting edge extends past an edge of the workpiece (Figure 1). In essence, it is the lateral deformation that occurs whenever any solid is compressed. The term Poisson Burr is derived from this burr's direct relationship to Poisson's ratio. The extent of deformation is a function of the workpiece material, the size and shape of the contacting body, and the applied load. In the case of a cutting tool in which no rubbing occurs on clearance surfaces, the effective shape of the indentor is a cylinder. Because cutting tools have cutting edge radii of 5.08 to 127.0 μm (0.0002 to 0.0050 in.), the extent of the lateral deformation (burr) is also relatively small. The actual size of the burr is proportional to cutting edge radius and applied pressure. If the cutting pressure is similar to the pressure applied to the inner surface of a small hollow cylinder, burr size is also a complex function of several material variables (Equations 1 and 2).

$$b_L = \left[\frac{h(1+\nu)\sigma_e e^{-\sqrt{3}\phi_a}}{\sqrt{3}E}\right]\left[-\frac{\sin\phi}{2(\sqrt{3}\cos\phi + \sin\phi)}\right], \quad (1)$$

$$b_t = r\left[e^{-\sqrt{3}\phi_a}\cos\phi_a - 1\right], \text{ and} \quad (2)$$

$$\phi_a = -\sin^{-1}\left[\frac{\sqrt{3}P}{2\sigma_e}\right] + \pi/6, \quad (3)$$

where:

b_L = Burr length,

b_t = Burr thickness,

h = Depth of cut,

ν = Poisson's ratio for elastic stresses,

σ_e = Yield stress of a perfectly plastic material,

Table 2. Basic Mechanisms of Burr Formation and Related Protrusions

Physical Principle of Formation	Name of Protrusion
Lateral Flow of Material	Poisson Burr
Bending of Material (Such as Chip Rollover)	Rollover Burr
Tearing of Chip From Workpiece	Tear Burr*
Incomplete Cutoff	Cutoff Protrusion
Redeposition of Material	Recast Material
Flow of Material into Cracks	Flash
Plating Buildup	Plating Nodules
Melting by Flame Arc	Dross
Plastic Flow in Inertia Welding	Weld Nugget

*In piercing operations this type of burr is called a tensile burr.

E = Modulus of elasticity,

r = cutting edge radius,

P = Pressure on cutting edge, and

ϕ = Angle defining state of plastic flow.

Entrance Burr

It is possible for another type of burr to form (Figure 2) when the cutting edge first indents the workpiece. An Entrance Burr is material which has flowed opposite the direction of the tool. It is similar to the ridge which forms around the indentation made by a Brinnell hardness tester.

Whether or not a burr forms at this point depends on the workpiece properties and, probably, the actual shape of the cutting edge. Assuming that a cylinder indenting metal produces effects somewhat similar to those of a ball indenting metal, strain hardening plays an important role. Brinell hardness test results have shown that a lip of material forms when the material has a

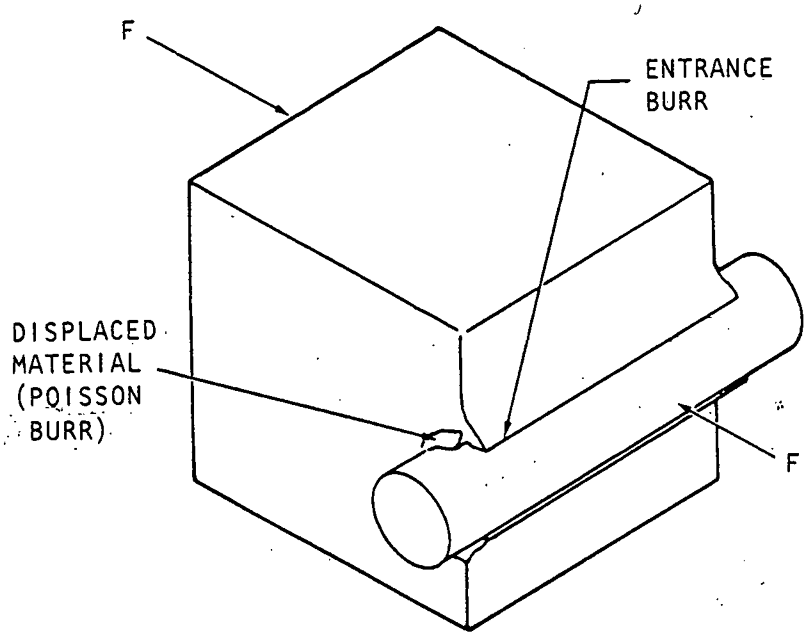


Figure 1. Formation of a Poisson Burr

low strain hardening exponent (Figures 3 and 4). Materials having high strain hardening exponents cause a bulge but not a sharp burr. Assuming constancy of volume, this bulge will be wide but short while in the previous case the burr will be long but narrow. In the case of high strain hardening exponents, the bulge will probably be so short that it is difficult to detect.

Rollover Burrs

When a cutting edge exits from a workpiece, a Rollover Burr forms (Figure 5). This burr occurs when it is easier to bend the chip than to cut it. If one makes the assumption that a Rollover Burr occurs whenever the energy required to bend the chip is equal to or less than the energy required to cut the chip, an estimate or burr thickness can be made.

Equation 4 works for a perfectly plastic material.

$$b_t = \left[2F_c + \sqrt{4F_c^2 - \frac{2b\sigma_e \theta t F_c}{\tan\phi}} \right] \left[\frac{1}{b\sigma_e \theta} \right] \text{ for } \lambda \geq \frac{t}{\tan\phi_c}. \quad (4)$$

Equation 5 applies to a strain hardening material.

$$b_t = \left[2F_c + \sqrt{4F_c^2 - \frac{2b\sigma_o \varepsilon_f^n t \theta F_c}{(n+1)\tan\phi}} \right] \left[\frac{n+1}{b\sigma_o \theta \varepsilon_f^n} \right] \text{ for } \lambda \geq \frac{t}{\tan\phi_c}. \quad (5)$$

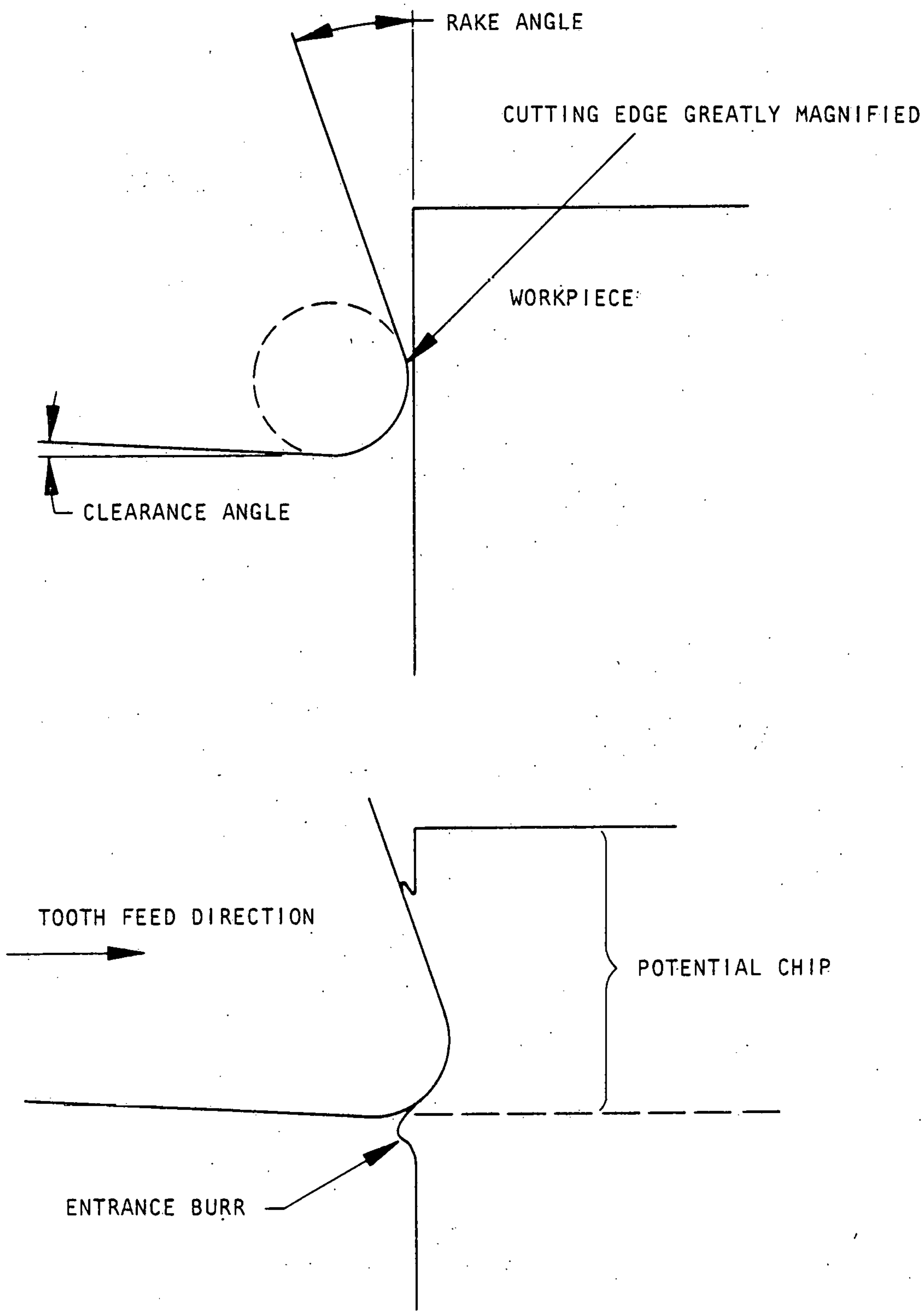


Figure 2. Cutting Edge Produces Indentation Burr as It Enters Workpiece

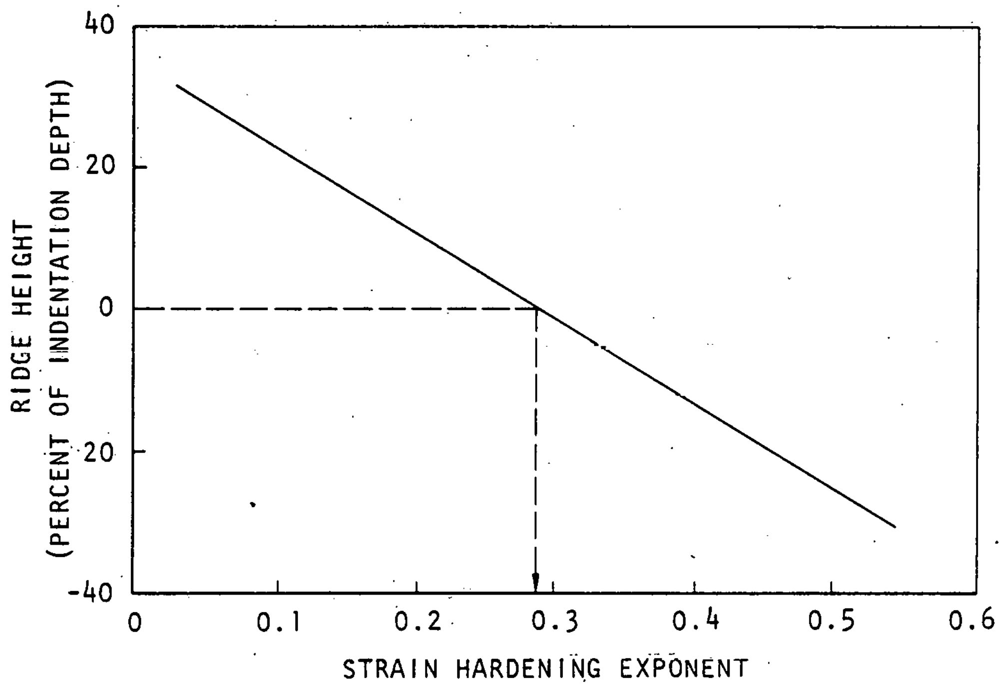


Figure 3. Effect of Strain Hardening Exponent on Ridging Burr Formation

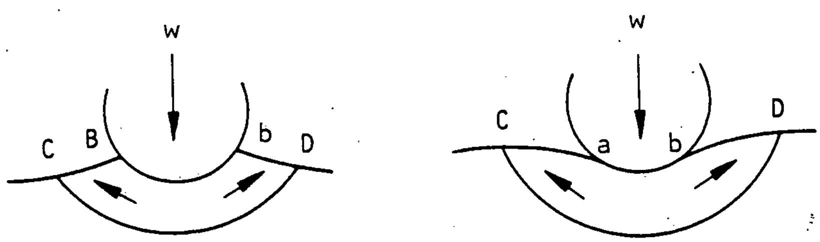


Figure 4. Material Displacement Using Spherical Indentors

In both Equations 4 and 5,

b_t = Burr thickness,

F_c = Cutting force,

t = Uncut chip thickness,

ϕ_c = Shear angle in cutting,

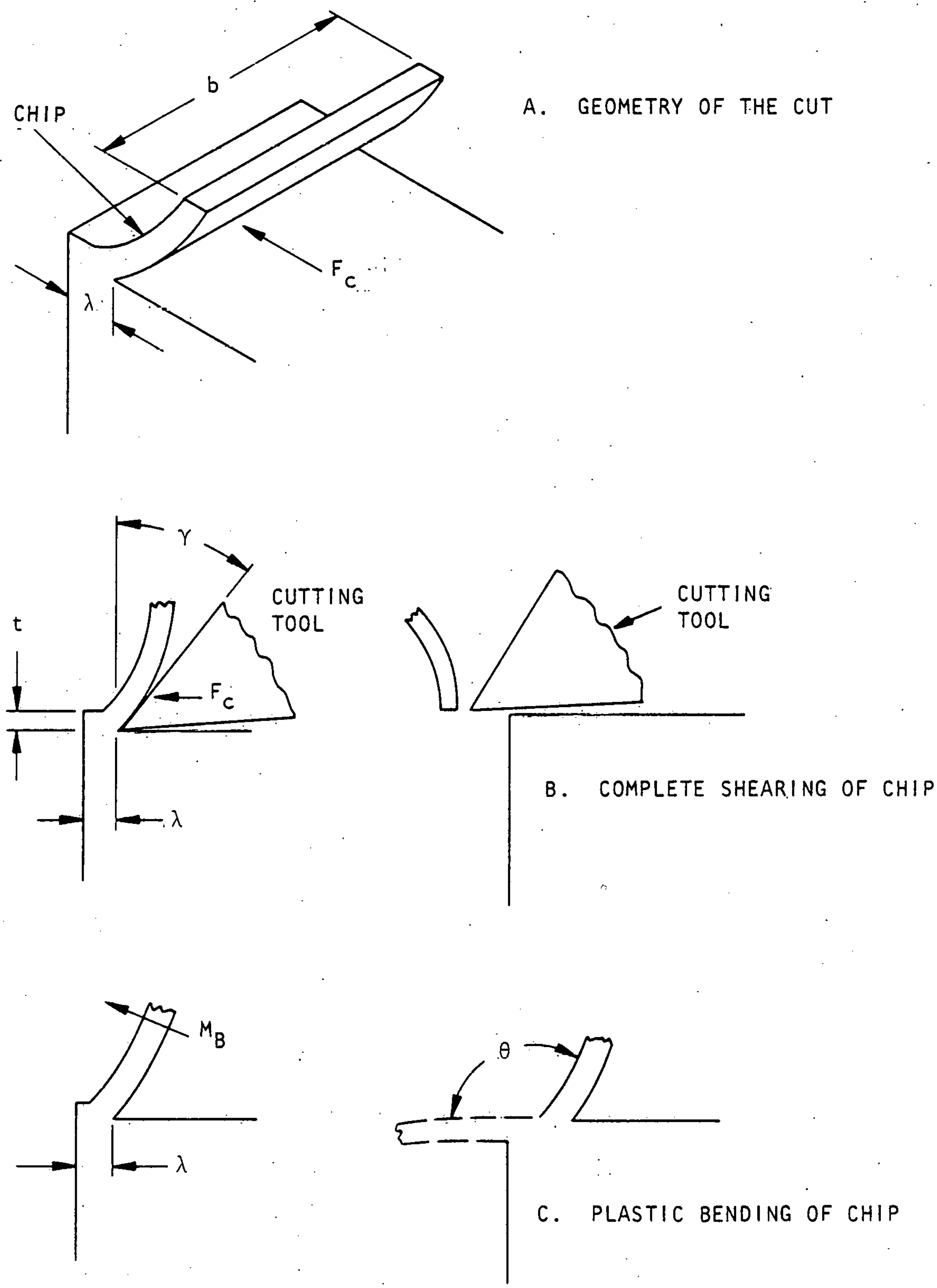


Figure 5. Chip Deformation Modes

b = Length of tool engaged in cut,

σ_e = Elastic limit of perfectly plastic material,

θ = Angle through which the burr is bent ($\pi/2$ + rake angle),

σ_o = Material stress at a true strain of 1.0,

ε_f = True strain at fracture, and

n = Strain hardening exponent.

The length of a Rollover Burr is a function of the cutting conditions and the plasticity of the workpiece. The length cannot be longer than the total depth of cut. If, in bending, the strain exceeds the strain required to fracture, then the majority of the burr will break off and leave only a short burr. Burr thickness is a linear function of depth of cut.

Tear Burrs

Tear Burrs form when the chip is torn rather than sheared from the workpiece. Although this burr can form in most of the basic cutting processes, it happens easiest during side milling operations. The cutter tooth forces the chip up and forward (Figure 6). As it does so, the sides of the chip are torn from the workpiece; the torn portion remaining on the workpiece is the Tear Burr. The tooth can stretch the material in such a way that the burr is formed by a bending mechanism, or it can shear the metal. The mechanism which predominates appears to be a function of cutting velocity and workpiece properties; however, at this time no quantitative theory exists for producing Tear Burr properties.

The Poisson Burr, the Rollover Burr, and the Tear Burr all have one property which has not been discussed. A radius occurs on the back side of these burrs (Figure 7). The total shape of the burr cross-section, then, can be expressed by length b_L, thickness b_t, and radius b_r. While some individuals consider b_{min} as burr thickness, it is obvious that when all the burr must be removed it is b_t which best defines thickness. Perhaps more significantly, b_{min} cannot be easily defined for some burrs (Figure 8).

For Poisson Burrs, this radius is actually an exponential function (Equation 2). Although a theory has not been developed for b_r for a Rollover Burr, it would appear that some of the theory developed for sheet metal bending is applicable.

Since all three of the plastic deformation burrs are the result of plastic strains, and since most materials are strain hardening, the burrs are harder than the parent material. Using the Meyer Hardness Number (MHN), for example,

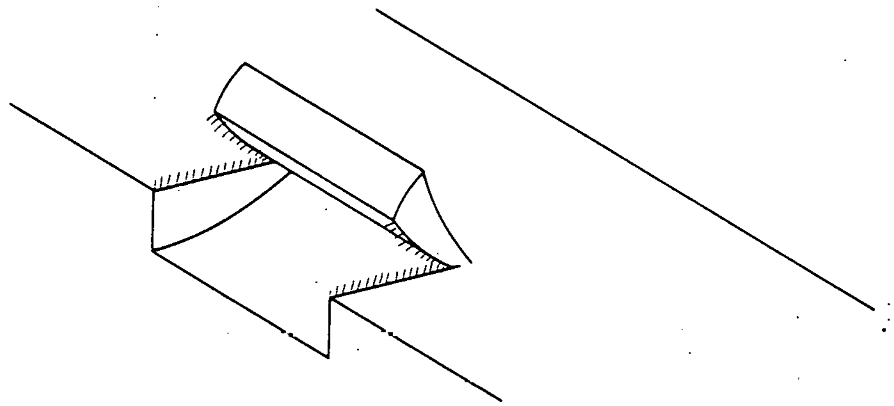


Figure 6. Separation of Initial Chip in Side Milling

$$MHN = 2.8\sigma_o \varepsilon^n, \tag{6}$$

where ε is the strain in the area of interest.

Burrs Formed in Drilling

Burrs form on both the entrance and exit sides of drilled holes (Figure 9). The burrs on the entrance side are typically small while those on the exit are typically very long and ragged. Entrance burrs typically have a triangular cross section while exit burrs are basically rectangular. Table 3 lists some typical burrs sizes observed in a study involving 4300 measurements.[34] The drills from which the data was obtained were 3.175 mm (1/8 in.) diameter with a variety of point geometries and other variations. As seen in Table 3, the only major difference between properties is that of burr height. Entrance burrs tended to be 50.8 µm (0.002 in.) high while exit burrs were 127 µm (0.005 in.) or higher. All burrs were roughly 63.5 µm (0.0025 in.) thick.

As seen in Table 4, increasing feedrate increases exit burr properties. Increasing the helix angle reduced all burr properties. The most significant changes to exit burr properties can be made by using high helix drills (37.5°). Reducing feedrate 60 percent can reduce burr height by 40 percent. Since exit burr height can be equal to the drill radius, drill diameter can be a major factor in burr size. Reducing spindle speed from 750 to 375 rpm reduced burr thickness less than 12.7 µm (0.0005 in.).

Exit burr height, the factor most influenced by feedrate, can be approximated by Equation 7 for 3.175 mm diameter drills, at feedrates of 38.1 µm/rev (0.0015 in./rev) or less.

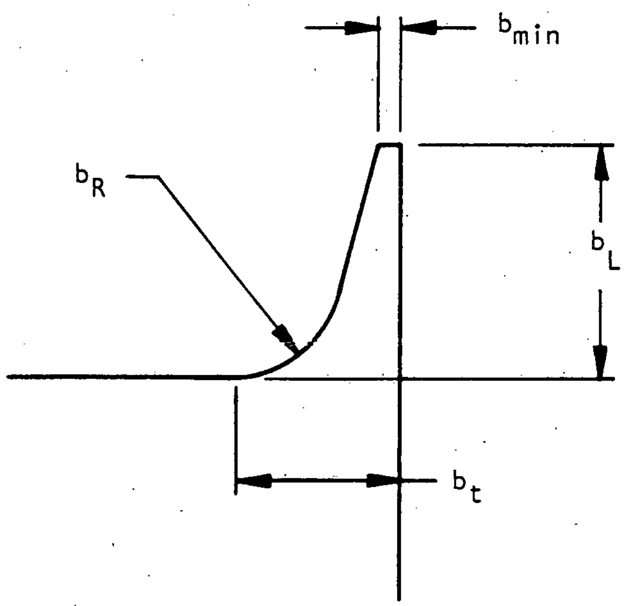


Figure 7. Cross Section of Typical Machining Burr

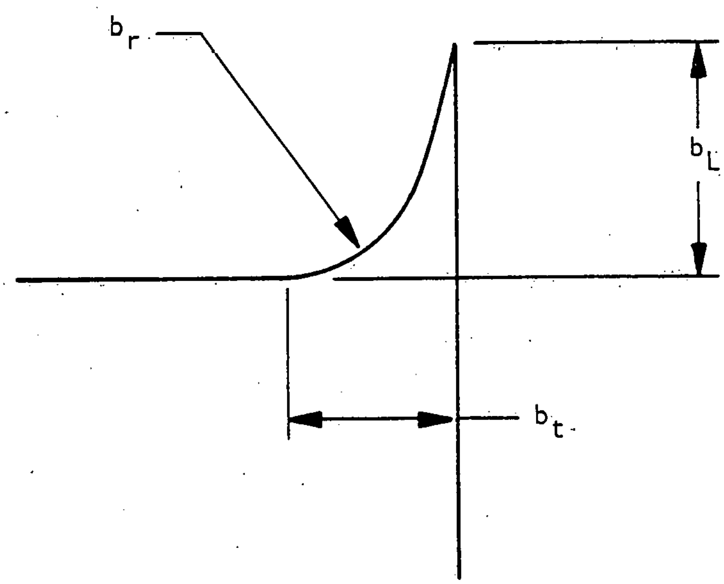


Figure 8. Cross Section of Blanking and Some Machining Burrs

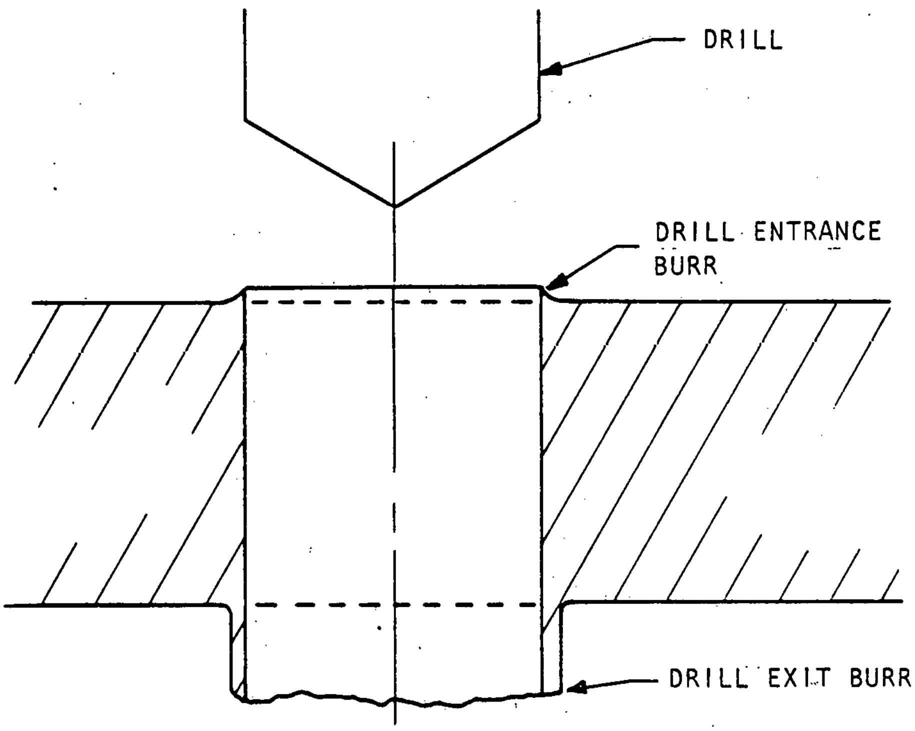


Figure 9. Shapes of Burrs Produced by Drilling

$$b_L = c_1 f + c_2 \quad (7)$$

where

b_L = Burr height,

f = Feedrate,

c_1 = Constant,

c_2 = Constant,

And the following constants may be used:

Material	Metric Units (μm) c_1	Metric Units (μm) c_2	English Units (in.) c_1	English Units (in.) c_2
303 Se Stainless Steel (R_c 29)	13.33	559	13.33	0.022
17-4 Ph Stainless Steel (R_c 42)	6.67	432	6.67	0.017

Table 3. Typical Burrs Properties Produced by 3.175 mm Drills

Material	Thickness µm (in.)	Height µm (in.)	Radius µm (in.)
Entrance Burr			
1018 Steel (R_B99)	58.4 (0.0023)	50.8 (0.0020)	48.3 (0.0019)
303 Se Stainless (R_c 34)	45.7 (0.0018)	38.1 (0.0015)	33.0 (0.0013)
6061-T6 Aluminum (R_B 54)	68.6 (0.0027)	55.9 (0.0022)	63.5 (0.0025)
Exit Burr			
1018 Steel (R_B99)	81.3 (0.0032)	139.7 (0.0055)	50.8 (0.0020)
303 Se Stainless (R_c 34)	63.5 (0.0025)	165.1 (0.0065)	45.7 (0.0018)
6061-T6 Aluminum (R_B 54)	76.2 (0.0030)	127.0 (0.0050)	61.0 (0.0024)

Material	Metric Units (µm)		English Units (in.)	
	c_1	c_2	c_1	c_2
1018 Steel (R_B 99)	4.00	406	4.00	0.016
6061-T6 Aluminum (R_B 54)	6.00	254	6.00	0.010

Exit burr thickness can be expressed as in Equation 8,

$$b_t = c_1 f + c_2, \quad (8)$$

when the following constants are used:

Table 4. Effect of Drilling Variables on Burr Size in 303 Se Stainless Steel

	Entrance Burr		Exit Burr		
Variable	Thickness	Height	Thickness	Height	Significance
Helix Angle	--	--	--	--	1
Feedrate	0	0	+	+	2
Diameter	0	--	+	+	3
Surface Velocity	+	--	+	x	4
Corner Angles*	x	x	--	+	5

-- = Increasing variable reduces burr property
0 = No effect
\+ = Increasing variable increases burr size
x = Conditions not studied

*For conventional drills, the corner angle equals 180 degrees minus half the point angle.

Drill	Metric Units	English Units
Four Facet		
c_1	1.0	1.0
c_2	0.33	0.0013
Eight Facet		
c_1	1.0	1.0
c_2	30	0.0012
Radial Lip		
c_1	1.0	1.0
c_2	25	0.0010

The use of a hard backup (R_C 42) minimizes exit burr size (Figure 10), as does the use of a hole in the bottom of the fixture holding the part. If the fixture hole is within 12.7 μm (0.0005 in.) of the drill diameter and on the same centerline, the burr size will be 12.7 μm or smaller.[30] In some cases, as described later, reaming after drilling will reduce burr size. Where drills must produce 150 to 1000 holes each, the radial lip drill point will result in shorter and thinner burrs, but this is not true in short run applications. In materials such as aluminum, the use of correct coolants can also noticeably reduce burr size. On precision miniature holes, a clearance hole diameter 50.8 μm (0.002 in.) larger than the drilled hole will only slightly improve burr properties above those of a large clearance hole.

With the exception of exit burrs in stainless steel, no relationship was observed between burr thickness and height. In stainless steel, high burrs also indicated the existence of thick burrs. The minimization of feedrate surges as the drill breaks through the bottom side of the workpiece also helps reduce exit burr size.

Burrs Formed in Reaming

Like drilling, reaming an initially burr-free hole produces burrs at both hole entrance and exit. Table 5 presents some burr properties observed in a study of 3.40 mm (0.134 in.) diameter holes reamed at a feedrate of 25.4 to 76.2 μm/rev (0.001 to 0.003 in./rev) from an initially burr-free condition.[28] The data presented is for a reamer removing 76.2 μm material from each side.

These burrs are significantly different from those produced by drilling (Table 3); because these burrs are much thinner than drilling burrs, they are much easier to remove.

In most situations, the drill burr is still on the hole when the reamer enters, so the final burr size is a function of both the drilling and reaming burrs. If a reamer only removes 25.4 μm (0.001 in.) material from each side of the hole and the drill produced a 76.2 μm (0.003 in.) burr, then the burr left after reaming would be 50.8 μm (0.002 in.) or thicker. As a general rule, however, reaming a drilled hole will reduce burr thickness and height.

The use of a lead-in radius rather than a standard chamfer on the reamer can reduce burr properties by 50 percent on an initially burr-free hole. Reducing the amount of stock removed by the reamer will also dramatically reduce burr size on initially burr-free holes. These changes probably will be in effect on large drill burrs. Feedrate has little effect on reaming burr sizes.

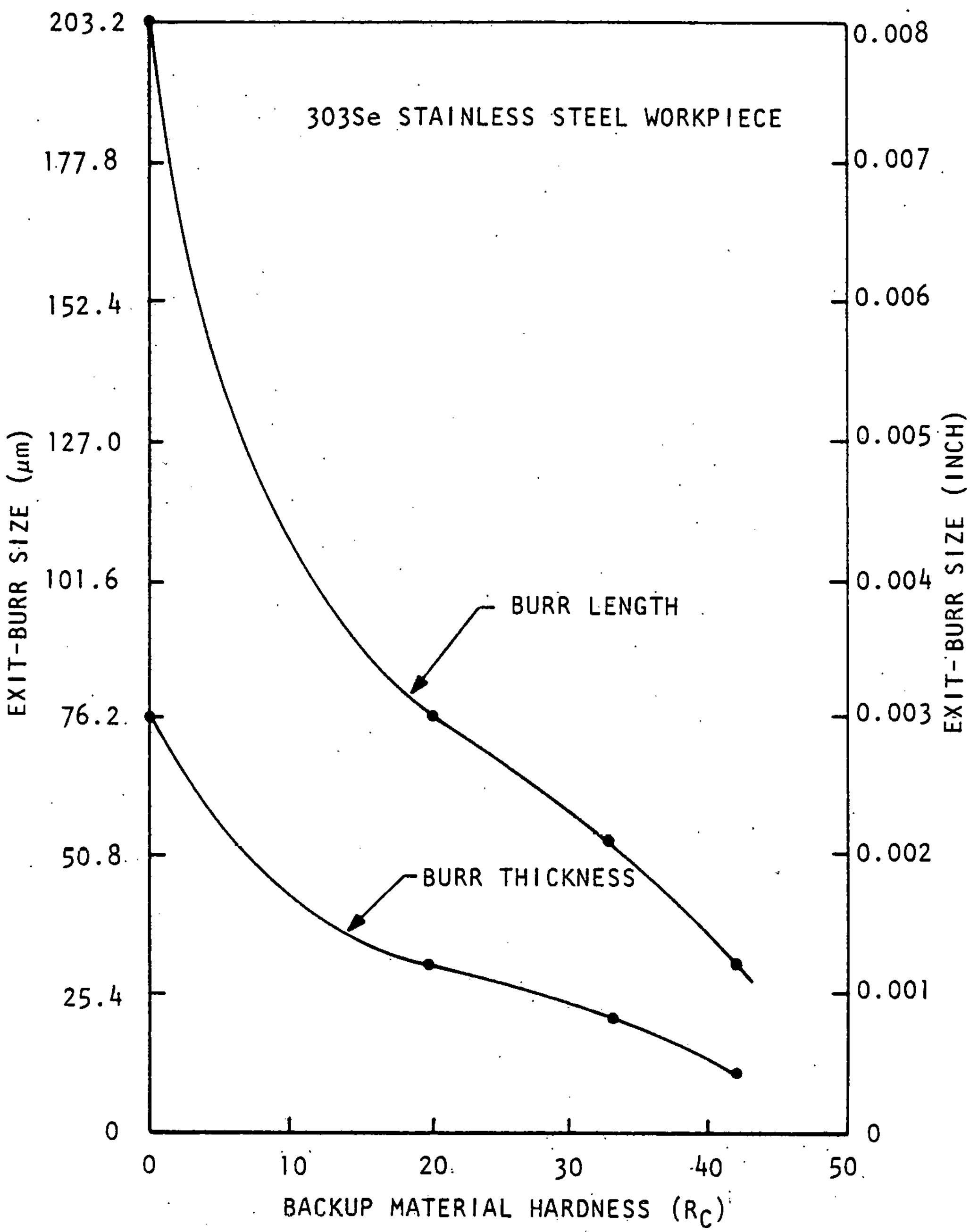


Figure 10. Effect of Backup Material Hardness on Burr Size

Table 5. Burrs Formed by Reaming Initially Burr-Free Holes

Material	Thickness		Height	
	μm	in.	μm	in.
Entrance Burrs				
303 Se Stainless Steel (R_c 34)	15.2	0.0006	30.5	0.0012
6061-T6 Aluminum (R_B 54)	12.7	0.0005	33.0	0.0013
Number 6 Brass (Half Hard)	17.8	0.0007	30.5	0.0012
Exit Burrs				
303 Se Stainless Steel (R_c 34)	12.7	0.0005	45.7	0.0018
6061-T6 Aluminum (R_B 54)	15.2	0.0006	152.4	0.0060
Number 6 Brass (Half Hard)	12.7	0.0005	66.0	0.0026

For reaming initially burr-free holes, burr height (b_L) and burr thickness (b_t) can be approximated by the following two equations. The constants C_1, C_2, and K given in Table 6 were obtained by a regression analysis of the test data. The geometry factor shown in the equations is a factor indicating the reduction in size caused by a starting radius as opposed to a chamfer. If the tool used has a starting chamfer, the geometry factor is 1.0.

$$b_L = C_1 \text{ (stock removed/side) (geometry factor 1)}. \quad (9)$$

$$b_t = C_2 \text{ (stock removed/side)}^K \text{ (feedrate) (geometry factor 2)}. \quad (10)$$

For 0.0045 inch stock removal in brass using a reamer with a starting radius, predicted exit burr height is

$$b_L = (0.83)\ (0.0045)\ (0.5) = 0.0019 \text{ inch}.$$

Exit burr thickness for 25.4 μm stock removal, a feedrate of 25.4 μm per revolution, using a standard reamer in 303 Se, would be

$$b_t = (0.000031)\ (25.4)^{2.1}\ (25.4)\ (1) = 0.7\ \mu m.$$

Table 6. Burr Size Constants to Use With Equations for Reaming Burrs

Workpiece	C_1	C_2	K	$geom_1$	$geom_2$
Entrance Burr Constants					
Aluminum, Brass, and 303 Se Stainless Steel	0.61	202.6 (0.0470)*	0.82	0.5	0.5
Aluminum	0.58	18.1 (0.0029)*	0.86	1.0	1.0
Brass	0.39	5.57 (0.0170)*	0.55	0.1	0.1
303 Se	0.89	144.0 (0.0011)*	1.16	0.25	0.5
Exit Burr Constants					
Aluminum, Brass, and 303 Se Stainless Steel	1.14	3.8 (0.039)*	45	0.62	0.5
Aluminum	1.31	0.11 (0.0333)*	-0.11	0.5	0.5
Brass	0.83	1.21 (0.079)*	0.27	0.5	0.5
303 Se	1.26	56037 (0.000031)*	2.1	0.5	0.5

*Metric units in parentheses

Burrs Formed by Ballizing

When a ball is forced through a smaller hole to produce the correct hole size and a good finish, the ball often also produces small chips and burrs. Table 7 illustrates the size of burrs produced when the hole size was changed 25.4 μm (0.001 in.) or less on 1.59 mm (0.062 in.) diameter holes.

The following equations, based on the experimental data, roughly estimate burr properties produced by ballizing 303 Se stainless steel. These three equations are valid for diameter changes greater than 2.54 μm (0.0001 in.).

$$b_{L\ enter} = -1.75(\Delta_{diameter}) + 0.0022, \quad (11)$$

$$b_{L\ exit} = [1.25(\Delta_{diameter}) + 0.0065]\,[L/0.130], \text{ and} \quad (12)$$

$$b_{H\ exit} = H_{parent} + 117.5e^{-4.45}(\Delta_{diameter}), \quad (13)$$

where:

$\Delta_{diameter}$ = Change in hole diameter,

L = Axial length of hole,

H = Knoop hardness,

$b_{L\ enter}$ = Predicted entrance burr length,

$b_{L\ exit}$ = Exit burr length, and

$b_{H\ exit}$ = Knoop hardness of exit burr.

The burrs produced by ballizing vary, even at supposedly fixed conditions. Some reduction in burr size may be achievable by a better selection of lubricants and the use of high velocity rams to drive the balls through the part.

Burrs Formed by End Milling

An end mill can produce eight different burrs in a single slotting operation. A total of ten different groups of burrs can be produced by an end mill, but eight is the maximum which can be produced in a single cut. These burrs all occur on different edges. For example, in a bottom profiling cut, six edges are produced and a different group of burrs occurs on each edge (Figure 11). When a blind channel slot is produced, six edges and six groups of burrs occur (Figure 12). In a through slot,

Table 7. Burrs Formed by Ballizing Initially Burr-Free Holes

Material	Thickness μm (in.)	Height μm (in.)	Hardness (R_C) Part	Burr
Entrance Burr				
304L Stainless Steel	15.2 (0.0006)	38.1 (0.0015)	Not Measured	
Hiperco	7.6 (0.0003)	43.1 (0.0017)	Not Measured	
Exit Burr				
304L Stainless Steel	27.9 (0.0011)	167.6 (0.0066)	29	42
Hiperco 50	15.2 (0.0006)	109.2 (0.0043)	36	37

eight edges and eight groups of burrs occur (Figure 12). The height, the thickness, the radius on the back side of each burr, the hardness, and the appearance of each of these groups of burrs are different from the other groups.

Two different mechanisms are involved in the production of these burrs. The burrs along Edges 3, 7, and 9 are Rollover Burrs. Burrs on Edges 1, 2, and 10 are generally Poisson Burrs. The burrs along Edges 4 and 6 are Entrance Burrs. Burrs along Edges 8 and 5 are a combination of Entrance and Rollover burrs.

Some typical properties of burrs produced with 6.35 mm (0.25 in.) diameter end mills at feedrates up to 50.8 μm/rev/tooth (0.002 in./rev/tooth) are shown in Table 8.

The large number of edges and burr properties prohibit a full discussion of machining effects on burr size (References 24 and 33 present the only known data available on end milling burrs.) but the following observations are significant.

- Fast feedrates (50.8 versus 12.7 μm/rev/tooth) reduce burr height by up to 50 percent but slightly increase burr thickness.
- Dull cutters significantly increase burr height and thickness.
- Helix angle changes increase some burr sizes while decreasing others.

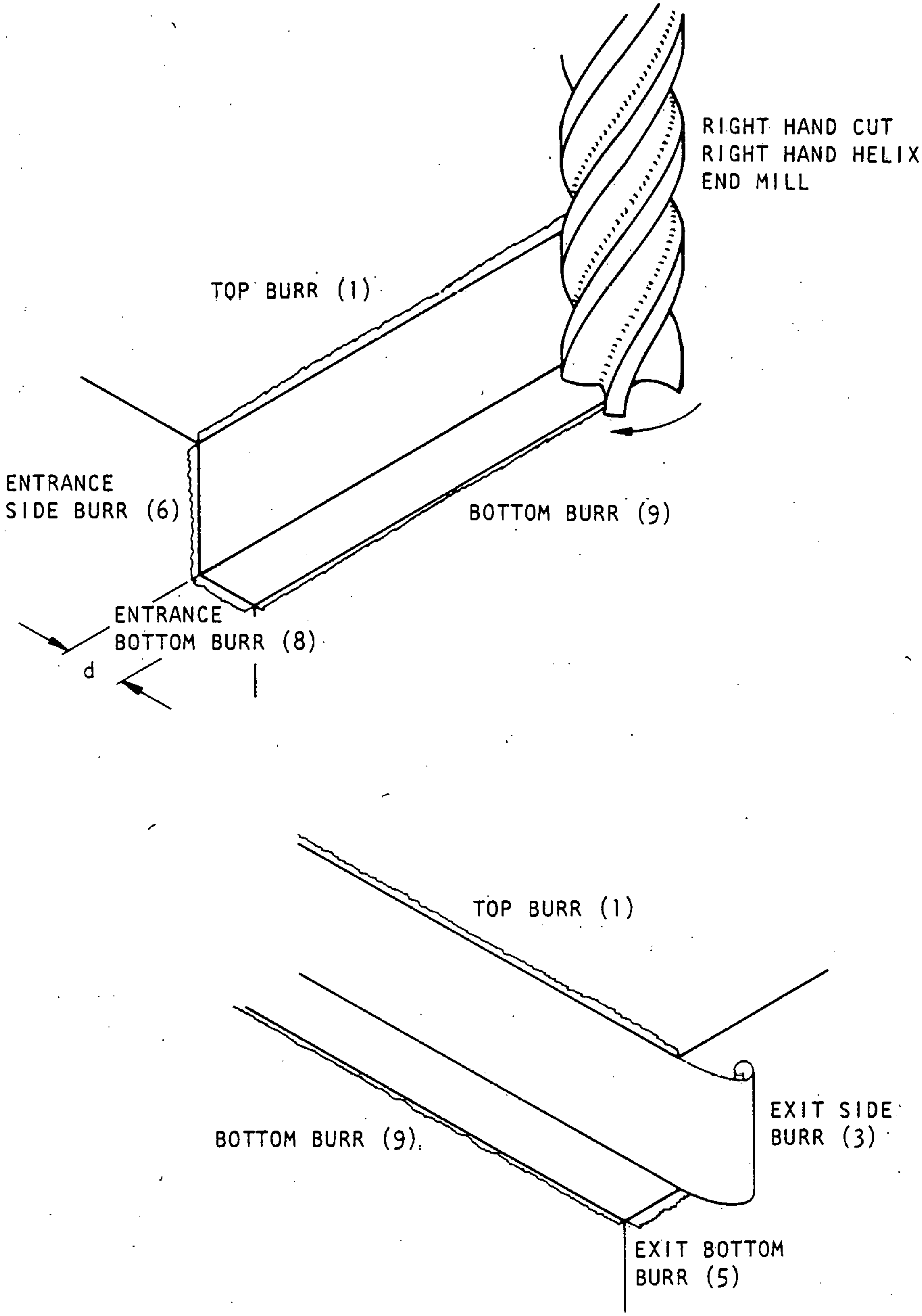


Figure 11. Identification of Burr Locations in End Milling Workpiece Edges

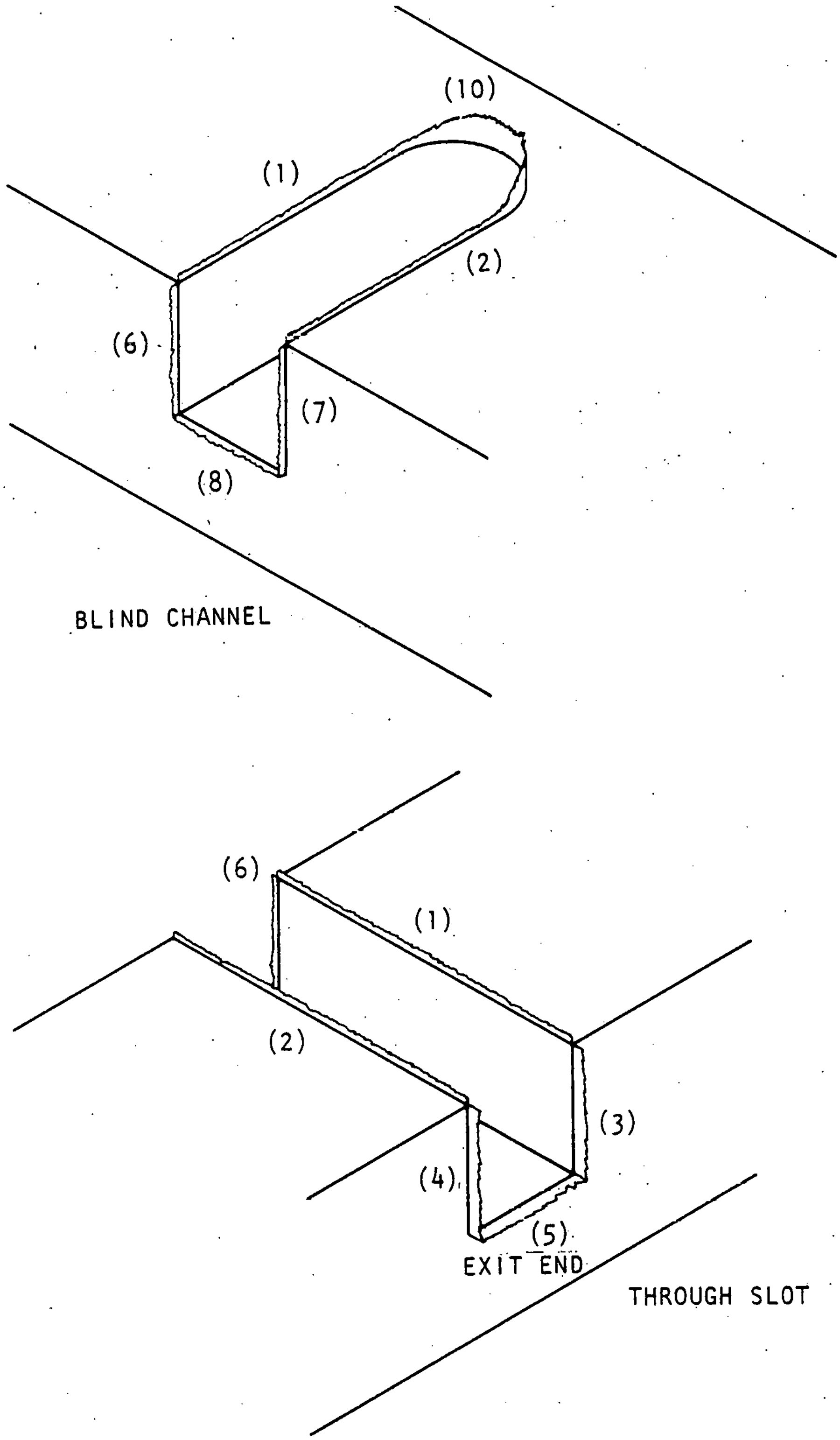


Figure 12. Identification of Burr Locations in Slots Produced by End Milling

Table 8. Typical Burr Properties From End Milling

Burr Location (Edge Number)	Burr Height		Burr Thickness		Burr Radius	
	μm	in.	μm	in.	μm	in.
17-4 PH Stainless Steel (R_c46)						
1	205.7	0.0081	55.8	0.0022	35.6	0.0014
2	287.0	0.0013	50.8	0.0020	30.5	0.0012
3	927.1	0.0365	88.9	0.0035	45.7	0.0018
4	132.1	0.0052	--	--	--	--
5	147.3	0.0058	66.0	0.0026	40.6	0.0016
6	35.6	0.0014	287.0	0.0013	--	--
7	426.7	0.0168	83.2	0.0033	30.5	0.0012
8	78.7	0.0031	--	--	--	--
9	127.0	0.0050	55.8	0.0022	80.5	0.0012
303 Se Stainless Steel (R_c24)						
1	221.0	0.0087	58.4	0.0023	40.6	0.0016
2	213.4	0.0084	53.3	0.0021	38.1	0.0015
3	1651.0	0.0650	88.9	0.0035	43.2	0.0017
4	307.3	0.0121	--	--	--	--
5	266.7	0.0105	88.9	0.0035	58.4	0.0023
6	25.4	0.0010	22.9	0.0009	--	--
7	734.1	0.0289	106.7	0.0042	50.8	0.0020
8	121.3	0.0048	--	--	--	--
9	91.4	0.0036	73.7	0.0029	58.4	0.0023
6061-T6 Aluminum (R_B63)						
1	134.6	0.0053	35.6	0.0014	17.8	0.0007
2	149.9	0.0059	45.7	0.0018	27.9	0.0011
3	1270.0	0.0500	73.7	0.0029	38.1	0.0015
4	121.3	0.0048	--	--	--	--

Table 8 Continued. Typical Burr Properties From End Milling

Burr Location (Edge Number)	Burr Height µm	Burr Height in.	Burr Thickness µm	Burr Thickness in.	Burr Radius µm	Burr Radius in.
5	370.9	0.0146	73.7	0.0029	35.6	0.0014
6	7.6	0.0003	15.2	0.0006	--	--
7	528.3	0.0208	83.8	0.0033	40.6	0.0016
8	154.9	0.0061	--	--	--	--
9	119.4	0.0047	55.8	0.0022	22.9	0.0009
1018 Steel (R_B90)						
1	210.8	0.0083	53.3	0.0021	35.6	0.0014
2	155.0	0.0061	58.4	0.0023	30.5	0.0012
3	1775.4	0.0699	93.9	0.0037	43.2	0.0017
4	226.1	0.0089	--	--	--	--
5	419.1	0.0165	96.5	0.0038	50.8	0.0020
6	2.5	0.0001	10.2	0.0004	--	--
7	198.1	0.0078	83.8	0.0033	40.6	0.0016
8	55.8	0.0022	--	--	--	--
9	160.0	0.0063	66.0	0.0026	60.9	0.0024

Burr height at Edge 3 is directly proportional to radial depth of cut. As a rule of thumb, cutters must be fed fast enough to prevent rubbing on stainless steel and they must be kept sharp. Tools with a cutting edge radius of 25.4 µm should be replaced.

Burrs Formed by Side Milling

Side milling operations can also produce burrs at ten different edges. In this case, burrs at Edges 6, 7, and 8 are Entrance Burrs. Tear Burrs occur at Edges 1, 2, 3, and 4 (Figure 13). Rollover burrs occur at Edges 5 and 10, and a Poisson Burr occurs at Edge 9. Table 9 describes some typical properties of burrs produced by side milling 303 Se stainless steel.

For conventional side milling cutters, burr thicknesses can be minimized by reducing the feedrate and using a 0° helix angle. Feedrate did not affect burr thickness when master cut style

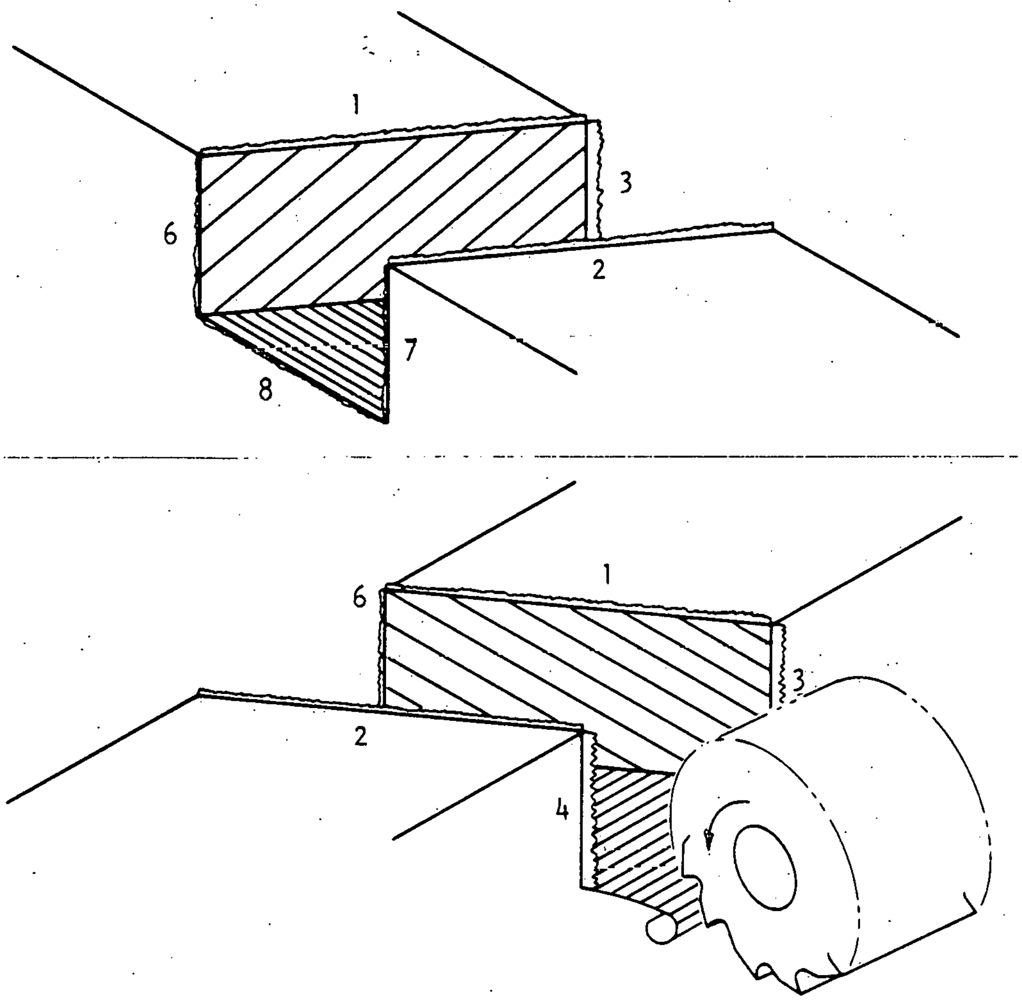


Figure 13. Burrs Produced in Side Milling (Conventional Cut)

cutters were used (except when feedrates were slower than 1.52 μm/rev/tooth (0.00006 in./rev/tooth). Full radius cutters (cutters which produce a U-shaped slot cross section) should not be used unless essential on materials that elongate noticeably. These cutters produce thicker as well as much longer burrs than do square edged cutters.

For 303 Se stainless steel, lowering the feedrate from 50.8 to 14.5 μm/rev/tooth (0.002 to 0.00057 in./rev/tooth) reduced some burr thicknesses by a factor of 2.0. In this range of feeds, burr thickness can be expressed approximately by Equations 14 through 16.

Table 9. Typical Properties of Side-Milling Burrs in 303 Se Stainless Steel

Burr Location	Burr Length µm	Burr Length in.	Burr Thickness µm	Burr Thickness in.	Knoop Hardness
1	71.1	0.0028	43.2	0.0017	360
2	50.8	0.0020	43.2	0.0017	345
3	355.6	0.0140	53.3	0.0021	350
4	185.4	0.0073	27.9	0.0011	350
5	1524.0	0.0600	25.4	0.0010	350
6	2.5	0.0001	38.1	0.0015	350
7	10.2	0.0004	2.5	0.0001	350
8	5.1	0.0002	2.5	0.0001	350

For Burr Locations 1 and 2, $b_t = 0.00024 + 1.3549f$. (14)

For Burr Locations 3 and 4, $b_t = 0.00097 + 0.7517f$. (15)

For Burr Locations 6 and 7, $b_t = 0.0001 + 0.361f$. (16)

A 0° helix and conventional cut are assumed and b_t = burr thickness in inches while f = feedrate in inches per revolution per tooth.

Burrs Formed by Face Milling Cutters

While no data has been published, this process is obviously similar to end milling. It is significant that burr height at least is a function of the angle ϕ at which the cutter teeth exit over the workpiece edge (Figure 14). Table 10 portrays burr height at several positions around a circular workpiece which has been face milled with a 76.2 mm shell mill at 160 rpm and 3.81 mm/s (9 in./min) with a 2.54 mm (0.1 in.) axial depth of cut. The obvious implication in the data in Table 10 is that burr height can be controlled by varying the position of the cutter teeth with respect to the edge of the workpiece.

Burrs Formed by Grinding

Burrs produced by surface grinding are typically smaller than those produced by milling (Table 11). On a rectangular part which is surface ground, different burrs will occur on each of the four edges (Figure 15).

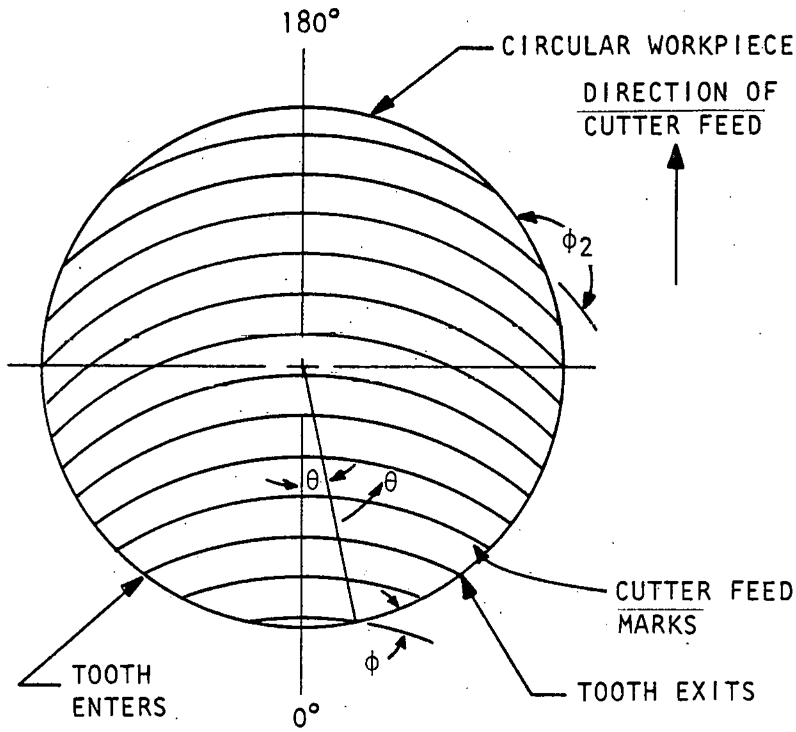


Figure 14. Angles Observed When Face Milling Cylinder Face

The data in Table 11 is a composite of data from 303 Se and 17-4 PH stainless steel and 1018 steel.[32] Feedrates varied from 5.08 to 25.4 μm/pass (0.002 to 0.001 in./pass) and grain sizes from 46 to 120 were used.

The fast down feedrate tended to increase burr height from 50.8 to 76.2 μm (0.002 to 0.003 in.). Burr height and thickness also doubled on some edges when ten passes were taken at 25.4 μm/pass (0.001 in./pass) as opposed to a single pass. Burrs in 1018 steel tended to be twice as thick as those in stainless steel.

Burrs Formed by Turning

Turning, like all other conventional metal cutting processes, generates burrs. These burrs can form by each of the mechanisms described earlier. Table 12 presents some typical properties obtained under a variety of conditions.[35] The speed and feed used for turning a 25.4 mm (1 in.) stepped shaft specimen were 36.6 μm/rev (0.00144 in./rev) and 300 rpm. The data in Table 12 describes the burr thrown up on the large diameter.

Table 10. Effect of Angle ϕ on Burr Height in Face Milling

Angle θ (Degrees)	Angle ϕ (Degrees)	Burr Height					
		303 Se (R_B84)		15-50H (R_c37)		BeCu (R_B96)	
		μm	in.	μm	in.	μm	in.
0	0	43.2	0.0017	88.9	0.0035	63.5	0.0025
30		83.8	0.0033	177.8	0.0070	114.3	0.0045
60		137.2	0.0054	91.4	0.0036	127.0	0.0050
90		175.3	0.0069	83.8	0.0033	297.2	0.0117
120		210.8	0.0083	614.7	0.0242	162.6	0.0064
150		221.0	0.0087	693.4	0.0273	1955.8	0.0770
180	180	944.9	0.0372	546.1	0.0215	2420.6	0.0953
210		114.3	0.0045	256.5	0.1010	3373.1	0.1328
240		0	0	182.9	0.0072	523.2	0.0206
270		10.2	0.0004	38.1	0.0015	187.9	0.0074
300		0	0	48.3	0.0019	38.1	0.0015
330	330	55.9	0.0022	95.6	0.0038	53.3	0.0021

Note that θ and ϕ between 0 and 180 degrees correspond to Rollover Burrs while angles larger than 180 degrees correspond to Entrance Burrs.

Table 11. Typical Burr Properties Produced by Surface Grinding

Burr Location	Burr Height		Burr Thickness	
	μm	in.	μm	in.
1	63.5	0.0025	38.1	0.0015
2	71.1	0.0028	35.6	0.0014
3	86.4	0.0034	58.4	0.0023
4	45.7	0.0018	22.9	0.0009

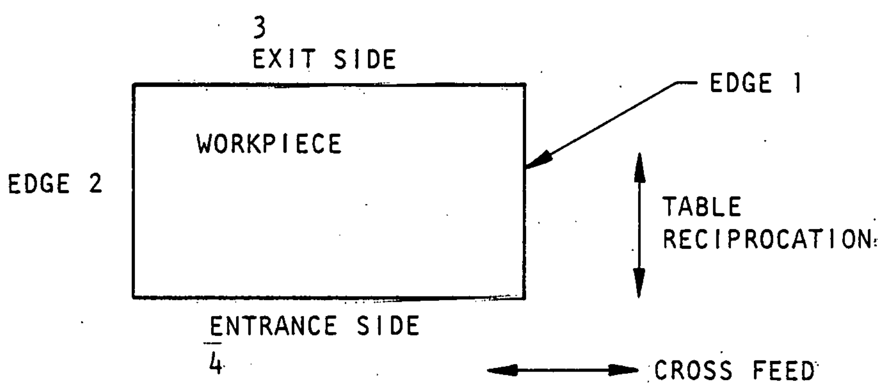


Figure 15. Burr Location in Grinding

Increasing the side cutting edge angle (SCEA) from 0 to 17.5 degrees decreased burr height in 303 Se stainless steel by a factor of 100.[24] The use of negative SCEA greatly increases all burr properties. Increasing the radial depth of cut increases burr height at a rate of 0.0005 mm/mm depth of cut. The change of burr height as a function of feedrate is essentially negligible in 303 Se. For a SCEA of 0 degrees, burr thickness in 303 Se increases at a rate of 0.7 mm/mm/rev.

Burrs produced by automatic screw machines on precision miniature parts of these materials typically are much smaller than indicated. A typical burr under these conditions is 25.4 μm thick by 25.4 μm high. This is attributed to the need to use sharp tools and controlled slow feedrate.

Table 12. Properties of Burrs Formed by Turning a Stepped Shaft

Property	Workpiece Material and Hardness				
	303 Se (R_B84)	15-5 PH (R_c37)	BeCu (R_B96)	Kovar (R_B88)	Hiperco 50 (R_c31)
Burr Height					
μm	493	46	41	208	30
in.	0.0194	0.0018	0.0016	0.0082	0.0012
Burr Thickness					
μm	114	43	56	91	41
in.	0.0045	0.0017	0.0022	0.0036	0.0016

Table 13. Burrs Produced on Precision Parts by Fine Edge Blanking

Property	Workpiece Material		
	302 SST	Alloy 6 Brass (Hard)	6061-T6 Aluminum
Burr Height			
μm	33	69	188
in.	0.0013	0.0027	0.0074
Burr Thickness			
μm	20	33	91
in.	0.0008	0.0013	0.0036

Burrs Formed by Abrasive Cutoff Saws

When abrasive wheels are used to cut parts from the bar stock, huge burrs can form on all edges cut. Burr size can be controlled by keeping the wheel and part cool. Burr size also is a direct function of wheel width: thin wheels do not generate as much heat or force as larger wheels. A 331 μm (0.015 in.) thick silicon carbide wheel will produce a burr only 25.4 by 25.4 μm if handled correctly. A wheel 3.175 mm (0.125 in.) thick can easily produce burrs 127 μm by 3.175 mm.

Burrs Formed by Blanking Operations

In blanking or piercing operations, burrs are produced only on the bottom of the workpiece. Table 13 presents some burr properties measured from Bendix parts produced by fine edge blanking.

Published data indicates that a large die radius reduces burr size in conventional blanking.[44] Burr thickness and height also increase as punch-to-die clearance increases, but the relationship is not linear.[45] For steels, clearance of 2.5 percent of the stock thickness generally produces the smallest burr but such tight fits greatly increase tool wear. Initial burr size is reduced as the punch face finish is improved. Burr size is also influenced greatly by the construction of the die button.[46] In conventional dies, burr height generally will increase at a rate of 50.8 μm (0.002 in.) per 100,000 strokes or faster, depending upon die construction and materials.[47]

Burrs Formed by Shearing

High speed shearing reportedly produces smaller burrs than conventional shearing. This is the result of a critical velocity for plastic deformation. Above this threshold, velocity shearing energies fall to up to half of their low speed values. Burr size therefore would similarly fall.

The Effect of Workpiece Material Properties on Burr Size

Two material factors are directly linked to burr size:

- Workpiece Ductility, and

- Strain Hardening Exponent.

Large burrs cannot form in brittle materials. Cast irons, for example, often have edges with no visible burr. These materials have values of elongation of 0.5 to 3.0 percent in a 50 mm gage length. Since the material has little capacity for plastic deformation, large burrs cannot form. If, however, the cutting tool heats the cast iron enough to change its structure, and the material is no longer brittle at the edges or machined surfaces, a noticeable burr can form. Tungsten is another example of a basically non-ductile material, as is Hiperco 50. Hiperco 50, however, is extremely sensitive to heat generated in cutting.

The strain hardening exponent n in the following equation is the second factor which influences burr size.

$$\sigma = \sigma_o \varepsilon^n \qquad (17)$$

where:

σ = True stress,

σ_o = Material stress at a true strain of 1.0,

ε = True strain in a specimen, and

n = Strain hardening exponent (also called strain hardening coefficient in some publications).

This equation describes the relationship between stress and strain for most materials. As n increases, burr thickness typically increases, although the relationship is not usually directly proportional. Equation 5 and Figure 3 illustrate the theoretical effects of n. Test data from turning tests indicate the same is true for Poisson burrs.[35]

These two material properties can be used to predict the tendency for a material to form large or small burrs. A brittle material which is not sensitive to cutting heat will produce short burrs; thus elongations of 5 percent or less will predict the existence of short burrs, while elongations of 60 percent, such as occur with 303 Se stainless steel, signal the likelihood of tall burrs. Since burrs form by different mechanisms, not all burrs will be shorter or taller than those in a less ductile material, although they will tend to be shorter or taller overall.

Values of n of 0.1 indicate a material will form a burr of normal thickness. An n of 0.5, such as associated with 303 Se stainless steel, indicates that thick burrs probably will occur.

Table 14 lists some common values of n and elongation. Seidel[51] indicates that, in brass, burrs become particularly noticeable if the ratio of ultimate tensile strength to elongation at rupture (in 50.8 mm gage length) is less than 7500. In the SI system of units, this ratio should be greater than 5.0. When the work required to reach the ultimate tensile strength exceeds 89.6 J/cm^3 (13,000 in. lb/in.^{3}) burrs will be noticeable in brass.

The Effect of Burr Size on Deburring Techniques

At the beginning of this report, it was indicated that, given enough time, any deburring process will remove any size burr. In the real world, however, the required surface finish and edge radius, as well as limitations in allowable part size change, constrain one to specific processes and conditions within processes.

Table 14. Elongation and Strain Hardening Data for Selected Materials

Material	Hardness (BNH)	True Strain at Failure (mm/mm) (in./in.)	Strain Hardening Data		Ultimate Elongation (Percent)
			Exponent (n)	Coefficient (GPa) (ksi)	
303 and 303 Se Stainless Steel					
Fully Annealed	160		0.45	(1.28)(185)	60
Cold Drawn Bar	228	(29.5)(1.16)	0.51	(1.41)(205)	40
Cold Drawn to 60 Percent RA	425				10
Titanium (99 Percent) Annealed					47
1020 Steel Annealed		(26.7)(1.05)	0.26	(0.53)(77)	30 to 40
17-4 PH Stainless					
H900	420	(16.5)(0.65)	0.22	(2.26)(328)	14
H1100	332	(16.5)(0.65)	0.01	(1.79)(260)	17
416 Stainless Temp and Cold Drawn	215				15
Cast Iron					0
Tobin Brass Rolled					40
6061-T6 Aluminum			0.05	(0.41)(60)	17
7075 Aluminum					8
Half Hard BeCu					5

While mathematical relationships have not been developed between all these constraints, the companion to this report[23] describes the general capabilities of 24 deburring processes by these criteria.

As seen in Table 15, processes such as water jet sanding, mechanized cutting, thermal energy, manual deburring, and electrochemical deburring are not greatly influenced by allowable stock loss under most conditions. They concentrate all forces at part edges rather than surfaces. All the processes, however, are limited by a relationship between the initial burr size and the final edge radius. For example, abrasive jet deburring can remove a 25.4 μm thick burr while removing 12.7 μm or less material from surrounding surfaces and producing a radius of 50.8 μm or less. If a 127 μm radius is allowed, a 76.2 μm thick burr can be removed while assuring stock losses of 12.7 μm or less.

The significance of Table 15 can be appreciated by briefly scanning the first 14 tables. As seen in those tables, a typical burr by most processes is 50.8 to 76.2 μm thick. In Table 15, no single process appears capable of removing these size burrs while maintaining stock losses less than 12.7 μm and guaranteeing final edge radii of 50.8 μm or less. If edge radii of 127 μm are allowable, several processes can be used.

When parts require precision low radii, low loss conditions, only two possibilities exist:

- Develop non-standard variations of the deburring processes, or

- Make smaller burrs.

A number of special techniques have been developed for all deburring processes to accelerate deburring action. These process alterations, however, generally increase the cost of the basic deburring operation. In vibratory deburring, for example, parts can be attached to fixtures which in turn are attached to the frame of the deburring machine. This can increase the deburring action two to three times, but tooling and individual handling are required for each part. Notable variations exist for abrasive flow, chemical, electropolish, and all the loose abrasive deburring processes. No data now exists which will allow one to compare the effectiveness of the altered processes to their more normal capabilities.

Smaller burrs can be produced by three techniques: the machining speeds, feeds, tool geometry, and workpiece hardness can be adjusted; the types of processes used to produce the parts can be changed so that only small burrs are produced; or two deburring techniques can be used, with the first removing a large burr and the second removing the small burr produced by the first.

Table 15. Burr Sizes Which Can Be Removed From 303 Se Stainless Steel When the Maximum Allowable Edge Radius and Stock Loss Are Specified

	Maximum Allowable Edge Radius and Stock Loss*							
	50.8 µm (0.002 in.) Radius				127 µm (0.005 in.) Radius			
	2.54 µm (0.0001 in.) Stock Loss		12.7 µm (0.0005 in.) Stock Loss		2.54 µm (0.0001 in.) Stock Loss		2.54 µm (0.00005 in.) Stock Loss	
Deburr Process	µm	in.	µm	in.	µm	in.	µm	in.
Barrel Tumbling	38.1	0.0015	38.1	0.0015	38.1	0.0015	76.2	0.003
Vibratory Deburring	38.1	0.0015	38.1	0.0015	38.1	0.0015	76.2	0.003
Centrifugal Barrel	38.1	0.0015	38.1	0.0015	38.1	0.0015	76.2	0.003
Spindle Finishing	38.1	0.0015	38.1	0.0015	38.1	0.0015	76.2	0.003
Abrasive Jet	25.4	0.001	25.4	0.001	25.4	0.001	76.2	0.003
Water Jet	12.7	0.0005	12.7	0.0005	25.4	0.001	25.4	0.001
Abrasive Flow**	2.5	0.0001	12.7	0.0005	2.5	0.0001	12.7	0.0005
Liquid Hone	5.1	0.0002	7.6	0.0003	5.1	0.0002	7.6	0.0003
Sanding***	25.4	0.001	25.4	0.001	76.2	0.003	76.2	0.003
Manual Deburring	25.4	0.001	25.4	0.001	76.2	0.003	76.2	0.003
Brushing	25.4	0.001	25.4	0.001	76.2	0.003	76.2	0.003
Mechanized Cutting	25.4	0.001	25.4	0.001	76.2	0.003	76.2	0.003
Flame	12.7	0.0005	12.7	0.0005	50.8	0.002	50.8	0.002
Thermal Energy Method†	25.4	0.001	25.4	0.001	50.8	0.002	50.8	0.002
Plasma Arc	12.7	0.0005	12.7	0.0005	50.8	0.002	50.8	0.002
Chlorine Gas	2.5	0.0001	12.7	0.0005	2.5	0.0001	12.7	0.0005
Chemical	2.5	0.0001	12.7	0.0005	2.5	0.0001	12.7	0.0005
Ultrasonic	2.5	0.0001	12.7	0.0005	2.5	0.0001	12.7	0.0005
Chemical Vibratory	2.5	0.0001	12.7	0.0005	2.5	0.0001	12.7	0.0005
Electropolish	2.5	0.0001	12.7	0.0005	2.5	0.0001	12.7	0.0005

Table 15 Continued. Burr Sizes Which Can Be Removed From 303 Se Stainless Steel When the Maximum Allowable Edge Radius and Stock Loss Are Specified

	Maximum Allowable Edge Radius and Stock Loss*							
	50.8 μm (0.002 in.) Radius				127 μm (0.005 in.) Radius			
	2.54 μm (0.0001 in.) Stock Loss		12.7 μm (0.0005 in.) Stock Loss		2.54 μm (0.0001 in.) Stock Loss		2.54 μm (0.00005 in.) Stock Loss	
Deburr Process	μm	in.	μm	in.	μm	in.	μm	in.
Electrochemical	25.4	0.001	25.4	0.001	76.2	0.003	76.2	0.003
Electrochemical Vibratory	5.1	0.0002	12.7	0.0005	5.8	0.0002	25.4	0.001
Magnetic Loose Abrasive	5.1	0.0002	12.7	0.0005	5.8	0.0002	25.4	0.001

*A triangular burr shape with height equal to thickness is assumed. Data represents best estimate with current information, assuming that a 0.81 μm (32 μin.) finish must be maintained or improved slightly, that the burr is exposed to the deburring process, that the workpiece has a volume in the order of 2.050 mm^3 (0.05 $in.^3$), and that the standard process approach is used. Better results may be possible by using unique process approaches.

**Extrude hone and Dynetics processes

***Sanding typically processes another small burr instead of a radius. With a slack belt sander, the burr shown should be removable at acceptable manufacturing rates.

†Surftran process

As an example, from Equation 7 and Table 4, at a feedrate of 38.1 μm/rev (0.0015 in./rev) in 303 Se stainless steel with a four facet drill, we can expect an exit burr thickness of 1.0 (0.0015) + 0.0013 = 71.1 μm (0.0028 in.). By slowing the feedrate to 12.7 μm/rev (0.0005 in./rev), the thickness drops to 45.7 μm (0.0018 in.).

Reviewing Table 15, however, indicates that the burr is still too thick for any process to remove while maintaining a stock loss of 12.7 μm and producing a radius of 50.8 μm or less. For larger allowable radii and stock loss, this reduction in burr thickness would be helpful but it requires increasing machining time by a factor of 3.0, making it is desirable to find another technique for minimizing burr thickness.

As seen in Figure 10, burr thickness can be dramatically reduced on holes in flat workpieces by placing hard backup material beneath the workpiece. For the conditions studied, this approach reduced burr thickness from 76.2 μm to 10.2 μm. The feedrate was not changed but an increase in cost would accompany this approach because of the cost of backup material and a somewhat shorter drill life.

Thus far in this section, burr thickness has been used as the criteria most significant in deburring. While that is true, burr height is also important. As indicated elsewhere,[17,20] for a given burr thickness deburring basically occurs at a fixed rate of change in burr height. As an example, burr height will decrease at a rate of 0.1 μm/s (0.00023 in./min) for a 25.4 μm thick burr in a centrifugal barrel tumbling unit under certain conditions. A 127.0 μm thick burr will decrease in height at the rate of 0.025 μm/s (0.00006 in./min) under the same conditions. Thus accurate predictions of deburring effectiveness must consider both burr thickness and height.

Changing the type of process used to machine the workpiece can significantly reduce burr size. Grinding, for example, generally produces a smaller burr than does milling. EDM produces a recast material at edges which can be easier to remove than conventional burrs. When properly used, abrasive cutoff saws can produce burrs smaller than other methods. Unless used carefully, many processes will produce a larger burr.

Two techniques are often used to remove burrs without realizing it. Many vibratory deburred parts are subjected to a quick hand removal of heavy burrs prior to vibratory deburring. Flat parts can be sanded to remove heavy burrs prior to buffing or vibratory finishing. In both of these examples, the first deburring process removes heavy burrs but also generates small burrs. The second process quickly removes the small burrs without affecting dimensions. EDM has also been tried as a quick technique for removing heavy burrs. When holes break out into a common center hole which is tightly toleranced, a sharp punch forced through the center hole will remove most of the heavy burr which occurs in such cases. Chemical deburring has been used as a quick method of softening heavy rollover burrs so they can be removed easily by vibratory deburring. Each of these examples requires two processes; yet, in many instances, two processes can be cheaper than one.

Specific Techniques For Minimizing Deburr Costs

The economic results of changing feeds, speeds, or machining processes have been documented in a number of publications. The Air Force Machinability Data Center,[48] for example, has published an excellent group of equations which can be used to calculate the cost of slowing feeds or speeds. The cost of changing feeds and speeds for most common processes is therefore easily determinable. These equations and some sample data are presented in Figures 16 through 19. It should be noted, however, that the data for tool life is not realistic for most precision miniature parts.

Calculating the cost of deburring operations is one facet which has not been discussed to any extent in the literature. In general, however, Equations 18 through 26 will provide close first estimates.

Loose Abrasive Processes:

$$C = \left[\frac{C_D+C_M+C_L(1+D_O)+WC_Pt+C_A+C_E+C_C+C_W}{N}\right], \tag{18}$$

Thermal Energy Method:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_g}{n} + \frac{C_t}{N_p}, \tag{19}$$

Brush Deburring:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_b}{N_{p1}}, \tag{20}$$

Flame Deburring:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_g}{n}, \tag{21}$$

Manual Deburring:

$$C = \left[C_L(1+D_O)+C_A\right]\frac{1}{N} + \frac{C_t}{N_p}, \tag{22}$$

TURNING

$$C = M\left[\frac{D(L+e)}{3.82f_r v} + \frac{R}{r} + t_i + \frac{DLt_d}{3.82f_r vT}\right] + \frac{DL}{3.82f_r vT}\left[\frac{C_p}{(K_1+1)} + Gt_s + \frac{Gt_b}{k_2} + \frac{C_c}{k_3} + C_w + Gt_p\right] \quad (1)$$

MILLING

$$C = M\left[\frac{D(L+e)}{3.82Zf_t v} + \frac{R}{r} + t_i + \frac{Lt_d}{ZT_t}\right] + \frac{L}{ZT_t}\left[\frac{C_p}{(K_1+1)} + Gt_s + \frac{Gt_b}{k_2} + \frac{ZC_c}{k_3} + C_w + Gt_p\right] \quad (2)$$

DRILLING OR REAMING

$$C = M\left[\frac{D(L+e)}{3.82f_r v} + \frac{R}{r} + t_i + \frac{Lt_d}{T_t}\right] + \frac{L}{T_t}\left[\frac{C_p}{(K_1+1)} + Gt_s + Gt_p\right] \quad (3)$$

TAPPING

$$C = M\left[\frac{mD(L+e)}{1.91v} + \frac{R}{r} + t_i + \frac{Lt_d}{T_t}\right] + \frac{L}{T_t}\left[\frac{C_p}{(K_1+1)} + Gt_s + Gt_p\right] \quad (4)$$

CENTER DRILLING OR CHAMFERING

$$C = M\left[\frac{D(L+e)}{3.82f_r v} + \frac{R}{r} + t_i + \frac{u_c t_d}{T_h}\right] + \frac{u_c}{T_h}\left[\frac{C_p}{(K_1+1)} + Gt_s + Gt_p\right] \quad (5)$$

HANDLING AND SETUP

$$C = M\left[t_L + \frac{t_o}{N_L}\right] \quad (6)$$

- $ / MIN.
- FEEDING TIME
- RAPID TRAVERSE TIME
- LOAD & UNLOAD TIME
- SETUP TIME
- CUTTER INDEX TIME
- DULL TOOL REPLACEMENT TIME
- TOOL DEPRECIATION COST
- TOOL RESHARPENING COST
- REBRAZING OR BLADE RESET COST
- INSERT OR BLADE COST
- GRINDING WHEEL COST
- TOOL PRESETTING COST

Figure 16. Equations for Calculating Machining Costs Per Piece[48]

SYMBOL	DEFINITION	APPLIES TO OPERATION				
		TURN	MILL	DRILL AND REAM	TAP	CENTER DRILL
C	cost for machining one workpiece; $/workpiece	✓	✓	✓	✓	✓
C_c	cost of each insert or inserted blade; $/blade	✓	✓	No	No	No
C_p	purchase cost of tool or cutter; $/cutter	✓	✓	✓	✓	✓
C_w	cost of grinding wheel for resharpening tool or cutter; $/cutter	✓	✓	No	No	No
d	depth of cut; in.	✓	✓	No	No	No
D	dia. of work in turning, of tool in milling, drilling, reaming, tapping; in.	✓	✓	✓	✓	✓
e	extra travel at feedrate (f_r or f_t) including approach, overtravel, and all positioning moves; in.	✓	✓	✓	✓	✓
f_r	feed per revolution; in./rev.	✓	No	✓	No	✓
f_t	feed per tooth; in./tooth	No	✓	No	No	No
G	labor + overhead in tool reconditioning department; $/min.	✓	✓	✓	✓	✓
k_1	no. of times lathe tool, or milling cutter, or drill, or reamer or tap is resharpened before being discarded	✓	✓	✓	✓	✓
k_2	no. of times lathe tool or milling cutter is resharpened before inserts or blades are rebrazed or reset	✓	✓	No	No	No
k_3	no. of times blades (or inserts) are resharpened (or indexed) before blades (or inserts) are discarded	✓	✓	No	No	No
L	length of workpiece in turning and milling or sum of length of all holes of same diameter in drilling, reaming, tapping; in.	✓	✓	✓	✓	✓
m	no. of threads per inch	No	No	No	✓	No
M	labor + overhead cost on lathe, milling machine or drilling machine; $/min.	✓	✓	✓	✓	✓
n	tool life exponent in Taylor's Equation	✓	✓	✓	✓	No
N_L	no. of workpieces in lot	✓	✓	✓	✓	✓
P	production rate per 60 min. hour; workpieces/hr.	✓	✓	✓	✓	✓
r	rapid traverse rate; in./min.	✓	✓	✓	✓	✓
R	total rapid traverse distance for a tool or cutter on one part; in.	✓	✓	✓	✓	✓
S	reference cutting speed for a tool life of T = 1 min.; ft./min.	✓	No	No	No	No
S_t	reference cutting for a tool life of T_t = 1 inch; ft./min.	No	✓	✓	✓	No
t_b	time to rebraze lathe tool or cutter teeth or reset blades; min.	✓	✓	No	No	No
t_d	time to replace dull cutter in tool changer storage unit; min.	✓	✓	✓	✓	✓
t_i	time to index from one type cutter to another between operations (automatic or manual); min.	✓	✓	✓	✓	✓
t_L	time to load and unload workpiece; min.	✓	✓	✓	✓	✓
t_m	time (average) to complete one operation; min.	✓	✓	✓	✓	✓
t_o	time to setup machine tool for operation; min.	✓	✓	✓	✓	✓
t_p	time to preset tools away from machine (in toolroom); min.	✓	✓	✓	✓	✓
t_s	time to resharpen lathe tool, milling cutter, drill, reamer or tap; min./tool	✓	✓	✓	✓	✓
T	tool life measured in minutes to dull a lathe tool; min.	✓	No	No	No	No
T_h	no. of holes per resharpening	No	No	No	No	✓
T_t	tool life measured in inches travel of work or tool to dull a drill, reamer, tap or one milling cutter tooth; in.	No	✓	✓	✓	No
u_c	no. of holes center drilled or chamfered in workpiece	No	No	No	No	✓
v	cutting speed; ft./min.	✓	✓	✓	✓	✓
w	width of cut; in.	No	✓	No	No	No
Z	no. of teeth in milling cutter or no. of flutes in a tap	No	✓	No	✓	No

Figure 17. Symbols for Cost and Production Rate Equations[48]

Operation: Turn shaft, 3.5 in. diameter by 19 in. long	Brazed Carbide Tool	Throwaway Carbide Tool	Solid HSS Tool
R = total rapid traverse distance for a tool on one part, in.	27.2	27.2	27.2
C_c = cost of each carbide tip or insert, $	.25	1.30	-
C_p = purchase cost of tool, $	3.00	16.30	2.00
C_w = cost of grinding wheel for resharpening tool, $	.07	-	.02
d = depth of cut, in.	.1	.1	.1
D = diameter of work in turning, in.	3.5	3.5	3.5
f_r = feed per revolution, in./rev.	*	*	*
G = labor and overhead cost on tool grinder, $/min.	.15	-	.15
k_1 = no. of times lathe tool is resharpened before discarding (or no. times insert is indexed before throwaway holder is discarded)	12	2000	36
k_2 = no. of times lathe tool is resharpened before rebrazing or resetting	6	-	-
k_3 = no. of times insert is resharpened (or indexed) before insert is discarded	6	8	-
L = length of workpiece in turning, in.	19	19	19
M = labor and overhead cost on lathe, $/min.	.15	.15	.15
N_L = no. of pieces in lot	20	20	20
r = rapid traverse rate, in./min.	100	100	100
t_b = time to rebraze lathe tool, min.	10	-	-
t_d = time to change and reset tool or time to index throwaway insert, min.	5	.4	5
t_L = time to load and unload workpiece, min.	2.3	2.3	2.3
t_o = time to set up lathe for operation, min.	21	21	21
t_s = time to resharpen tool, min.	15	-	10
T = tool life, total time to dull tool, min.	*	*	*
v = cutting speed, ft./min.	*	*	*
e = extra travel of tool in feed (includes approach and overtravel in feed)	.5	.5	.5

Figure 18. Example: Turning on Conventional Engine Lathe[48]

MATERIAL	CONDITION AND MICROSTRUCTURE	BHN	TOOL MATERIAL		TOOL GEOMETRY						CUTTING FLUID Code*	DEPTH OF CUT	FEED	TOOL LIFE END POINT	TOOL LIFE – minutes vs SPEED – feet/minute			
			TRADE NAME	INDUSTRY GRADE	BR°	SR°	SCEA°	ECEA°	RELIEF°	NOSE RADIUS inch		inch	ipr	inch				
4340	Quenched and Tempered	300	78	C-7	0	6	0	6	6	.040	00	.100	.010	.015	(1) 15	(2) 30	(3) 45	(4) 60
	Tempered Martensite														470	400	360	325
4340	Quenched and Tempered	300		T1 HSS	0	15	0	5	5	.005	11 1:20	.060	.010	.060	(5) 15	(6) 30	(7) 45	(8) 60
	Tempered Martensite														77	63	54	45

*Cutting Fluid Code
00 Dry
11 Soluble Oil

Figure 19. Tool Life Data: Turning[48]

Mechanical Deburring:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_t}{N_p} , \quad (23)$$

Chemical Deburring:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_s}{N_p} , \quad (24)$$

ECD Deburring:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_t}{N_p} + \frac{C_s}{N_{p1}} , \text{ and} \quad (25)$$

Electropolish Deburring:

$$C = \left[C_D+C_M+C_L(1+D_O)+WC_Pt+C_A\right]\frac{1}{N} + \frac{C_t}{N_p} + \frac{C_s}{N_{p1}} , . \quad (26)$$

where:

C = Deburring cost per part,

C_D = Depreciation cost per hour = machine cost per operating hours,

C_M = Maintenance cost per hour of operation,

C_L = Labor cost per hour to run machine,

C_P = Cost of power used ($ per kilowatt hour),

C_A = Cost of cleaning per hour after deburring (labor + material),

C_E = Cost of media per hour = media cost times percent hourly attrition,

C_C = Cost of compound per hour,

C_W = Cost of water per hour,

D_O = Overhead as percentage of labor rate,

N = Number of parts run per hour = n/t,

n = Number of parts run per cycle,

t = Time (hours) per cycle,

C_g = Cost of gas per cycle,

C_b = Cost of brush,

N_p = Total number of parts run,

N_{p1} = Number of parts run for a given quantity of solution or tool life,

C_t = Total tool cost,

C_s = Total cost of solution, and

W = Power used, in kilowatts (1 hp = 0.75 kW).

The equations assume the conventional process is used. As previously mentioned, it is frequently possible to alter the process slightly to obtain faster or better results. Such alterations may insert another cost term to the equation. These equations therefore should only be used to provide initial estimates or if, in fact, the conventional approach will be used. In either case, the reader is advised to read the few articles which discuss economics in some depth.[48-52]

The second limitation is that all these equations assume that one knows the value of each individual component and the time required to remove the burr. While it is possible to use rule of thumb costs for media, compounds, and the like, no publications other than two on vibratory deburring[20] and centrifugal barrel finishing[17] provide any information on the time required to remove specific burr sizes. As additional research is reported, this limitation will recede. In the interim, analogies can be drawn between other parts subjected to the same process.

As an example of economics, assume that 400,000 parts are to be deburred and the machine used must have a life that will accommodate that many parts. Then further assume that the values shown in Table 16 are representative.

For the values shown, the TEM would be the least expensive process ($0.018 per part) while manual deburring is obviously an undesirable approach ($1.20 per part). These calculations are predicated on the fact that these processes will in fact remove the burrs without adversely affecting parts.

The data shown in Table 16 is believed to be a reasonable estimate of costs but, before decisions are made, the values should be discussed with knowledgeable vendors or users. The number of parts per cycle and the cycle duration are of course functions of part size, burr size, and other variables. Some of these variables have been defined in detail in previous reports.[6-20,23]

Table 16. Process Used and Cost Values in Dollars Per Unit

Cost Item*	Vibratory	TEM**	Manual	Chemical
C_D	0.40	$5.00	---	0.20
C_M	0.04	1.00	---	0.02
C_L	5.00	5.00	5.00	5.00
C_P	0.04	0.04	0.04	0.04
C_A	0.60***	5.80	5.50	5.50
C_E	0.60	---	---	---
C_C	0.30	---	---	---
C_W	0.15	---	---	---
D_O	0.8	0.8	0.8	0.8
N	50	1500	12	400
n	100	6	1	100
t	2	.004	0.08	0.25
C_g	---	.024	---	---
W	4	4	---	---
C_t	---	1000	1000	---
N_p	400,000	400,000	400,000	400,000
C_s	---	---	---	6,000
Calculated C	0.210	0.018	1.202	0.038

*Assume no automatic load/unload is used.
**Thermal Energy Method
***Assumes operator has time during cycle to clean parts from previous run.

Other Approaches To Controlling Burr Size

Changing feedrate and cutting tool geometry are not the only ways to minimize burr size. Figure 20 illustrates a part in which the sequence of machining operations was changed to produce a smaller burr. In this example, the part was initially produced in two chucker lathe operations, after which the three flats were milled. This resulted in a large burr. By milling the flats before the diameter was finished, that is, before the second lathe operation, the milling burrs were removed in the turning operation. These burrs were smaller than the milling burrs.

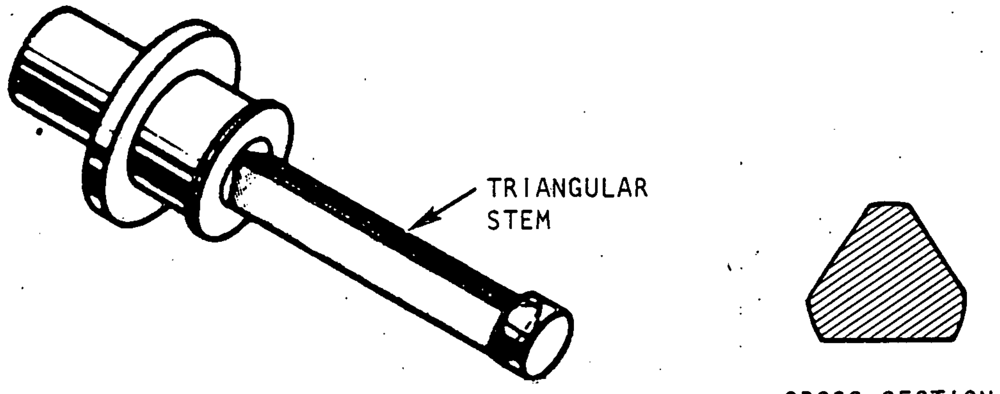


Figure 20. Effect of Process Sequence on Deburring

In this particular example, the part was also deburred in the turning operation by putting a brush in one turret position. This saved considerable manual handling and guaranteed better edge uniformity.

When holes are drilled and tapped, removing a long rollover burr is often easier after tapping because the tap cuts away the root of the burr.

Burr size can be controlled on automatic screw machines by three approaches.

- Use a form tool to form diameters. No burr can form when the tool produces the diameter and the adjoining face at the same time. Any intermediate burr formed is wiped off.
- Break all edges with a chamfering tool. Since tool position can accurately be controlled to 5.08 μm on many materials, the chamfer tool can remove the burrs and still assure small final edge breaks. Chamfering precision miniature stainless steel components typically produces burrs smaller than 12.7 μm.
- Generate corner radii by cam design. While the cutting tool can be programmed to cut radii at edges, it is difficult and severely limits the adjustment capability of tools producing adjacent features.

As a general rule, automatic screw machines which hold tolerances of less than 12.7 μm, fillet radii of 76.2 μm or less, and finishes of 0.8 μm (32 μin.) or better in stainless steel will produce burrs less than 25.4 μm thick and 25.4 μm high. This is a direct result of the low feeds required when using tools having near zero nose radii and the need for keeping sharp cutting tools.

If heavy burrs form in a lathe operation, an extra lathe step of machining off this burr may be much less expensive than using traditional deburring methods. This is frequently true of all heavy burrs--they can be machined off cheaper than deburring.

Chamfering holes before tapping often eliminates the mound of material the tap produces at hole entrance and exit.

Heavy cut-off burrs such as the one shown in the left hand portion of Figure 21 can be prevented by using a vise which holds the workpiece as well as the bar stock until the cut is completed.

As previously indicated, drill exit burr size can be minimized by minimizing the clearance hole in the fixture below the hole to be drilled. For commercial parts, a clearance hole 50.8 μm larger than the drill diameter has been recommended (Figure 22). For precision holes, the value should be smaller although tool life may be greatly shortened by this approach.

One manufacturer of ordnance items found that a previous indenting of the drill exit side minimized burr size as shown in Figure 23. A ball is used to make an indentation on the inside of the part. When the drill comes through, the burr produced will be smaller because of the hardening produced by the indenting operation and because of the geometry of the exit edge. Although the minimum burr is produced when the indentation diameter equals the drill diameter, a smaller indentation diameter will make noticeable improvements.

While backup material will not prevent burr formation, it will often minimize burr size. Material of any hardness can be used to prevent the formation of long rollover burrs. Minimizing other burrs requires the use of back-up materials harder than the workpiece material.

Other Machining Approaches to Minimizing Deburring Costs

Several approaches beside those already mentioned can be used to minimize deburring costs, including:

- Putting the burr where it can be removed easiest,
- Deburring on machine cycle,
- Providing special design deburr tools,

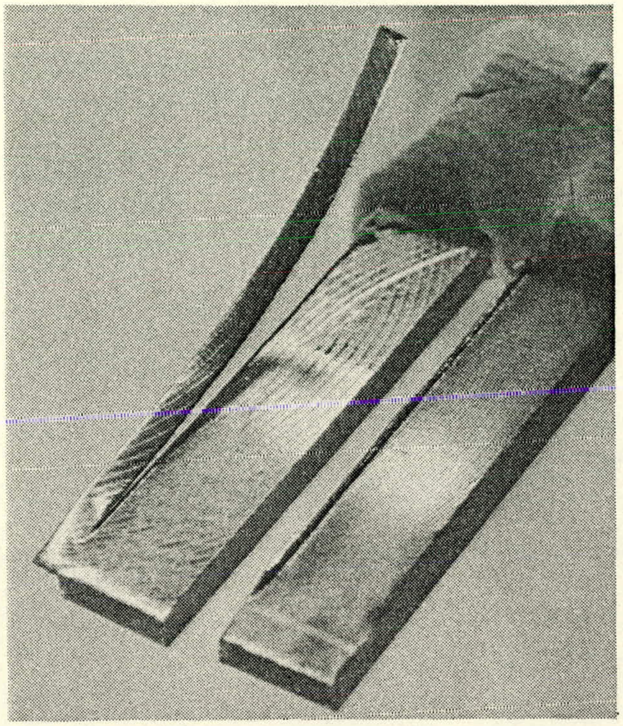


Figure 21. Examples of Cutoff Burr

- Designing the part for burr minimization and ease of removal,
- Designing tooling to accommodate burrs, and
- Specifying actual requirements.

When a rollover burr forms near a hub such as shown in the upper left view of Figure 24, extra care must be exercised to prevent scratching the hub if the burr is removed by hand. If the rollover burr is located at the opposite end of the part, no projection will interfere with the deburring. The same is true of the burr shown in the right hand view. For the easiest and cheapest burr removal, the burr must be carefully positioned.

Locating the burr cannot be an afterthought, however. If a redirection of cutting forces is required, existing tooling may have to be altered to resist the forces. Deburring requirements must be visualized *before* the machining process and tooling are finalized.

Figure 25 is another excellent example of the effect of burr location. If the hobbing exit burr is allowed to form on the hub side, precision deburring will be very time consuming. By fixturing the part so the hob exits over the flat face, the hobbing

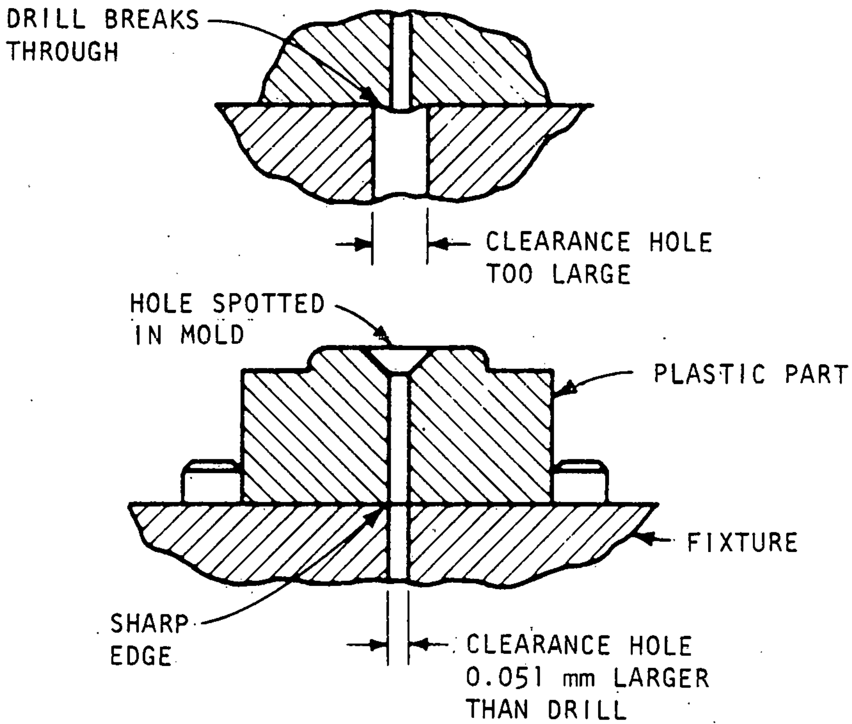


Figure 22. Drill Clearance for Burr Minimization

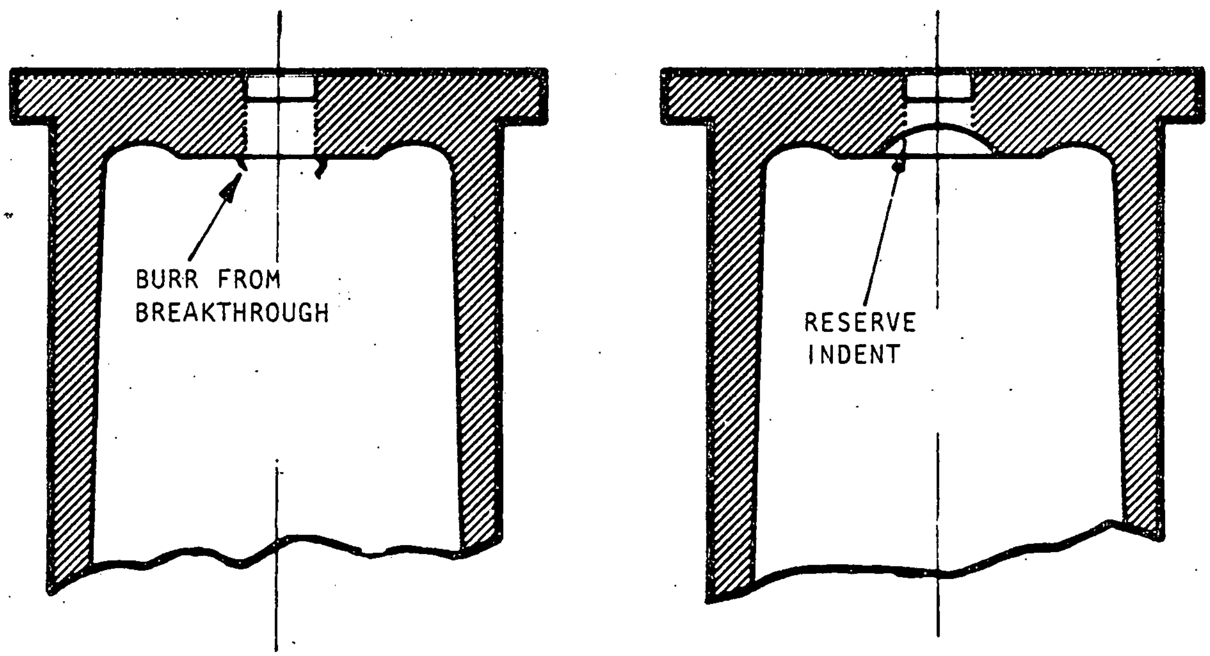
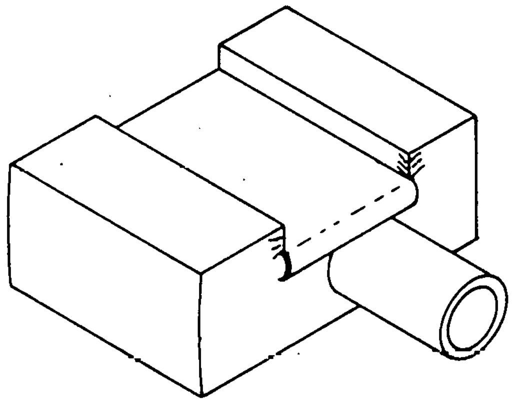
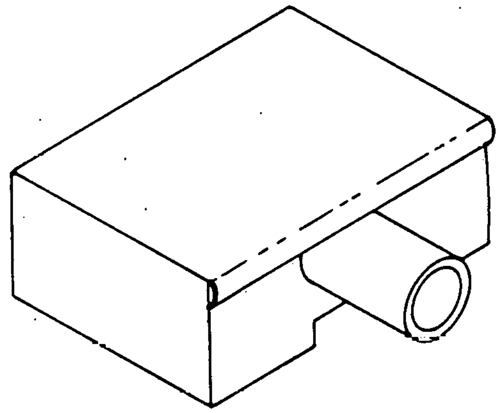


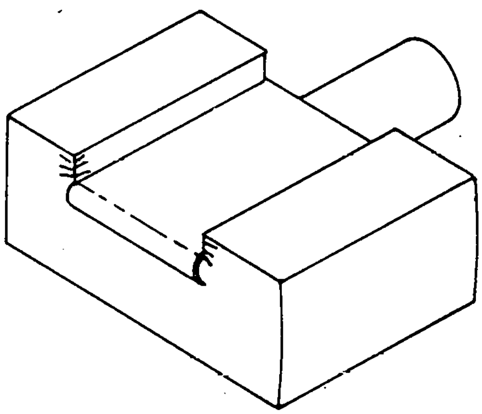
Figure 23. Indenting to Minimize Burr Size



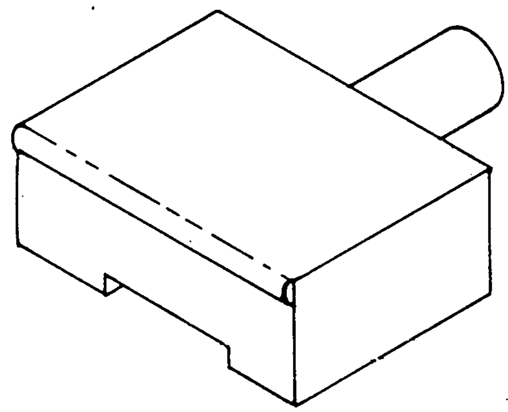
POOR CHOICE OF EXIT BURR LOCATION



POOR CHOICE OF EXIT BURR LOCATION



BETTER CHOICE OF EXIT BURR LOCATION



BETTER CHOICE OF EXIT BURR LOCATION

Figure 24. Burr Locations

burrs can be removed easily by a quick hand sanding operation. The small sanding burrs can then be removed by brushing or in one of the loose abrasive processes.

Even when back-up material is used in multiple part hobbing (Figure 26), the cutter should exit from the flat surface. Since direction of feed or rotation cannot be changed on ratchet teeth and non-gear shapes, burr location must be chosen before hobs are ordered.

When milling "L-shaped" configurations (Figure 27), exit burrs should be placed on the back and top rather than under ledges.

The part in Figure 28 has five holes, four of which require countersinking or counterboring on the bottom surface. By drilling this part with the "to be countersunk" side down, some

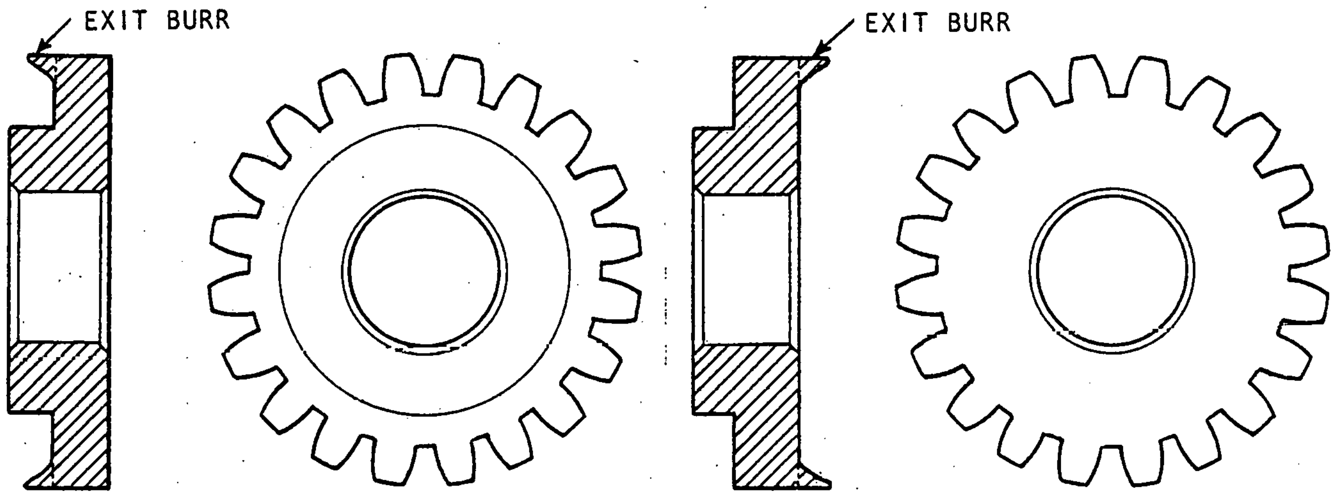


Figure 25. Effect of Burr Location

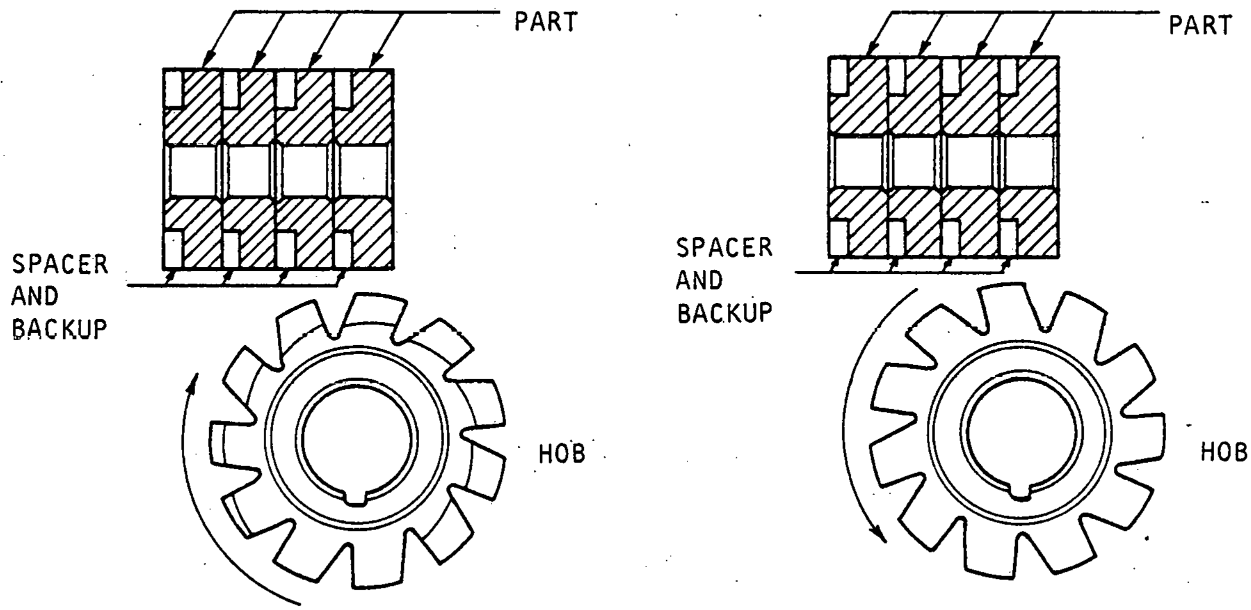
deburring of heavy burrs can be saved. The countersinking tool will remove these heavy burrs while countersinking. If the part is drilled with Side A down, the heavy burr will have to be removed in a special deburring operation.

Although tubular sieve-like parts normally are drilled or punched from the outside inward, this does not have to be the case. One company designed a punch (Figure 29) to pierce outward to put the heavy burrs on the exterior where they can easily be removed.

On small precision gears, it is highly desirable to put the burr on a face which has room for a burr knife. If the burr is allowed to form in the small step where the diameter changes, as shown in Figure 30, it will be extremely difficult to remove the burr without scratching the part.

If cut-off burrs are placed at the nose of the part, as shown in Figure 31, they can be removed relatively easily by vibratory deburring. Removing a burr from behind the square shoulder requires a full radius on the back of the part.

If an undercut for a shoulder relief is produced before the mating surface is machined, the burr produced will be thrown into the undercut and may not have to be removed (Figure 32). This is particularly significant if the parts are cylindrical ones requiring press fits and locating up to a shoulder. In these



PREFERRED APPROACH: THIS PUTS LARGE BURR ON FLAT FACE OF LAST PART.

POOR APPROACH: THIS THEORETICALLY ELIMINATES LARGE EXIT BURR SINCE CUTTER CUTS AGAINST BACKUP. FROM A PRACTICAL STANDPOINT, THIS OFTEN DOES NOT OCCUR BECAUSE OF VARIATIONS IN SPACER AND WORKPIECE THICKNESS AND FLATNESS WHICH ALLOW GAPS BETWEEN BACKUP AND WORKPIECE SOFT SPACERS WILL ALLOW BURR TO FORM EVEN IF GAPS DO NOT EXIST.

Figure 26. Preferred Versus Poor Approaches to Hobbing

situations, the burr in the relief is completely encapsulated by the mating press fit sleeve. If it ever breaks loose, it can never come out of the undercut.

Machinist Influences on Deburring

Production operators can help minimize burr removal costs. They can deburr parts while their machine is cycling on the next part. Even a partial deburr will save time in subsequent operations. Shops in which deburr operators and machine operators are in separate labor classifications should encourage machine operators to work with deburr operators in deciding when tools should be changed. In many shops, unfortunately, the machine operator could care less about the burr he produces because he is not held accountable for the extra work required to remove gross burrs.

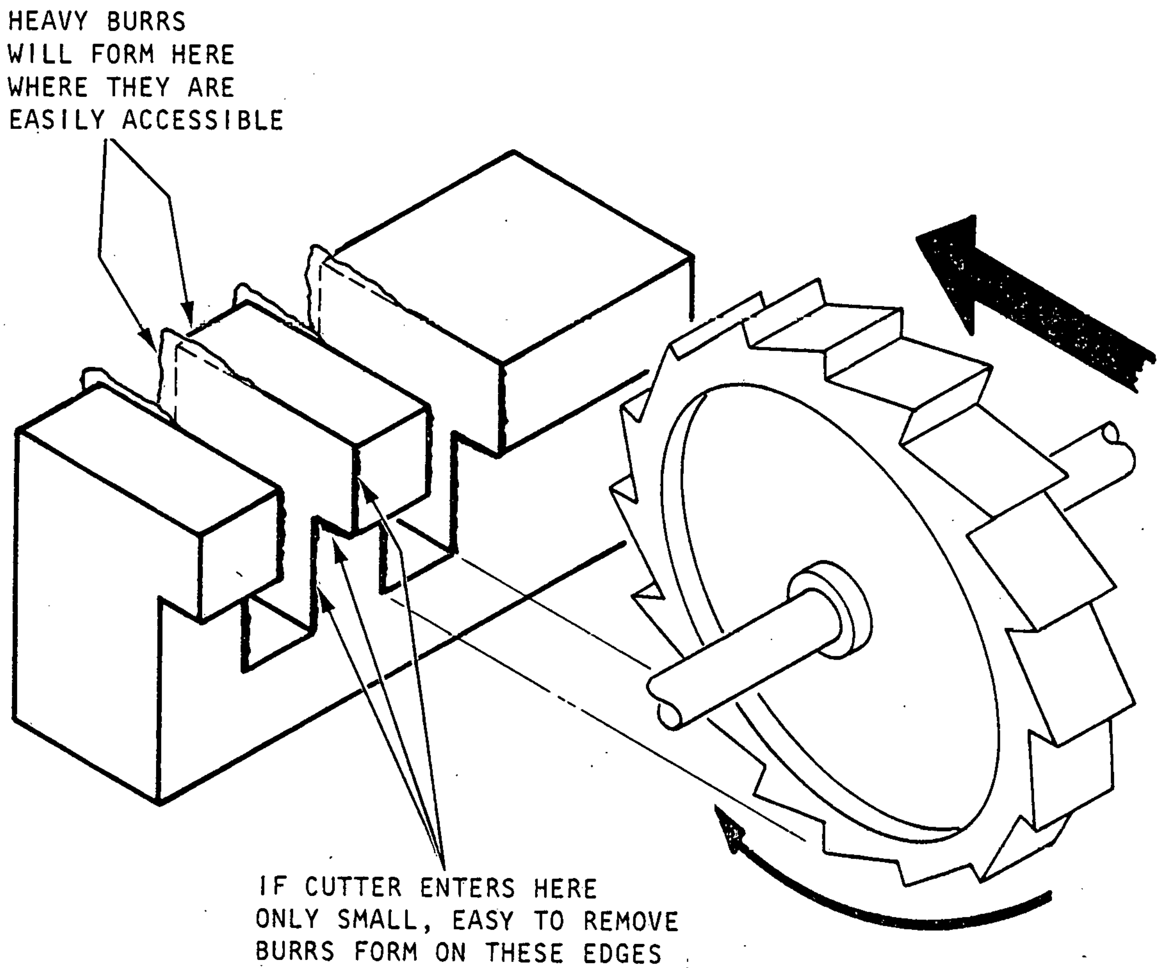


Figure 27. Place Heavy Burrs in Proper Location

As previously indicated (Figure 20), it can be cheaper to combine the deburring operation with the machining operation than to perform two separate operations. It is cheaper to do this in the machining cycle than to have an operator pick up, fixture, deburr, and verify an edge. In addition, it eliminates the flow time associated with an extra deburr operation, it is controllable, and it is independent of operator efficiency. Examples of this include brush deburring on screw machines and lathes, touching edges with sandpaper while the part is still chucked on the lathe, and milling off a heavy rollover burr. These steps can be added on lathes, automatic screw machines, numerical control (N/C) drills and N/C mills.

Minimizing Hand Deburring

Two points should be considered when evaluating manual deburring.

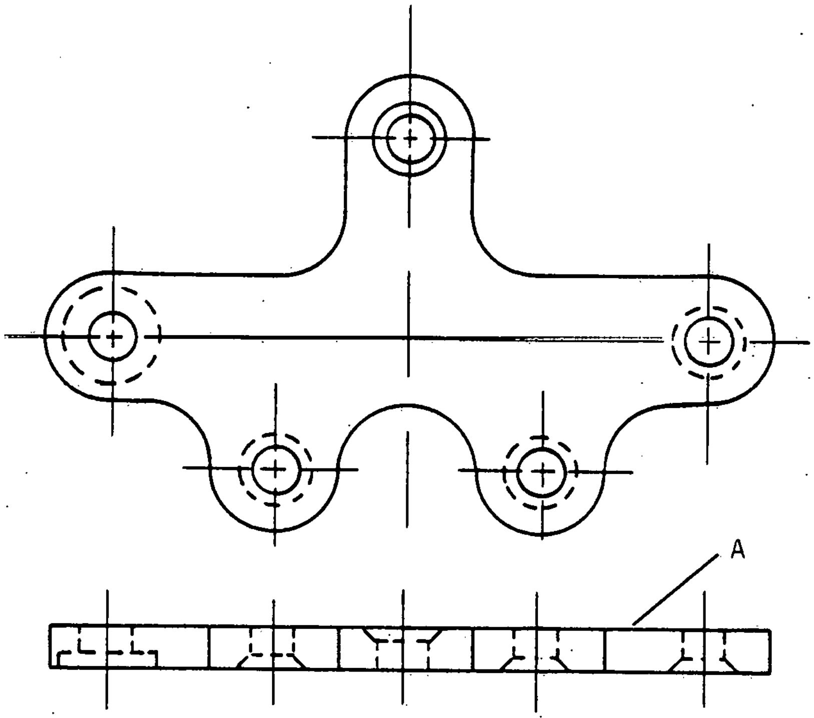


Figure 28. Part Orientation for Minimum Deburring

- Some heavy rollover burrs can be removed quicker manually than on mechanized equipment. On such parts, manually deburr only what will not be removed by mechanized processes.

- Provide operators with special tools to remove heavy burrs. Special knives, reamers, countersinks, or cutters can dramatically speed burr removal.

Deburr only as required for later fixturing and save the majority of the deburring for the final operation. This reduces the time operators spend scrutinizing edges which have already been deburred. Some burr-laden edges may be cut off in later operations; thus, complete in-process deburring would have added unnecessary expense. And if part is scrapped in a later machining operation, deburring costs will not have been wasted.

Special Design Tools for Deburring

Although a number of burr tools can be purchased commercially, special design tools can often save time. Figure 33 illustrates a punch designed to remove the burrs caused by drilling into the

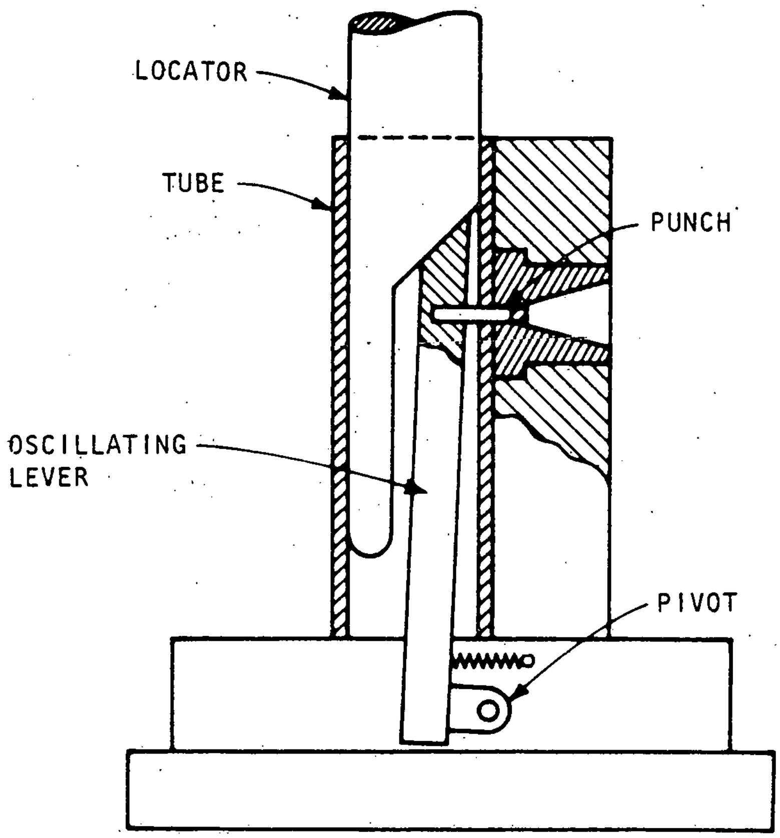


Figure 29. Piercing Burrs Placed on Exterior of Tubular Sleeve

6.35 mm diameter hole. This punch, which is a piece of drill rod relieved at one end, saves hours of work with conventional knives. The small burrs left by the punch can easily be removed by liquid hone or abrasive flow deburring. Such tools should be considered whenever cross holes are encountered.

A simple sanding block with a slot milled to accept a hub saved hours of deburring time on the aluminum gear shown in Figure 34. If the burr had been produced on the flat surface, such a tool probably would not have been required. On extremely small gears, sanding blocks such as this may not be successful because only a narrow strip of the sandpaper is available to deburr and it quickly wears.

Every year new deburring tools are introduced commercially. As an example, it is now possible to obtain cross hole deburring brushes only 0.82 mm (0.032 in.) in diameter. These brushes are ideal for removing burrs from small threads.

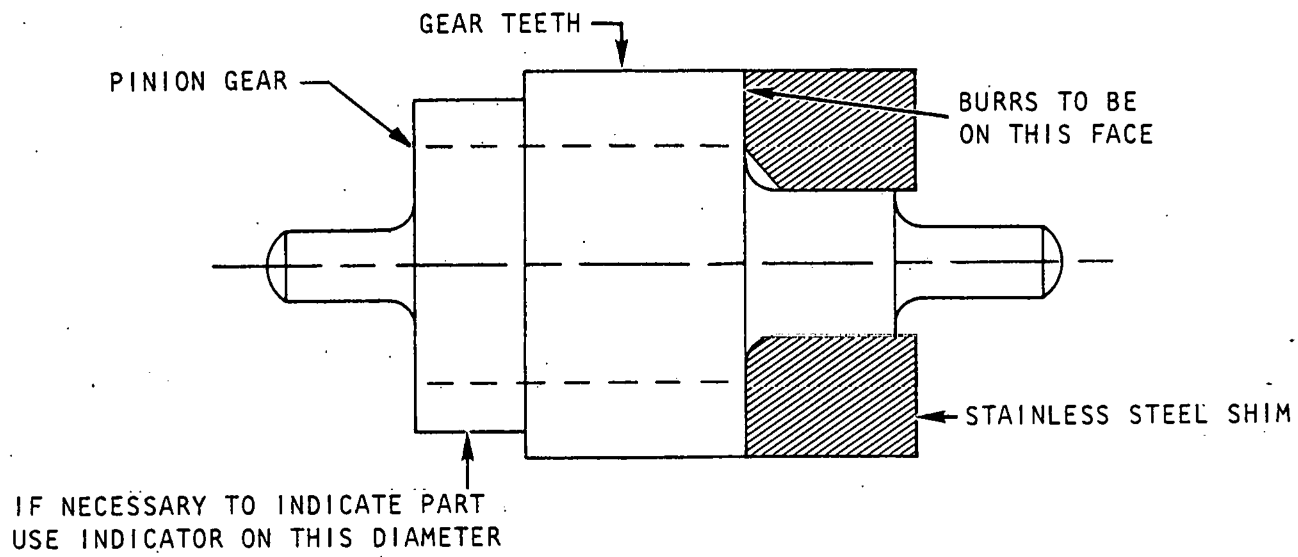


Figure 30. Identify Desired Burr Location and Use Backup Materials to Minimize Burrs

VIBRATORY DEBURRING CAN BE EXPEDITED IF CUTOFF BURR IS LEFT ON ROUNDED END OF SCREW MACHINE PART RATHER THAN ON FLAT END

Figure 31. Place Burr for Easiest Removal

Designing to Minimize Deburring Costs

As previously indicated, deburring and machining costs can be minimized by appropriate changes in workpiece and tooling designs.

Figure 22 is one example of designing tooling to minimize burrs. The need for a special cutting tool in Figure 31 is another example. When a lathe part is produced by a one piece form tool, burrs can only form at the two outer edges of the part rather than all edges because the tool will not allow burrs to form (Figure 35).

Designing burr clearance in fixtures (Figure 36) will eliminate some of the in-process deburring frequently required. In some

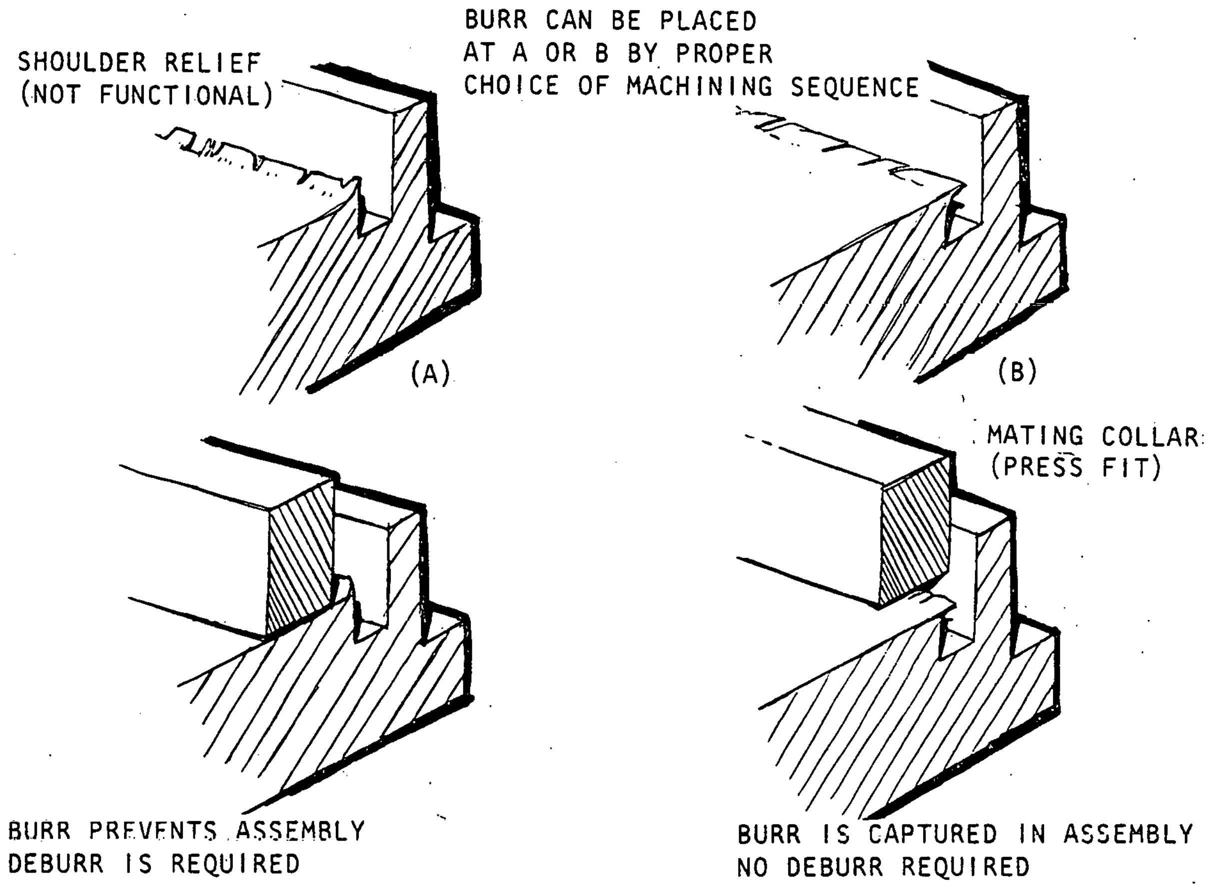


Figure 32. Impact of Burr Location

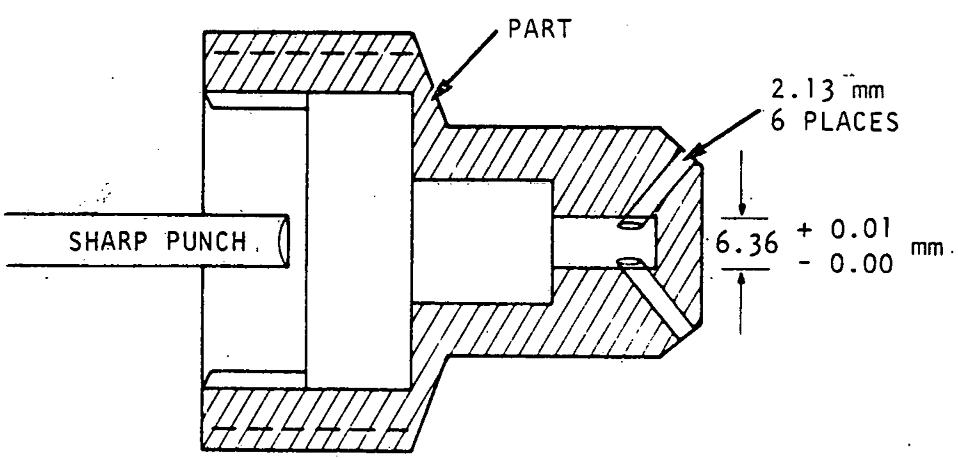


Figure 33. Punch Designed for Deburring Intersecting Holes

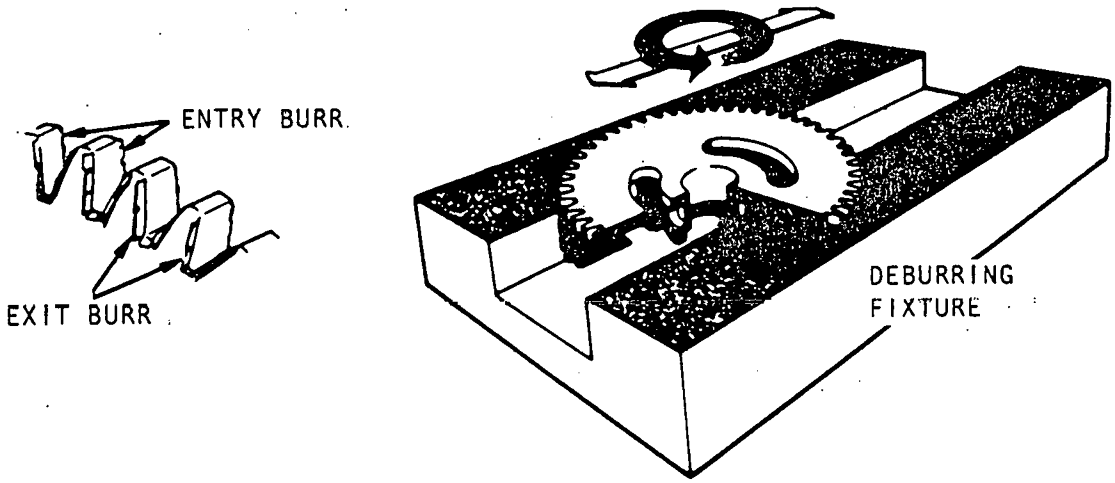


Figure 34. Sanding Block for Gears With Hubs

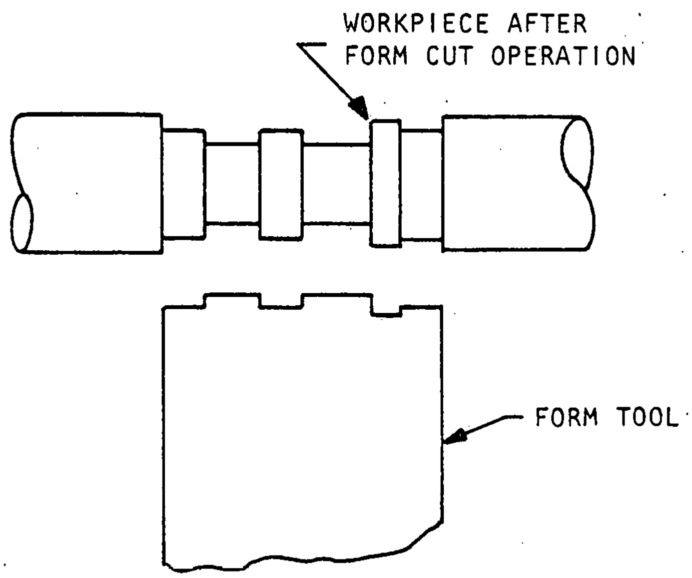


Figure 35. Form Tool for Turned Parts

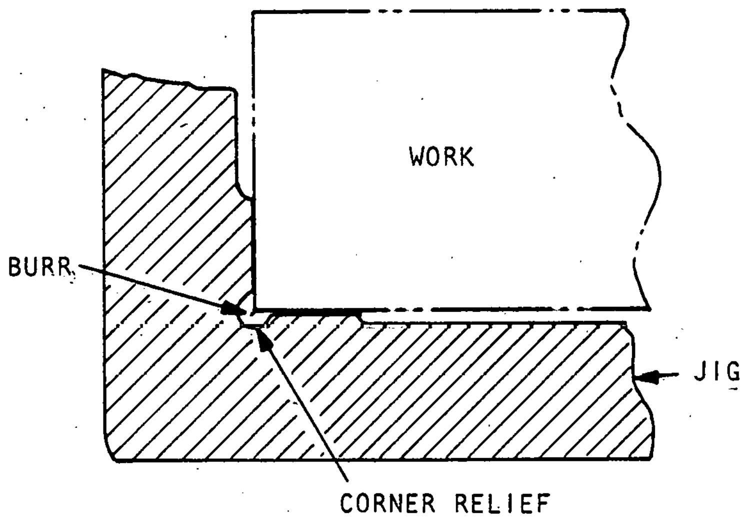


Figure 36. Burr Clearance in Fixtures

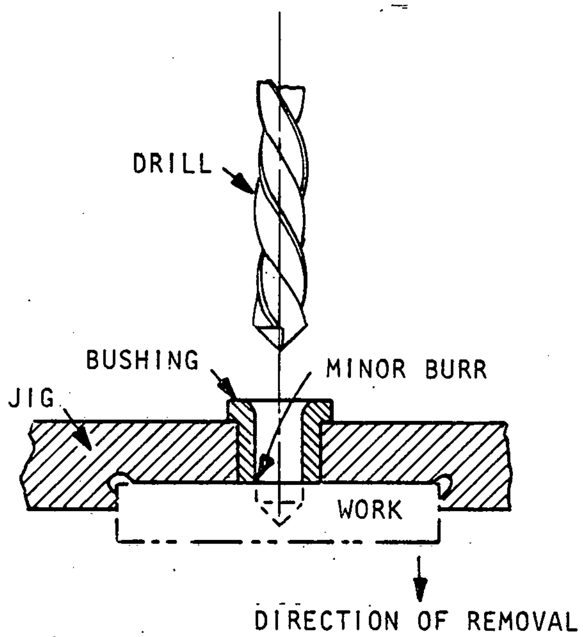


Figure 37. Burr Clearance in Drill Fixtures

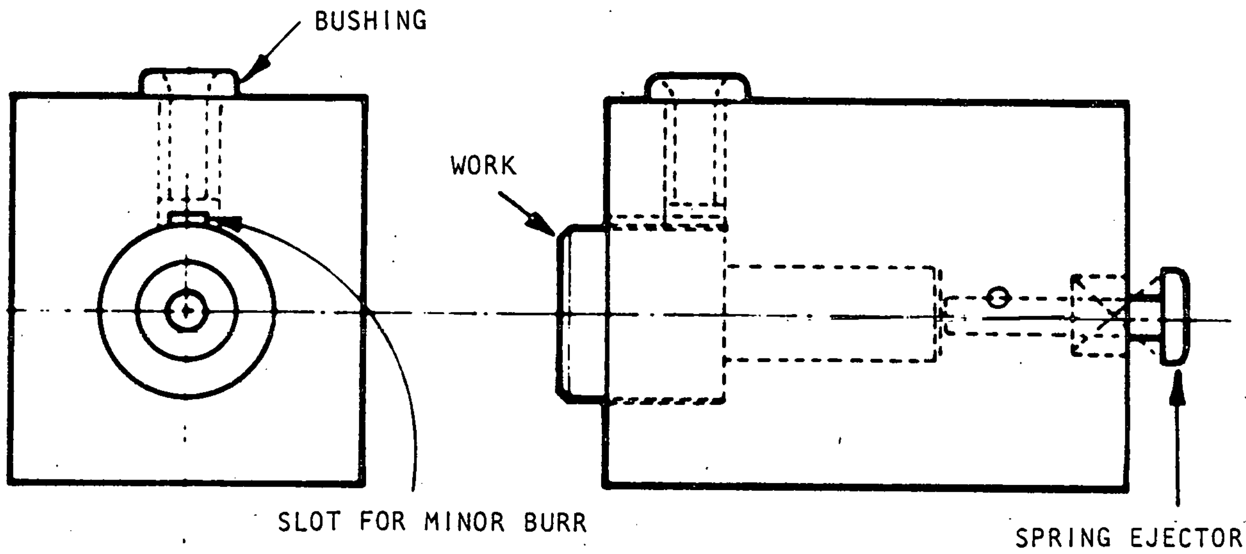


Figure 38. Knockout for Removing Part Having Drill Burr

cases, clearance is required just to remove the part from the fixture. Tooling must be designed with the realization that burrs may prevent easy part removal (Figures 37 and 38).

Figure 39 illustrates a die-made part which could not be effectively deburred by vibratory or centrifugal barrel methods because the dimension *b* was reduced below allowable limits before the burr in the holes was removed. Assuming the die is sharp, the solution in this case is to design the die so *b* is at its maximum size. The deburring process will reduce it while removing the burr from the hole. In this particular case, the two holes were drilled and the burrs were much larger than the burr produced from blanking. This example again emphasizes the need to coordinate deburring needs with initial tool design and process selection.

Cost reductions associated with product design fall into two categories:

- Design of components to eliminate or minimize the need for deburring, and
- Understanding component function and actual deburring requirements.

Some components and assemblies can operate adequately without deburring. The mechanisms in many children's moving toys, for example, need not be deburred. Sheet metal edges are often more aesthetic and troublefree if a rolled edge is produced, and there

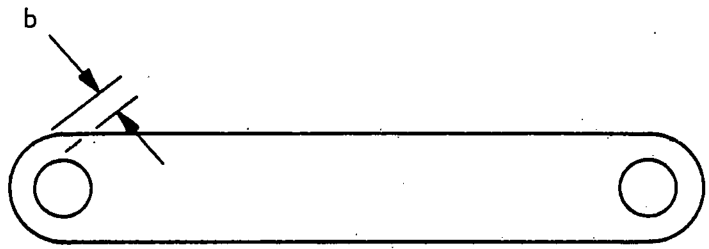


Figure 39. Die Should Be Designed So b Will be Within Drawing Requirements *After* Deburring

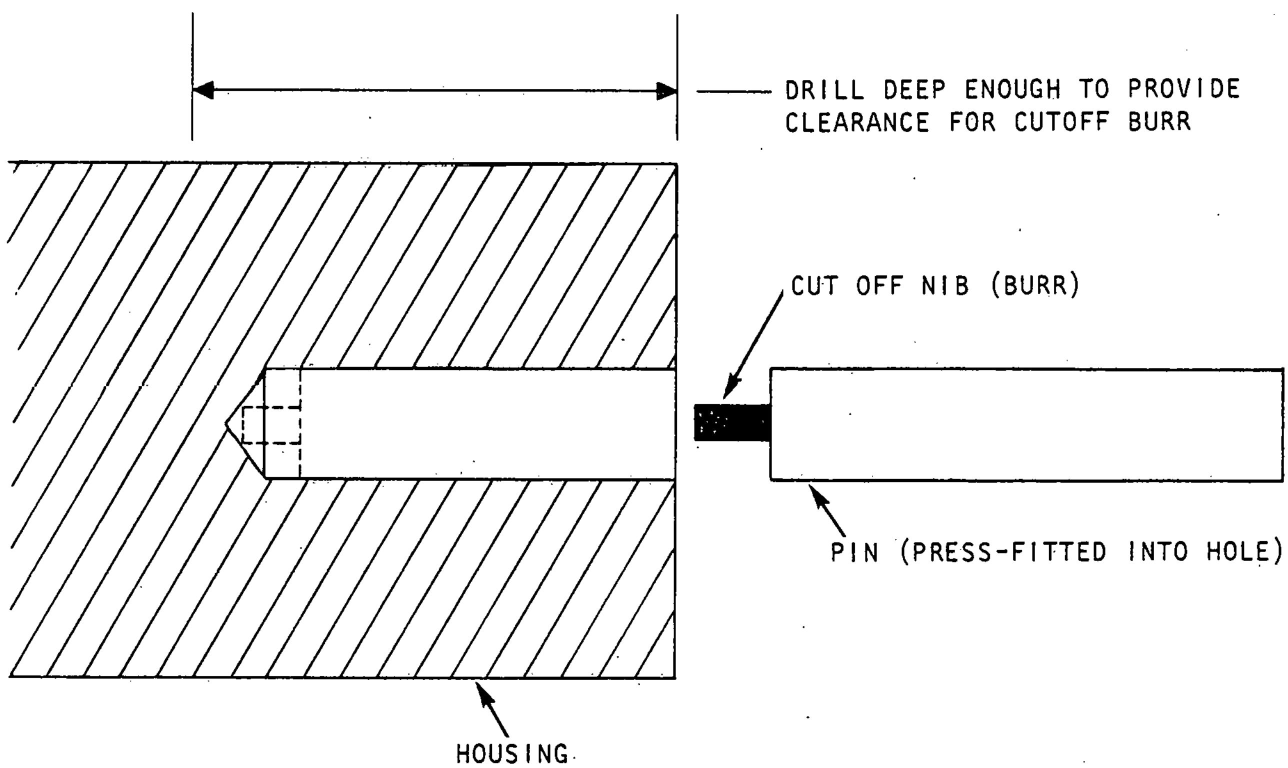


Figure 40. Take Advantage of Part Design to Minimize Deburring

is no need to deburr the hidden edge. Both of these examples are a direct result of design requirements. In the first case, the designer somehow had to specify that edges could have burrs. In the second case, the designer utilized the geometry of the part to reduce deburring.

The majority of assemblies may not lend themselves to such obvious design changes. However, if deburring is eliminated from even one part in an assembly there is a consequent cost savings. Two common examples in which burr removal is not required are shown in Figures 32 and 40. Pins which are pressed into a hole often do not have to be entirely burr-free. In Figure 32, the part was machined so that the burr was thrown into the shoulder relief. Since the burr does not interfere with part function and cannot escape from the relief, deburring is not required.

Probably the greatest cost savings can result from understanding what edge requirements actually are. Although the product engineer is theoretically responsible for product definition, historically the manufacturing or quality engineers have assumed responsibility for indicating what is really required in the area of surface finishing. In the rush to get new products into production, actual requirements often are glossed over.

To do the best job of designing products to deburring standards, one must be able to affirmatively answer this question: *Do you know what level of quality is needed?*

Actually answering this question opens a Pandora's box of subsequent questions. Answering the question affirmatively requires a knowledge of component and assembly functions. Then one needs to know just how critical each edge is to the function of the component and assembly. Most individuals assume that all edges should have the same edge radius or burr-free condition. *In most situations, this is not true.*

In-process deburring should be considered at this point. Even though some burrs may be removed in a subsequent machining operation, fixturing or inspection requirements may dictate that these burrs be removed earlier. In this situation, the deburring quality level is not as critical as the final functional requirement.

These are some of the questions the product and manufacturing engineers must answer in this evaluation.

- *Is a burr allowable?*
- *Would it cause an electrical short circuit?*
- *Would it jam a mechanism?*
- *Would it cause interference fits?*
- *Would it cause misalignment?*
- *Would it be a safety hazard? (Could it cut someone's finger during assembly?)*

- *Would it cause unallowable stress concentrations?*

- *Would it accelerate wear beyond allowable limits?*

The manufacturing engineer must also be able to answer the following questions.

- *Why is a burr-free condition required?*

- *Why is a specific maximum edge radii required?*

- *Where is a burr-free condition required?*

- *Where is the specific maximum edge radii required?*

- *How is a burr-free condition measured?*

- *What happens if the part is not burr-free?*

- *What happens if part does not have a specific maximum edge radii?*

- *How can part be redesigned to minimize the burr?*

When product function dictates that burrs cannot be allowed, designers can use two other approaches to minimize the cost of deburring:

- Change the shape of the part to minimize burr size, and

- Change the geometry to put the burr in an area more accessible to the deburring media.

Sheet metal parts, for example, should have large radii rather than sharp corners to minimize burrs (Figure 41). When sharp corners are necessary, it is sometimes possible to provide them by using more expensive progressive dies.

Burrs formed by machining through threads are extremely difficult to remove. This problem can be eliminated by turning a relief diameter that is smaller than the minor diameter (Figure 42). Threading typically swells material at the entrance and exit of the hole. When the shoulders must fit flush in the assembly, specifying a small countersink or undercut may eliminate the need for a deburring operation to remove the heavy swell (Figure 43). The addition of a recess at the bottom of a blind broached hole can simplify burr and chip removal (Figure 44).

If a small burr is allowable on the outer diameter of a slotted part, an optional V-groove can be placed at the bottom of the slot (Figure 45). This groove permits the existence of a burr at the

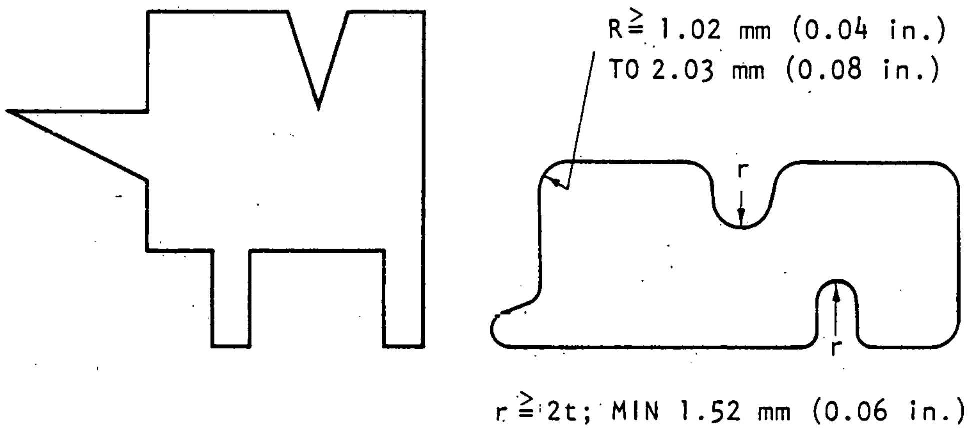


Figure 41. Utilize Large Radii on Blanked Parts[54]

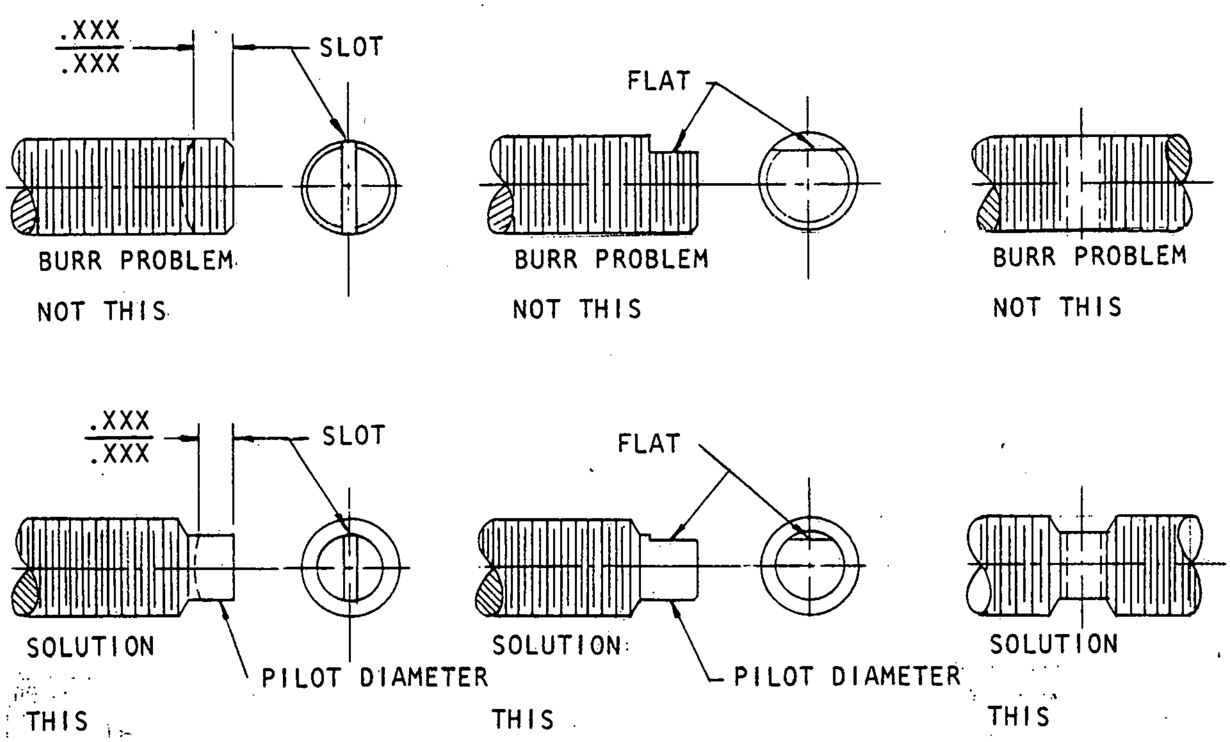


Figure 42. Utilize Thread Undercuts[55]

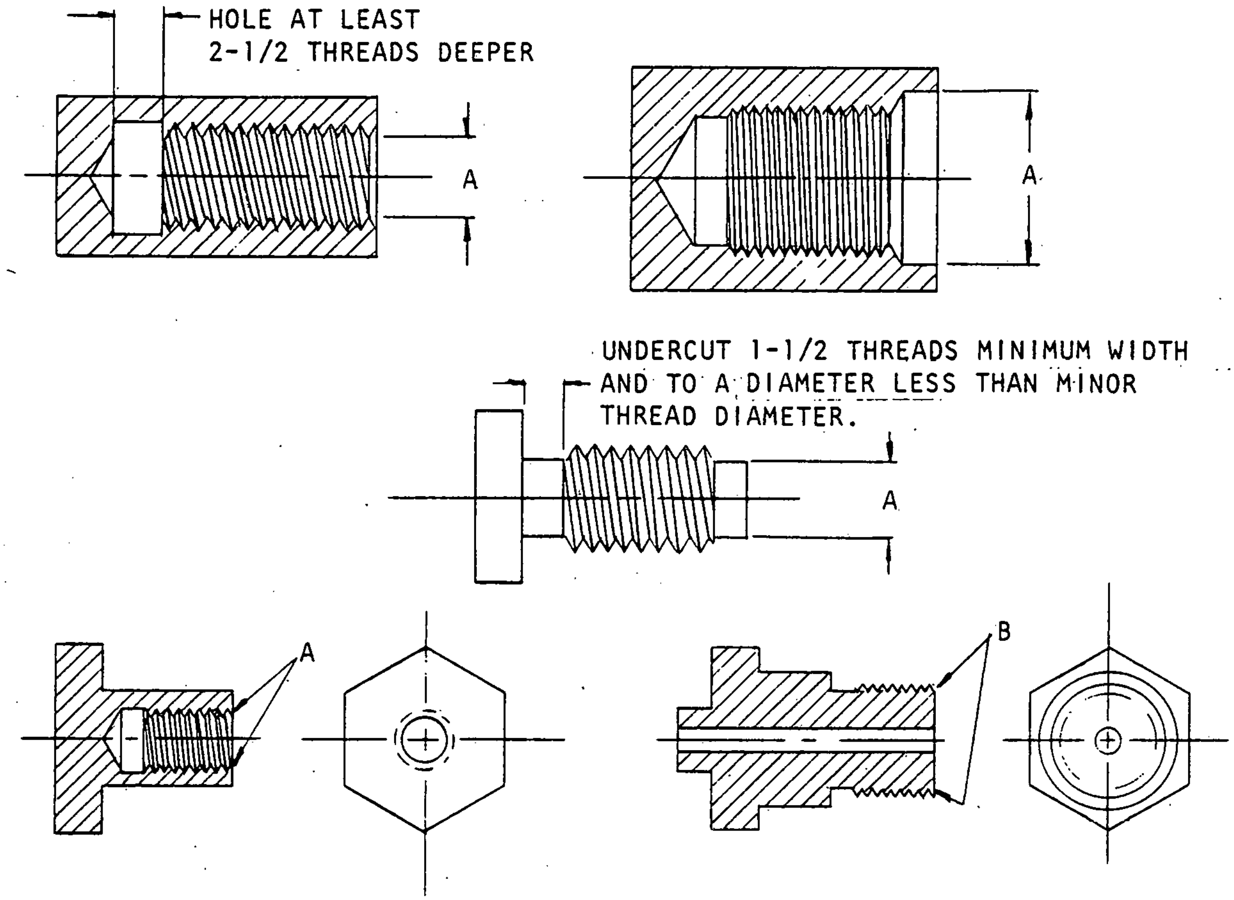


Figure 43. Utilize Thread Undercuts and Chamfers[55]

bottom of the slot without affecting outer diameter size. Although a small burr also forms at the sides of the slots, it may not be large enough to require removal and, if it does, it is much easier to remove than the burr normally left at the bottom of the cut.

Figure 46 illustrates a simple design change which reduced deburring time in a casting. The original design required that a portion of the bottom flange face be machined to provide a locating surface. Because of the geometry of the part, the face mill passed over the inner diameter. In doing so, it formed a very heavy burr which had to be removed by hand. Relieving some of the area to be machined made it possible to produce a small burr which could easily be removed. There were two reasons for the success of this approach. First, the shell mill is just skimming the surface when it passes over the inner diameter; it is almost not cutting and thus cannot produce a big burr. And when the angle ϕ between the cutter tooth feed direction and the edge of the

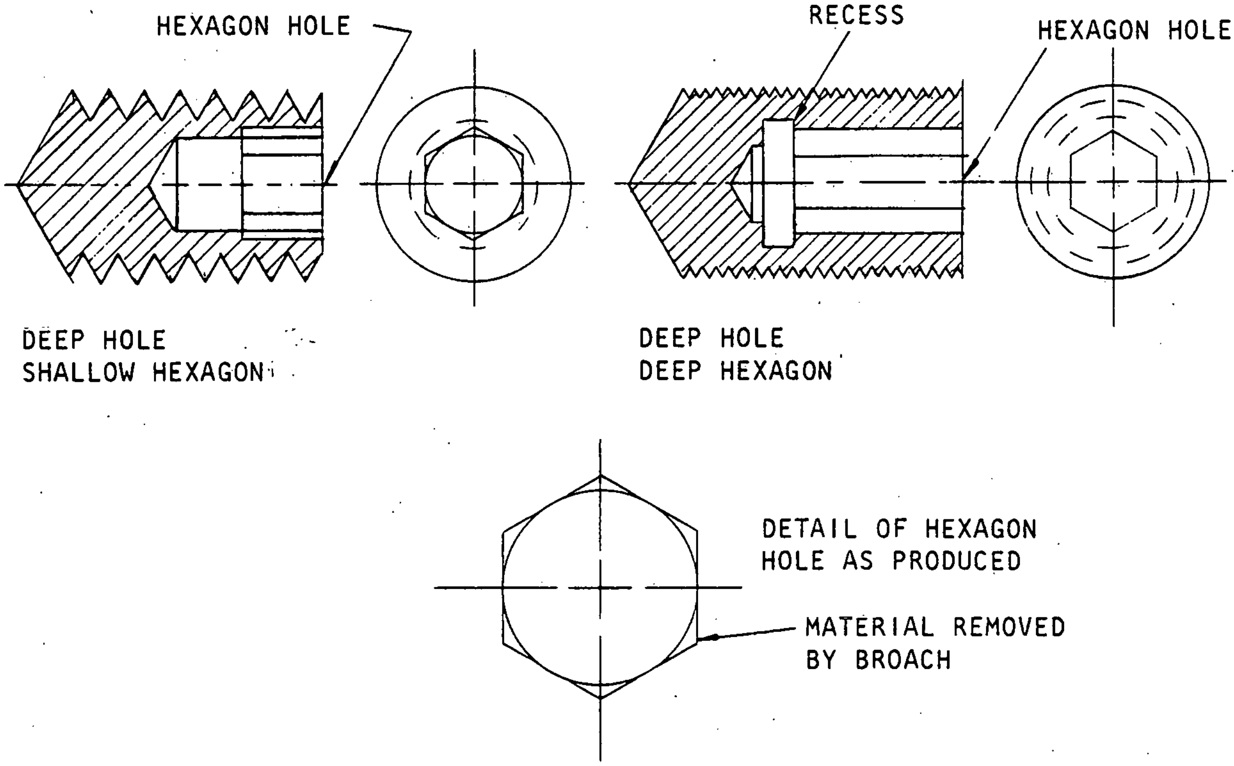


Figure 44. Provide Recesses in Blind Broached Holes[55]

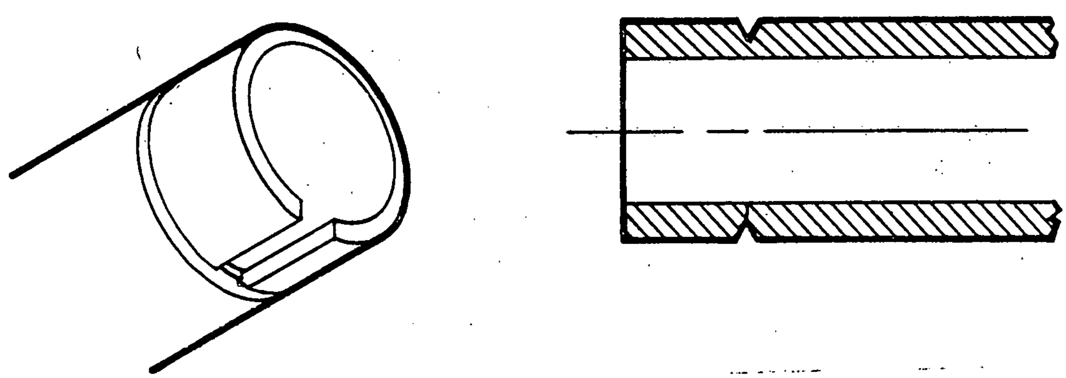
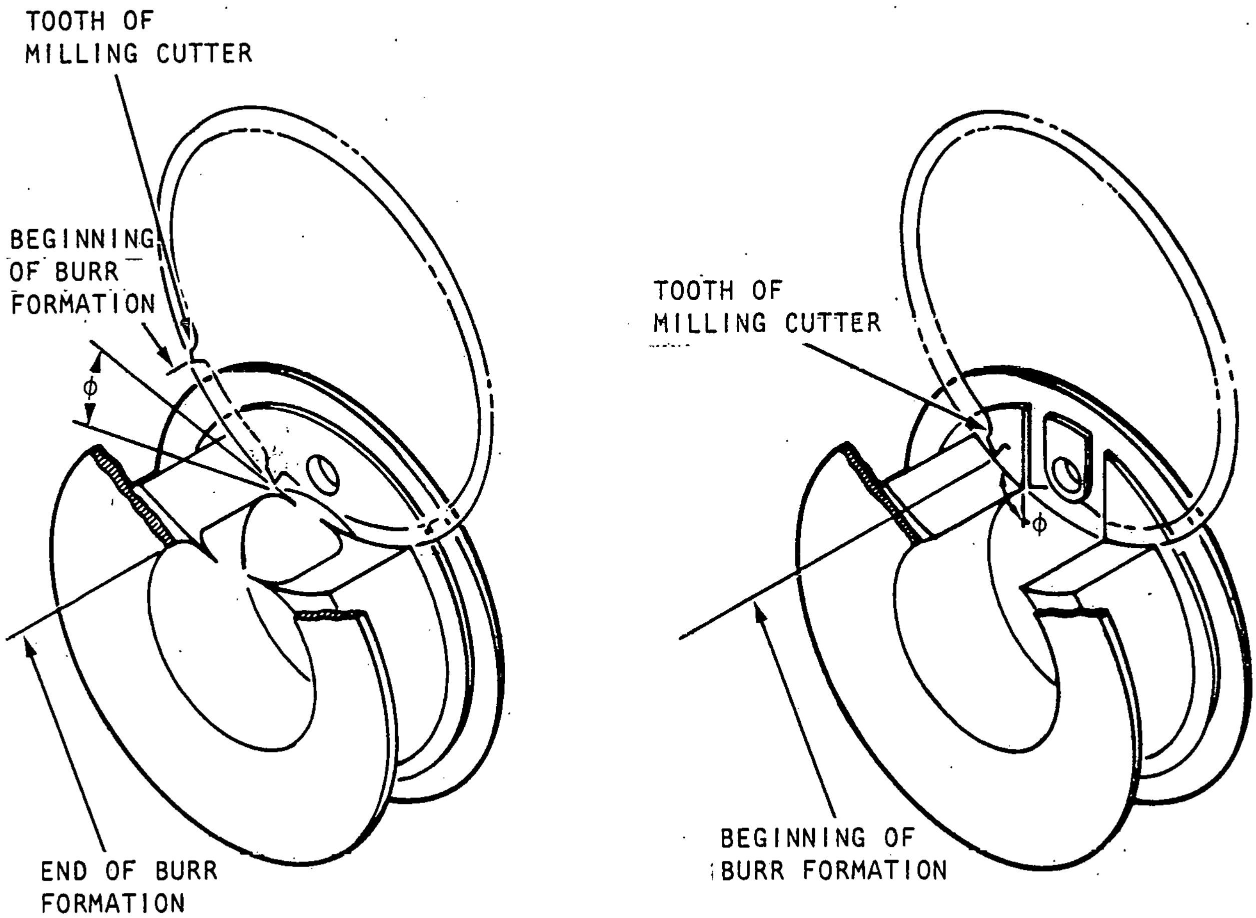


Figure 45. Utilize Groove to Minimize Milling Rollover Burr[56]



ORIGINAL DESIGN:

SMALL EXIT ANGLE ϕ
CREATES BIG BURR

AFTER REDESIGN:

SMALL BURR FORMS AT
EDGE OF DEPRESSION

Figure 46. Change Geometry to Minimize Burr Size[57]

workpiece is large, a relatively small burr forms (Figure 47). In cases like this, the designer and the manufacturing engineer must work together because machining techniques and limitations can nullify the benefit of these design changes.

Recent research also points out that the angle between two intersecting surfaces greatly influences burr size. When the included angle is 150 degrees or larger, little or no burr typically forms (Figure 48). As this angle decreases, burr become much thicker and longer.

The amount of radius that can be produced economically after removing the burr is also a function of the angle between intersecting surfaces (Figure 49). Large radii can be produced relatively

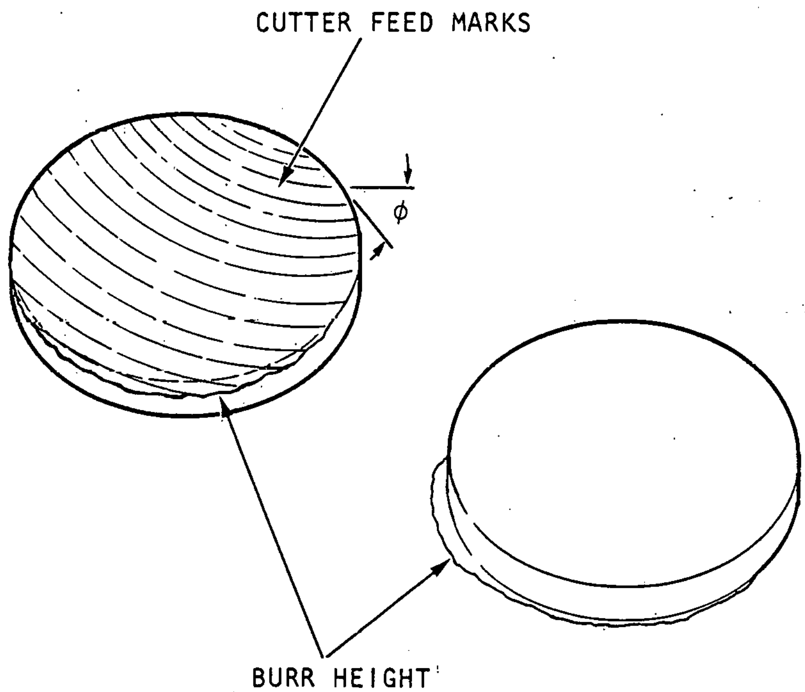


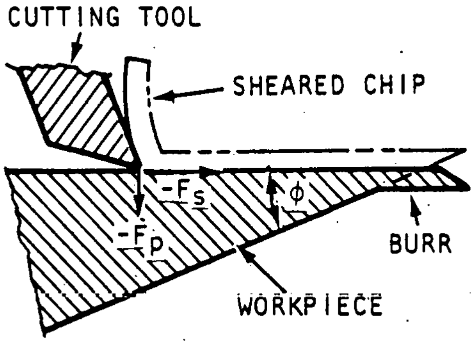
Figure 47. Burr Height as a Function of Geometry

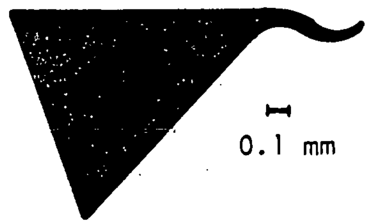
quickly when the included angle is large. Finishing times are 20 times longer when the included angle is 30 degrees than when it is 120 degrees (Figure 50). Precision edge radius tolerances are harder to maintain when large angles are present, however. When a component has features involving several different edge angles, edge radii will vary significantly (Figure 51 and Table 17). Designers must recognize this when assigning tolerances to edge radii if they want to eliminate the extra costs required to produce equal radii.

Undercuts of the type shown in Figure 52 should be avoided because it is difficult to reach burrs under ledges and in corners. If an undercut occurs on only one side of the part, the manufacturing engineer can prevent the occurrence of heavy burrs by assuring that the cutter enters the workpiece at these edges (Figure 27).

Designing for Easy Flash Removal

Since flash on die cast or molded parts has many of the same characteristics as burrs, many of the previous suggestions apply to flash, fins, and gates. Two additional rules, however, need to be observed for parts which will have flash on them:



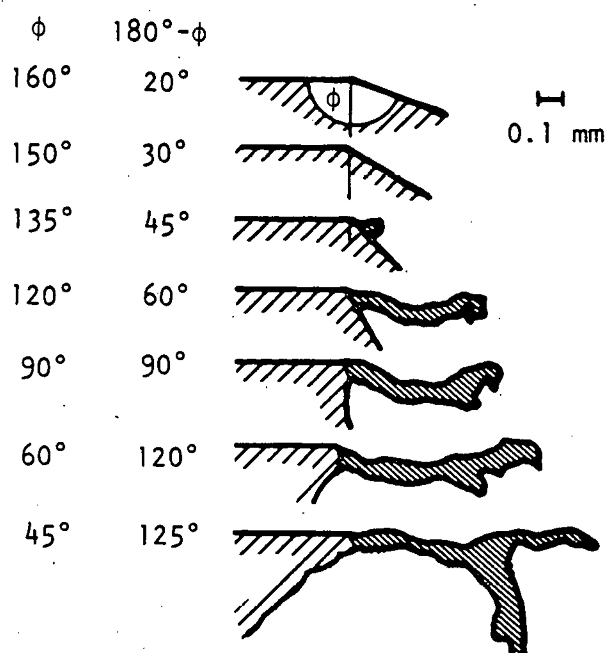


F_S = CUTTING FORCE

F_P = COMPONENT OF RESULTANT CUTTING FORCE

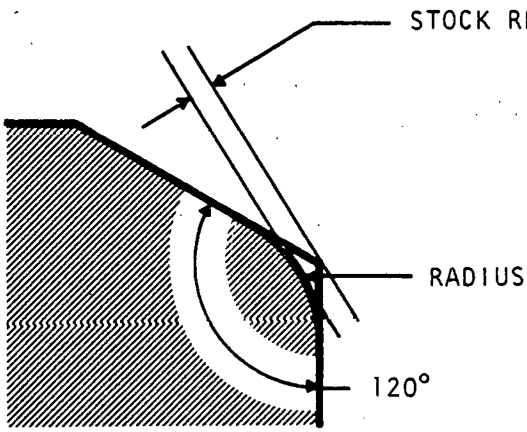
MICROSECTION

BURR FORMATION WITH EDGE ANGLE $\phi << 90°$



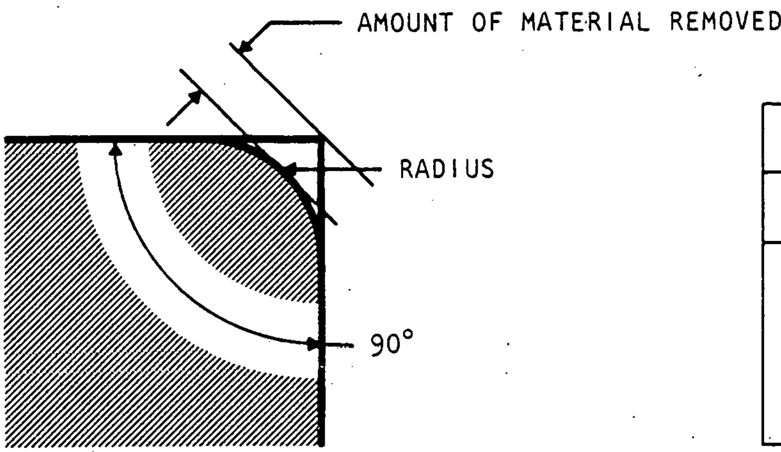
EFFECT OF WORKPIECE EDGE ANGLE ON SIZE OF ROLLOVER BURR

Figure 48. Rollover Burr Height as Function of the Angle Between Surfaces[57]



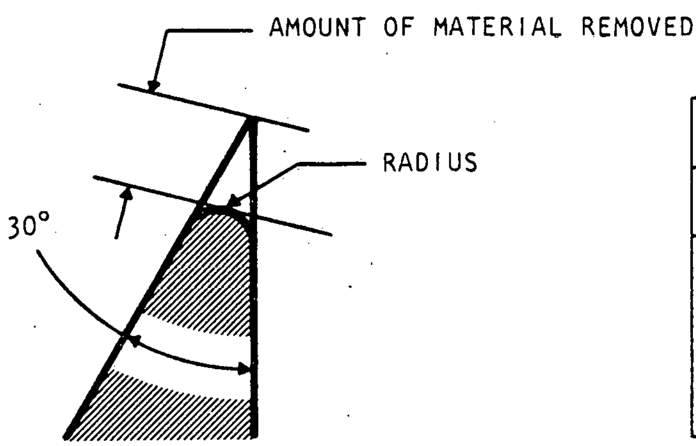
RADIUS		S	
INCH	μm	INCH	μm
0.002	50.8	0.0003	7.6
0.003	76.2	0.0004	10.2
0.005	127.0	0.0007	17.8
0.010	254.0	0.0015	38.1
0.015	381.0	0.0022	55.9

DIFFICULT



RADIUS		S	
INCH	μm	INCH	μm
0.002	50.8	0.0008	20.3
0.003	76.2	0.0012	30.5
0.005	127.0	0.0021	53.3
0.010	254.0	0.0041	104.1
0.015	381.0	0.0062	157.5

TYPICAL



RADIUS		S	
INCH	μm	INCH	μm
0.002	50.8	0.0077	195.6
0.003	76.2	0.0116	294.6
0.005	127.0	0.0194	492.8
0.010	254.0	0.0387	983.0
0.015	381.0	0.0581	1475.7

LESS DIFFICULT

Figure 49. Effect of Geometry on Edge Radiusing

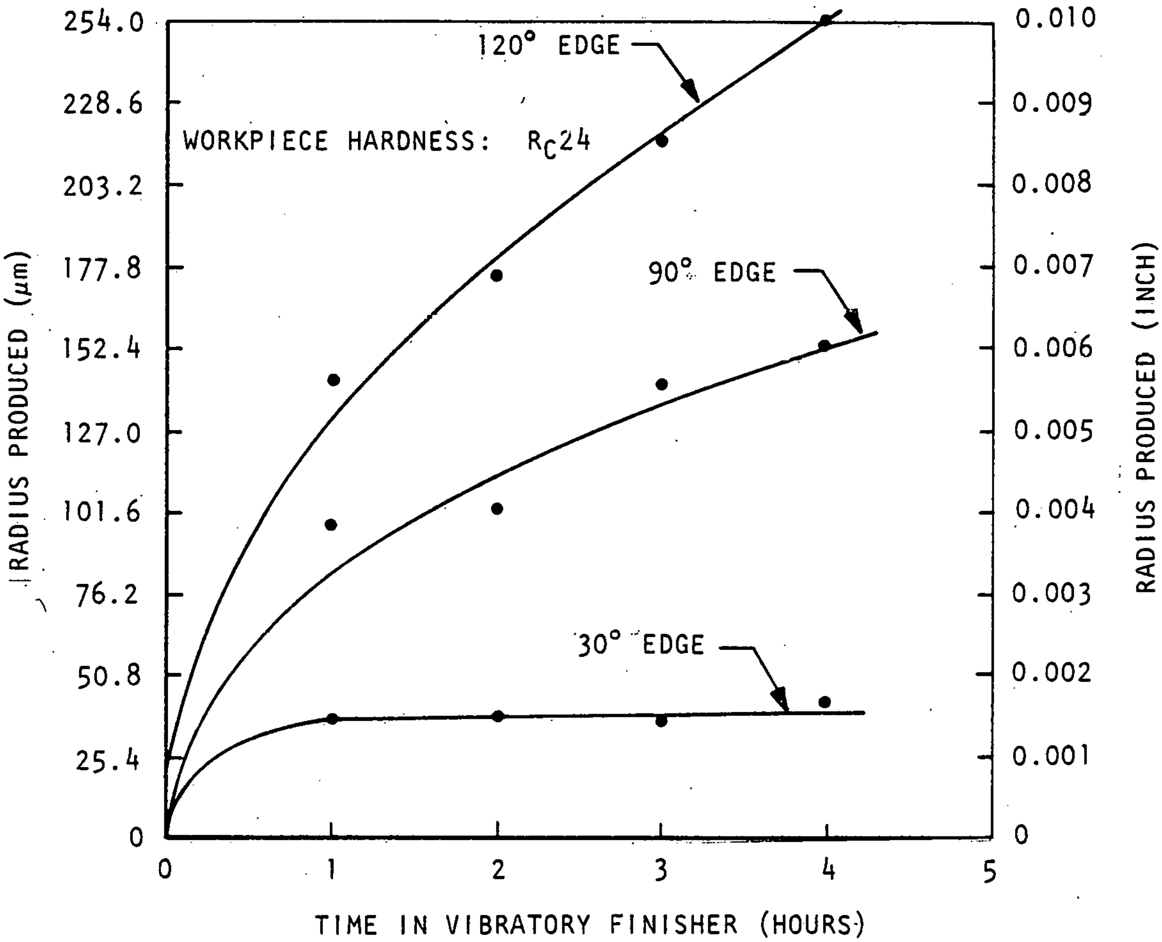


Figure 50. Effect of Edge Angle and Vibration Time on Edge Radiusing of Phosphor Bronze Workpiece

- For appearance and ease of removal, parts should be designed so flash occurs at edges rather than on surfaces; and
- Gates should be designed to facilitate the removal of flash.

Figure 53 illustrates the first of these rules. Note that while the addition of the rib or bead around the part does not make flash removal any easier, it does help mask incomplete flash removal and slight offsets between the die halves. This can be an important consideration when aesthetics rather than function are involved.

When piercing the "cap" of flash which occurs at hole exits results in torn edges, it may be necessary to grind off the cap. In this case, it is essential that the surface to be ground does not have any projecting bosses (Figure 54).

Table 17. Radii Produced on Three Edges of Part in Figure 51 While Maintaining Tolerance of Radius R_2 on Phosphor Bronze

Radius Feature	Edge Angle (Degrees)	Radius Produced	
		μm	in.
R_1	60	45.7 ±25.4	0.0018 ±0.001
R_2	90	127.0 ±25.4	0.005 ±0.001
R_3	125	287.0 ±25.4	0.0113 ±0.001
R_4	140	307.3 ±25.4	0.121 ±0.001

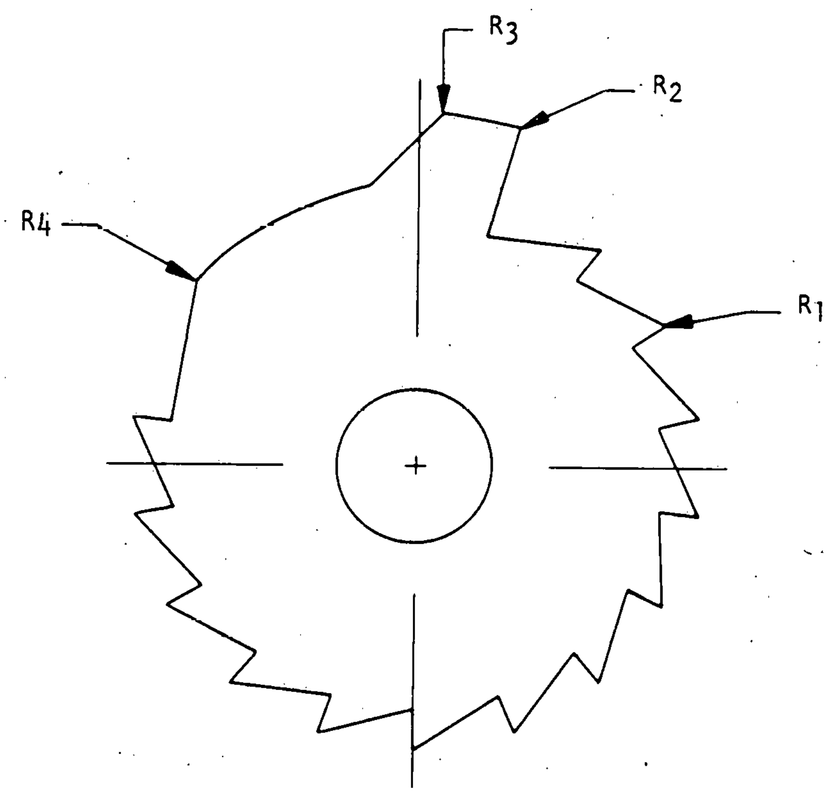


Figure 51. Example of Different Edge Angles on a Single Part

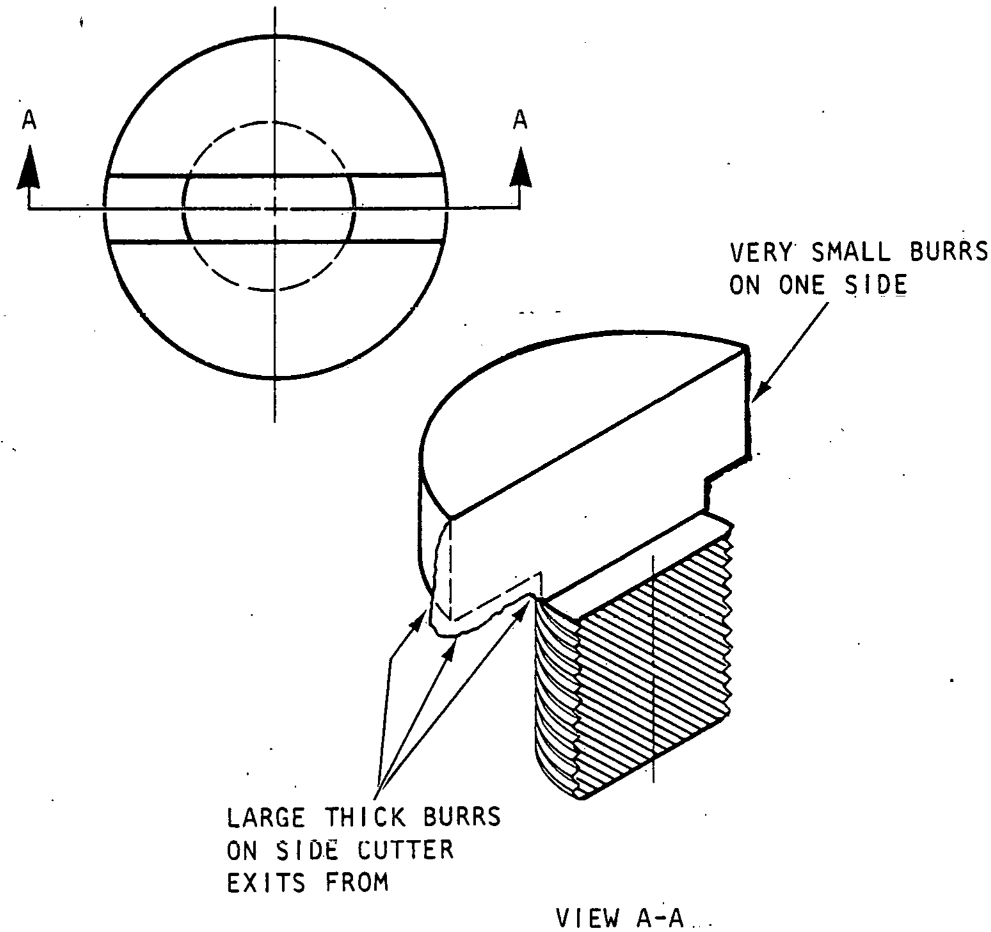


Figure 52. Slotting Through Flanges Makes Deburring Difficult

Feather edges at the ends of threads should be avoided because they make mold fit more critical and promote flashing.

Research at the University of Stuttgart on compression molded rubber pieces indicates that abrasive jet deburring can be effectively used for deflashing or degating if the criteria in Figure 55 are maintained.

Gates should always have a shape which ensures that fracture of the gate occurs at the edge of the part (Figure 56); they should also be as thin as possible to get a clean fracture (Figure 57). As noted by Barton and Barton,[59]

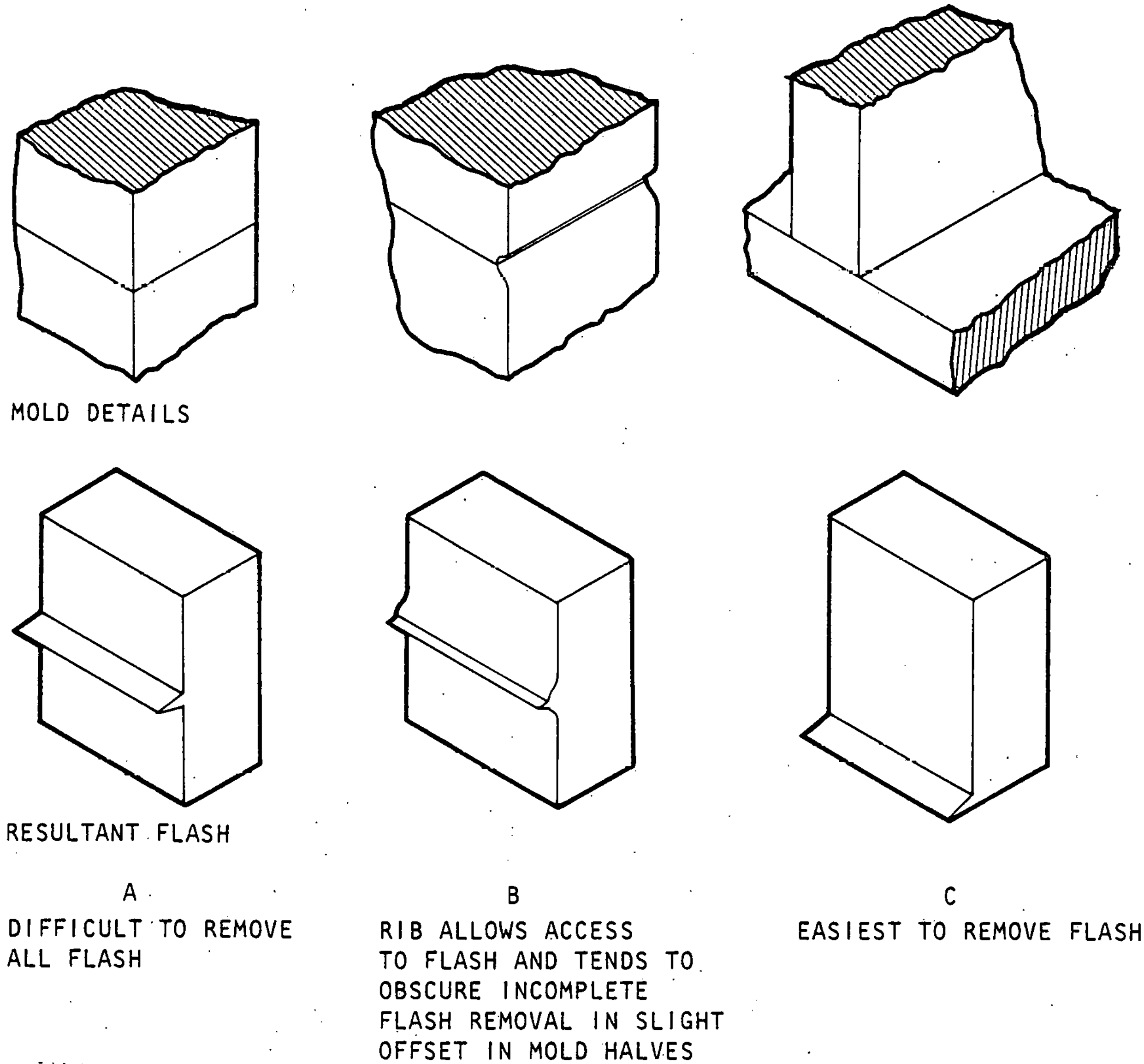


Figure 53. Effect of Flash Location on Ease of Removal

With a shallow gate, the fracture is almost straight and follows the vertical face of the component, whereas a wider gate (centre view) breaks on an insweeping curve which finishes at a point a few thousandths of an inch inside the correct line, shown chain-dotted.

For maximum trimming die life, overflow wells should be designed to permit use of a strong tool (Figure 58).

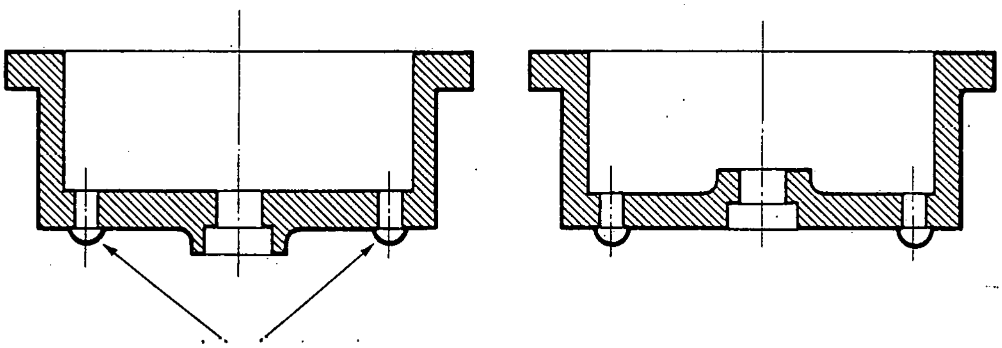


Figure 54. Plane Surface Facilitates Grinding of Burr Cap[57]

Defining Allowable Conditions

The single most significant factor in minimizing deburring costs is knowing what edge condition is actually required on each edge of a part. The second most significant factor is defining these conditions in such a way that manufacturing engineers, production operators, and inspection personnel know exactly what is allowable. In some industries, it is possible to establish a standard which says, "Deburring not required unless otherwise noted." Unfortunately, for the majority of companies, it is not that easy. Most products require that the majority of edges be burr-free. This requires three things:

- That in-plant standards of what constitutes burr-free and what edge and corner breaks on radii are allowable be available,
- That cases in which a burr can be permitted be explicitly defined, and
- That exceptions to allowable edge breaks be explicitly defined.

Failure to be explicit will sooner or later result in parts which the designer thinks are bad but by conventional standards are acceptable. As an example, members of the National Screw Machine Products Association have standards which allow small burrs. If deburring or chamfering (to eliminate big burrs) is not specified, it will not be done. Failure to know the standards of a particular industry or to specify requirements explicitly will, sooner or later, result in rejected parts.

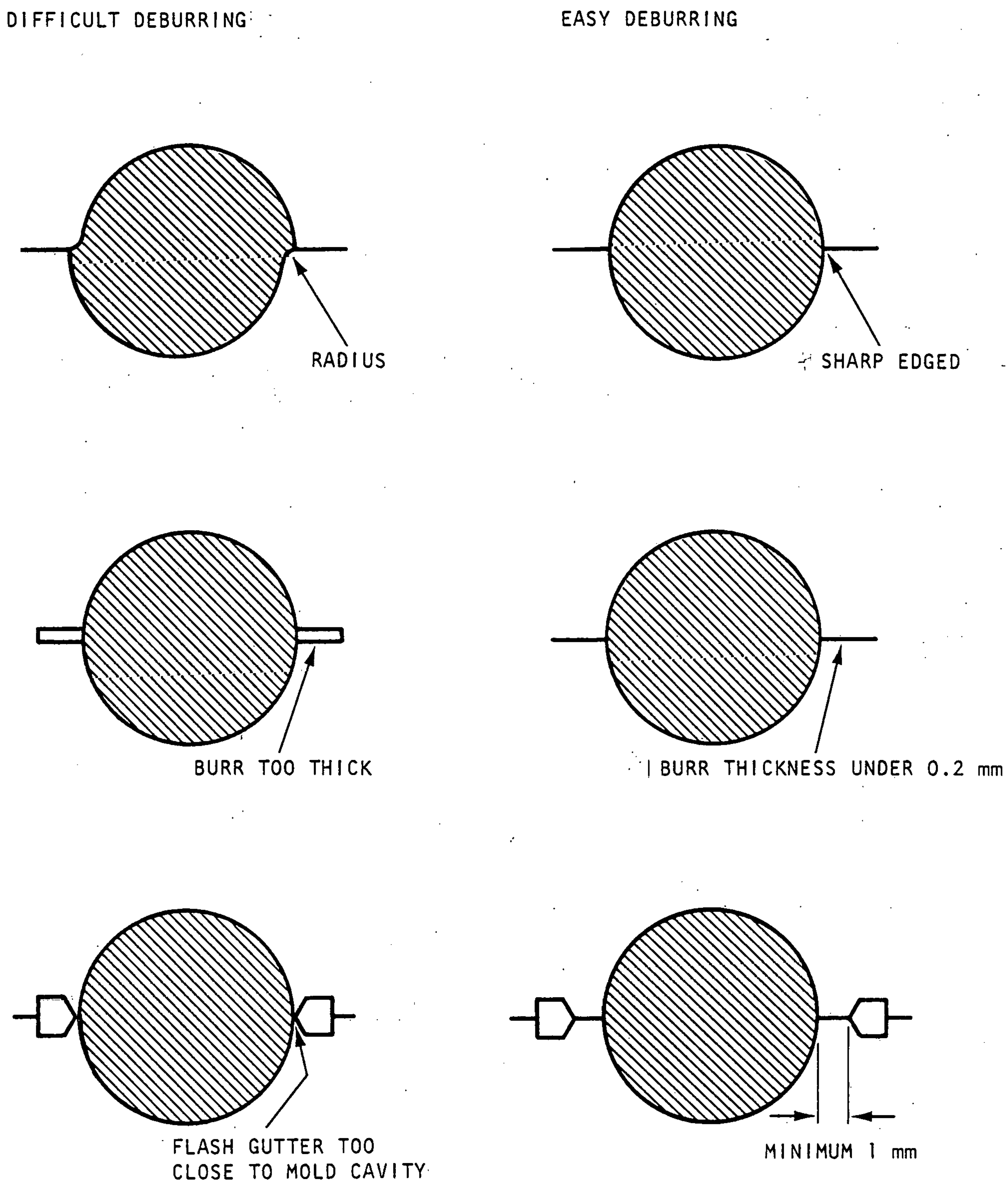


Figure 55. Design for Easy Gate Removal[57]

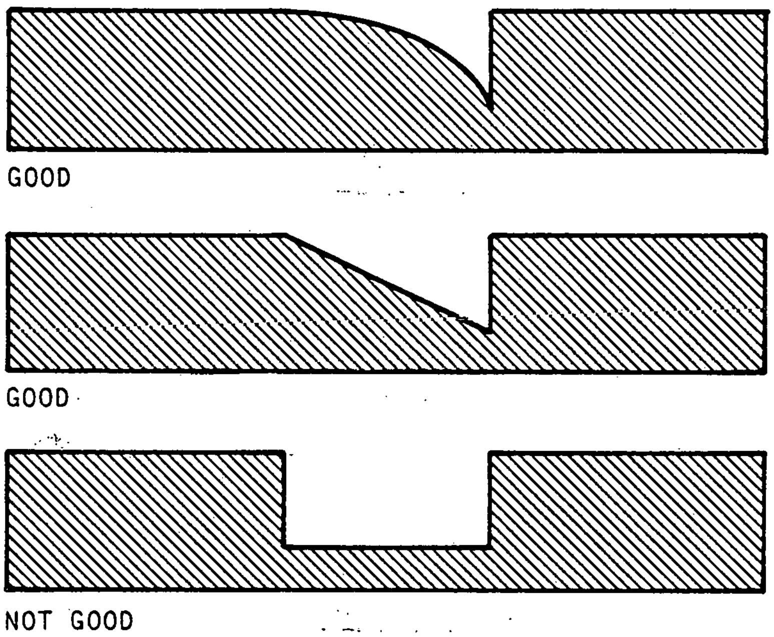


Figure 56. Gate Design[58]

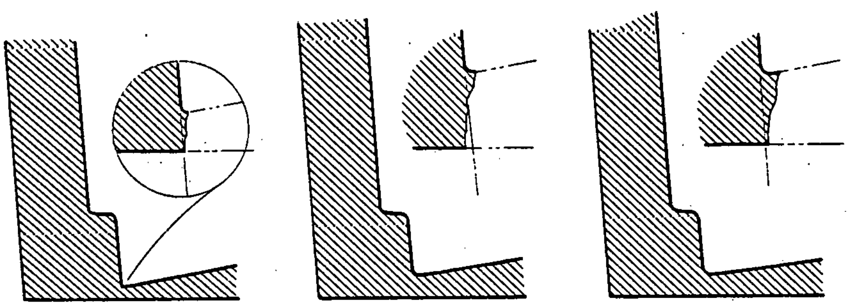


Figure 57. Effect of Gate Thickness on Edge Quality[59]

Several approaches can be used to define allowable burrs or edge conditions:

- Define it on the print,
- Define it in a Process Engineering Specification (Manufacturing Specification),
- Define it on the production traveler (routing sheets),

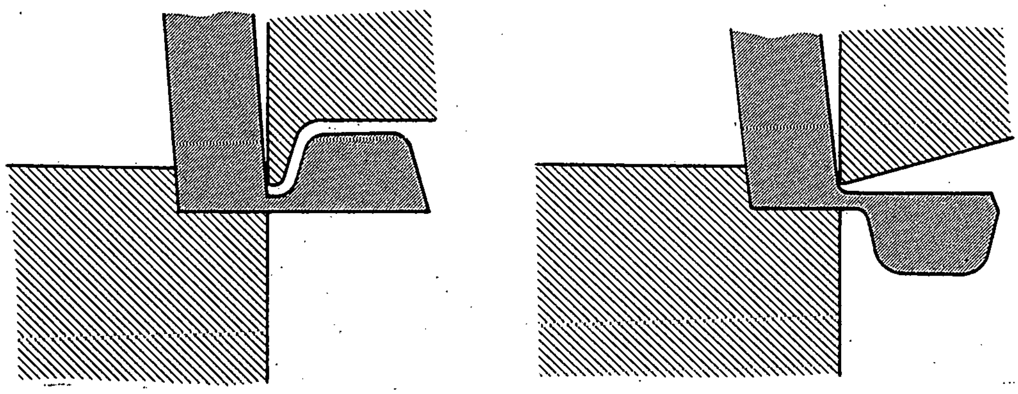


Figure 58. Design Overflow Wells to Allow Use of Strong Trimming Tools[57]

- Define it by interpretive memo (include sketches, photos, measuring techniques, and so on),
- Define it on the inspection traveler (routing sheets),
- Define it with photos of acceptable and unacceptable conditions,
- Define it by the use of comparative masters (the master is given a tool or gage number, or a visual aid or visual standard number),
- Define it by *go/no go* (if it fits the gage, the burr is acceptable),
- Define it by taking specific exception to general workmanship specifications,
- Define it by special specifications, and
- Define it by such phrases as *Firmly adhered burrs or raised metal is allowable in this area provided a micro tool 90° hook will not dislodge them.*

While notes such as shown in Figures 59 through 61 may be adequate for parts made within a specific plant, they should be avoided if parts are to be made by outside vendors. Sooner or later the product designer will be asked to define *small burr*. A 127 μm tall burr is small on a farm plow but it is big on a 406 μm diameter precision miniature screw.

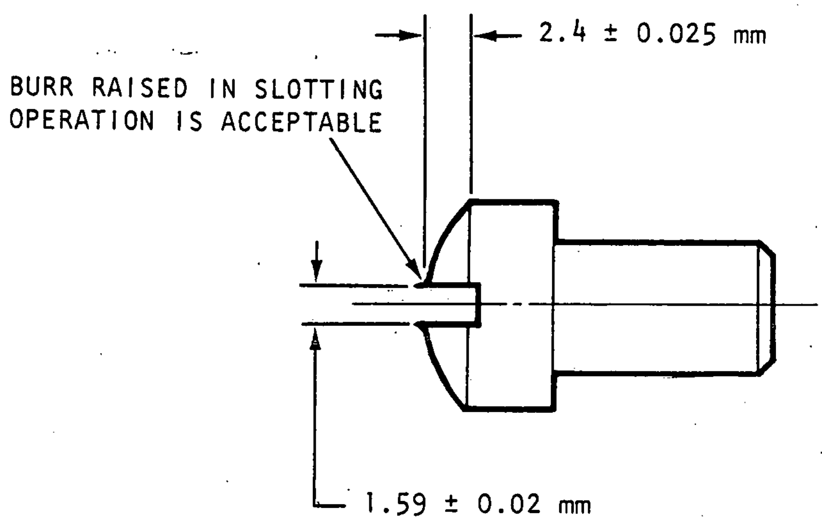


Figure 59. Note for Slotting Burrs[60]

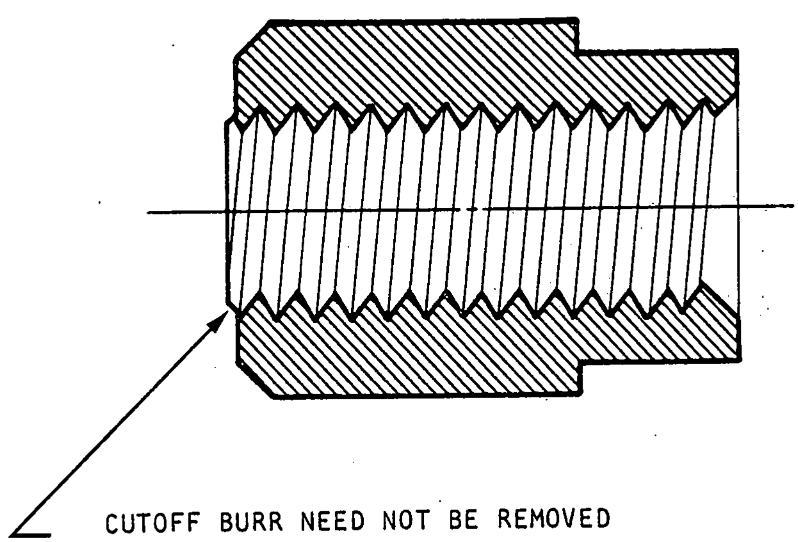


Figure 60. Note for Tapped Hole Burrs[60]

Figures 62 through 66 illustrate the preferred practice for specifying edge quality. Allowable burr sizes are described in Figures 62 through 65. Although chamfering produces a small burr, it is generally smaller than the burrs produced by the other processes and thus chamfering may represent all the deburring which is required. Either drawing notes or an in-plant standard should be used to indicate whether chamfering represents adequate deburring. When a smooth blend is required, it should

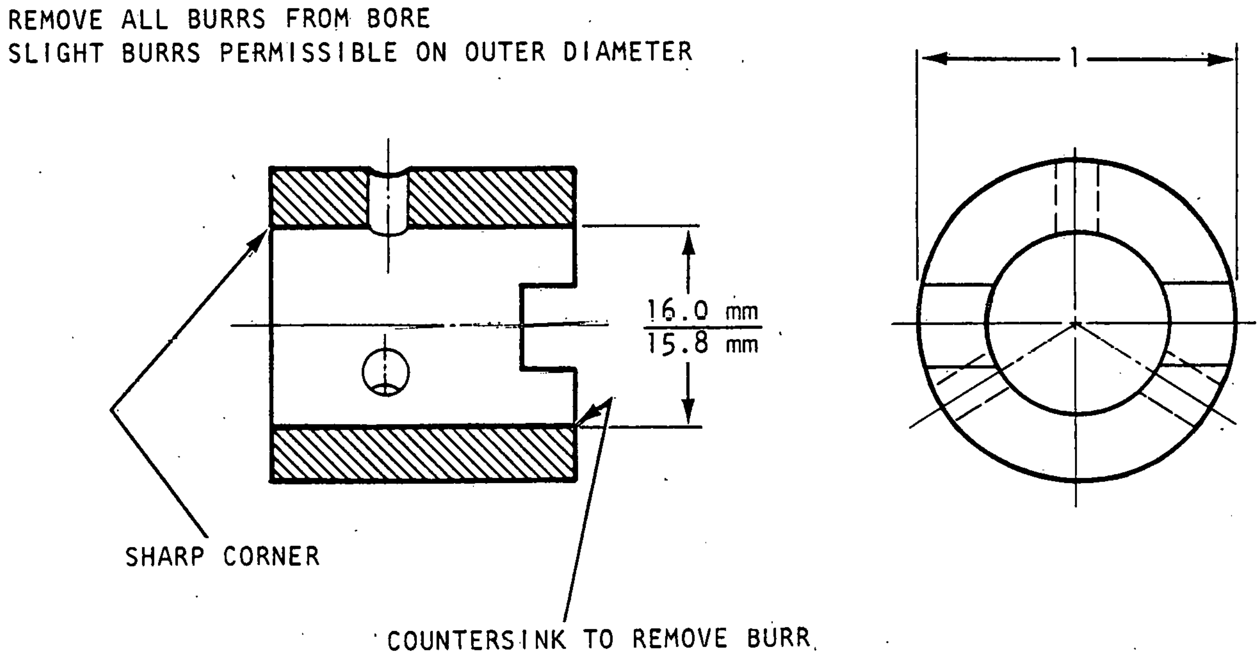


Figure 61. Burr Notes[60]

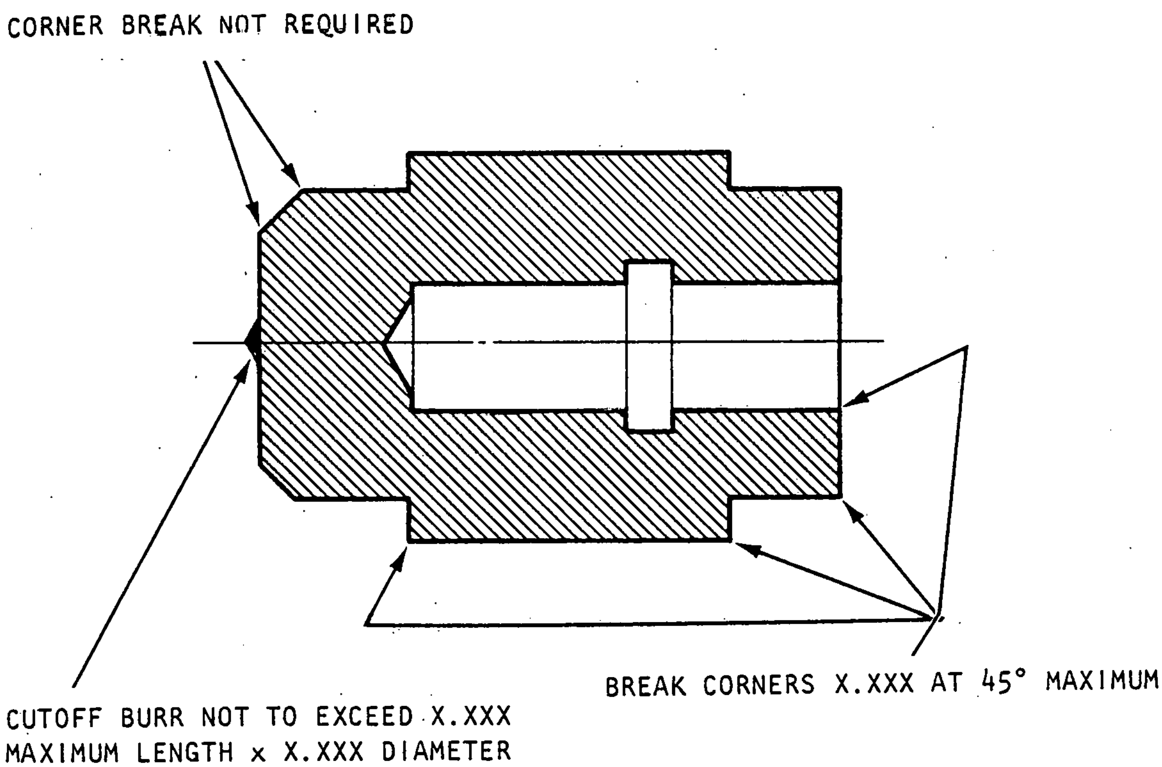


Figure 62. Typical Burr Notes for External Edges[55]

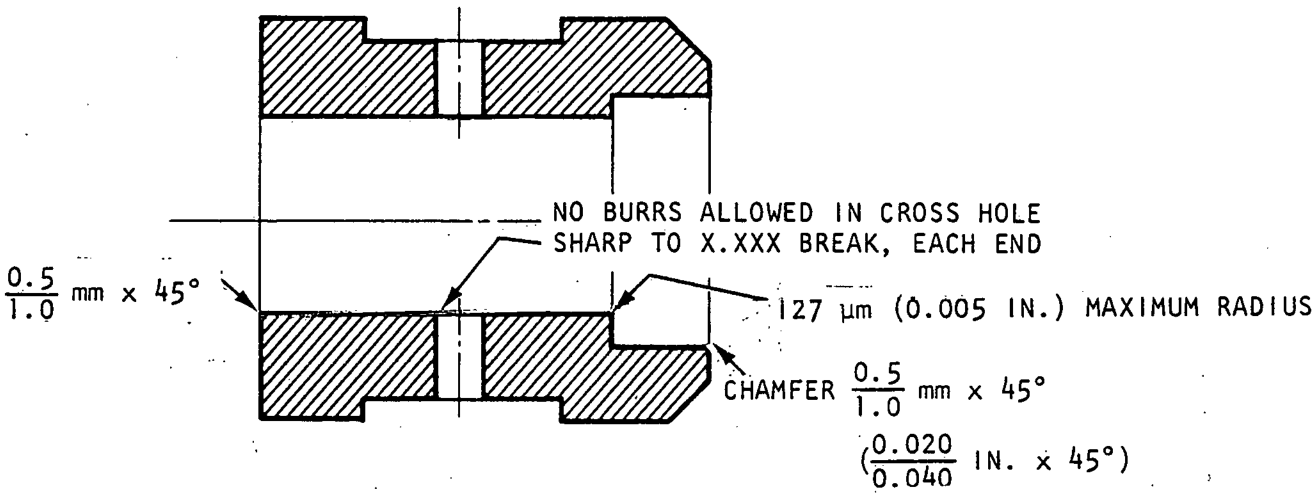


Figure 63. Typical Burr Notes for Internal Edges[55]

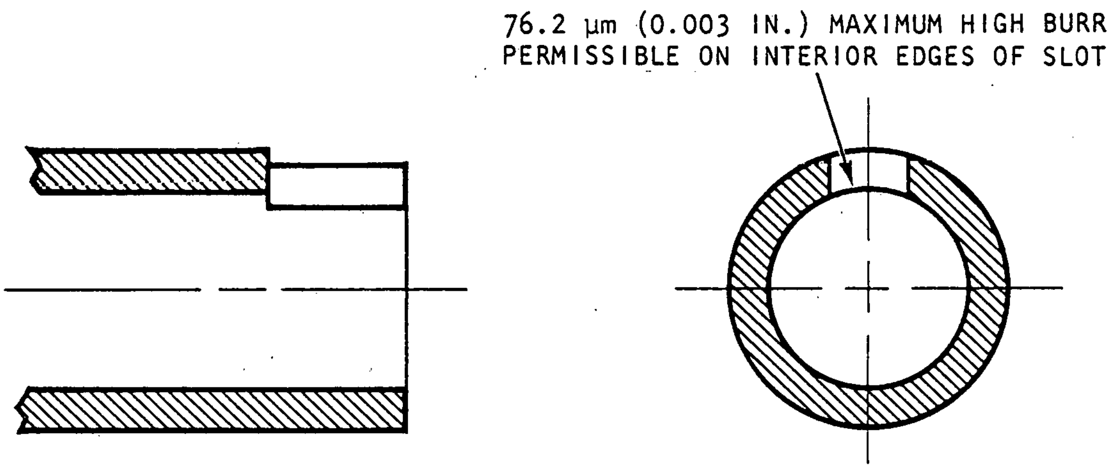


Figure 64. Define Allowable Burr Size and Location on Intersecting Features

be specified as a radius. Edge breaks (chamfers) should be so specified that either a chamfered or a radiused condition is allowable. This allows the manufacturing engineer to determine whether a machining or a deburring process will provide the most economical edge condition. Typical corner breaks are 0.397 mm by 45° (0.0156 in. by 45°) or 254/381 μm by 45° (0.010/0.015 in. by 45°). Radii should not be specified larger than 254 μm nor smaller than 76.2 μm.

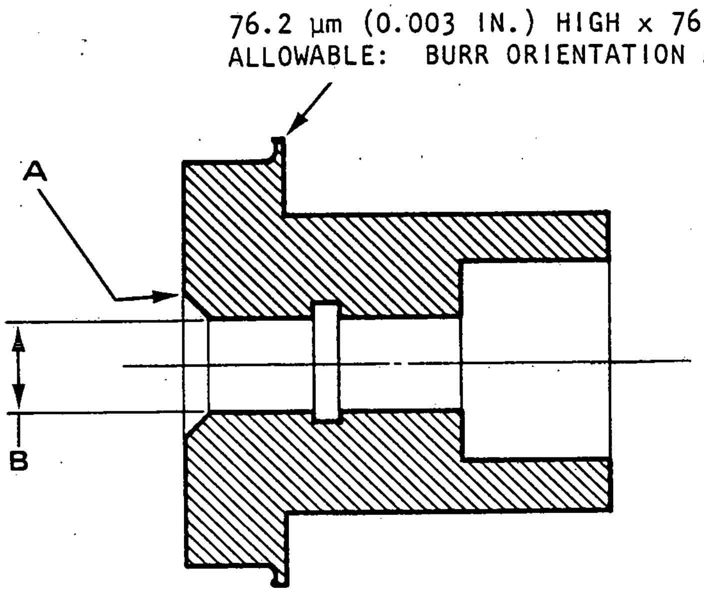


Figure 65. Define Allowable Burr Size and Location on Simple Parts

The direction a burr faces is sometimes more critical than its actual size. In these cases, the orientation of the part should be noted on the drawing (Figures 65 and 66). In the case of symmetrical threaded parts, it is helpful to the manufacturer if the designer indicates which end of the part the screw is started from. This may eliminate the need to deburr both ends.

A burr always forms at the intersection of two holes. If a burr cannot be tolerated in one hole, but can in the other, this must be noted (Figure 66). Defining where burrs can exist on formed parts may eliminate the need to deburr the sheet stock. With proper thought and communication between product designer, tool designer, and manufacturing engineer, forming dies can be designed so burrs on the blank will be in an out-of-the-way location in the finished part.

On many parts, the only significant edge requirement is that all sharp edges be removed. In this case, beating over burrs and dulling edges is adequate. The sole plates on some vacuum sweepers are treated in this manner. Designers can handle these situations in at least two ways:

- By specifying the process which gives an acceptable edge; and

- By defining the actual edge quality needed.

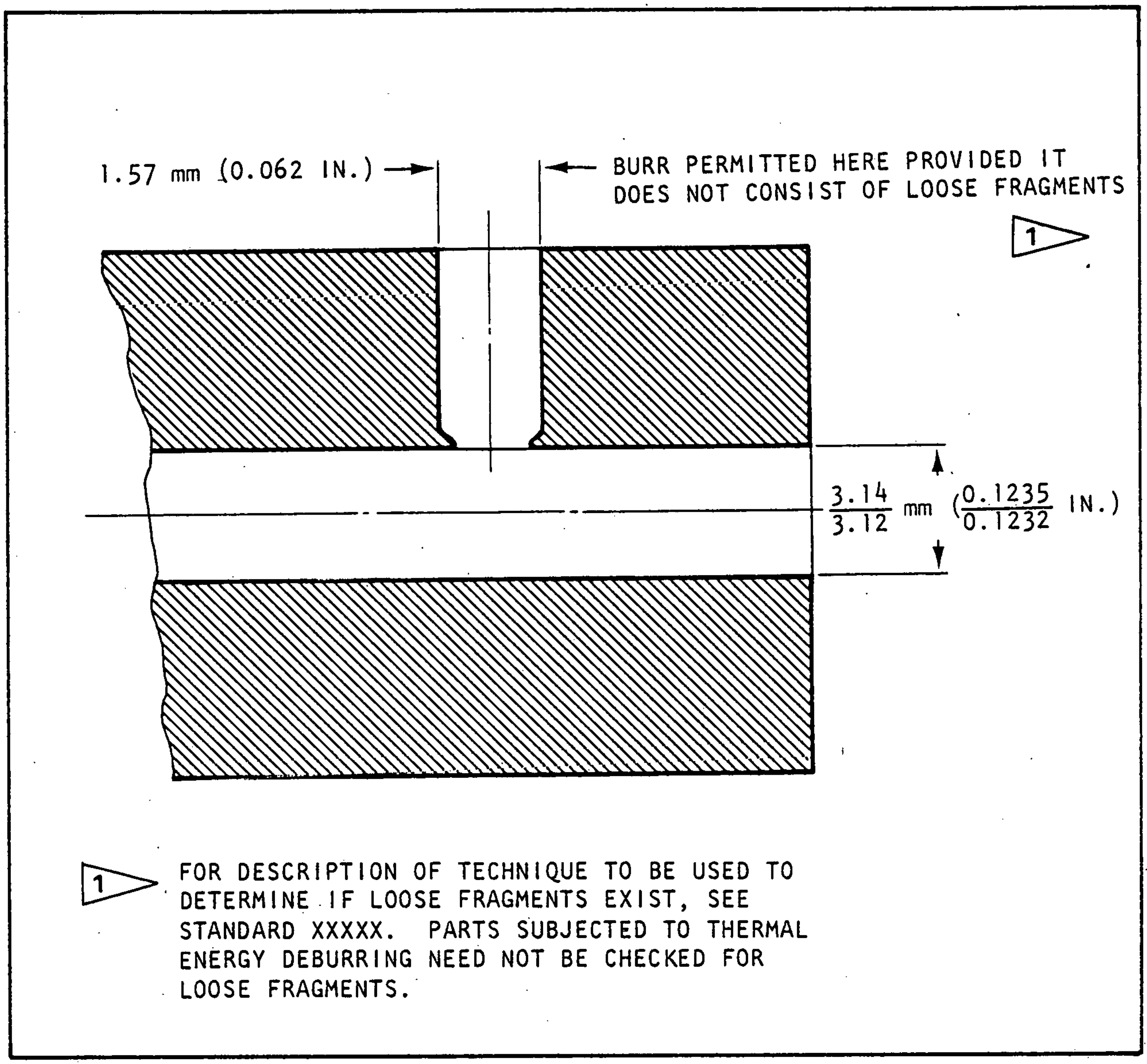


Figure 66. Define Allowable Burr Size and Location at Hole Intersections

Vibrating parts in steel balls will dull the edges of most parts very economically. Similarly, thermal energy deburring (TEM) can be used to assure that no loose burrs or particles will be present to jam assemblies. While specifying on the drawing that *parts shall be vibrated in steel balls to dull edges* is often done for parts made within a plant, such notes are not complete enough for work contracted to others. Others must know what size ball, how long to run, and the amplitude and frequency of the machine to be used. These can be specified by developing explicit processing standards and referring to them on the part drawings. Such an approach is easy and relatively problem-free when the majority of parts have similar requirements.

When a wide variety of parts is designed and manufactured every year, this technique may restrict the manufacturing engineer's ability to make parts by the least expensive process. For example, a standard may specify that abrasive blasting be used. On some parts, a centrifugal barrel finisher might be noticeably more economical. Although drawing notes can be changed, the paperwork and delays involved add unnecessary costs. Five different manufacturers may have five different approaches to providing the same edge quality. Each uses the cheapest method at that time.

At this time there are no national standards for specifying allowable edge conditions. The previous examples have illustrated some logical approaches now in use. On complex parts having both precision and commercial features, a drawing can quickly become cluttered with notes describing allowable edge quality. In-house standards may not be adequate for such parts because of the variety of edge requirements. A scheme, however, has recently been presented which can be used in these situations.

The proposed system is based on the observation that allowable or desirable edge conditions can exist in any of the four quadrants defined by two perpendicular lines. Although a radius typically occurs after deburring (Figure 67), often a slight protrusion exists (Figure 67b, c, d, f). The proposed system utilizes the two intersecting surfaces to define the four quadrants.

To simplify numerical definitions of edge condition, a series of deburring classes have been established (Figure 68). An edge radius of 0.3 mm (0.012 inch) or smaller (Figure 67a) represents a Class 6 (Figure 68). Since no material is allowed past the theoretical intersection of the two surfaces, a zero is indicated in those quadrants. Any numerical value in the fourth quadrant can only represent a radius or a chamfer. In the cases shown, the fourth quadrant corresponds to the conventional definition of quadrants. In some instances, because of the view shown, the quadrant in which a radius occurs will be different (Figure 69).

A Class 1 edge allows 0.01 mm (0.0004 in.) high projections or radii. A Class 9 allows 2.50 mm (0.100 in.) conditions at edges. Note that when edges intersect at angles other than 90 degrees, quadrants are defined by the planes on the part and not by orthoginal planes (Figure 67f).

Using this system requires the use of at least one of three notes (either on drawings or on in-plant plant standards).

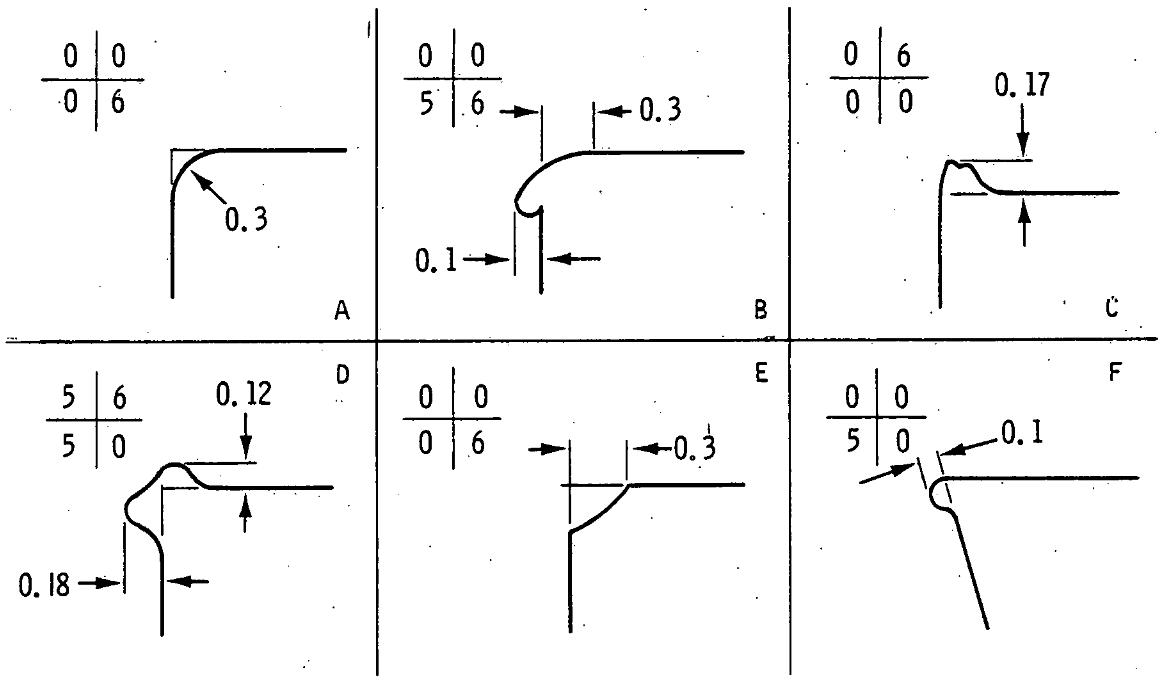


Figure 67. Edge Conditions and Related Notation[61]

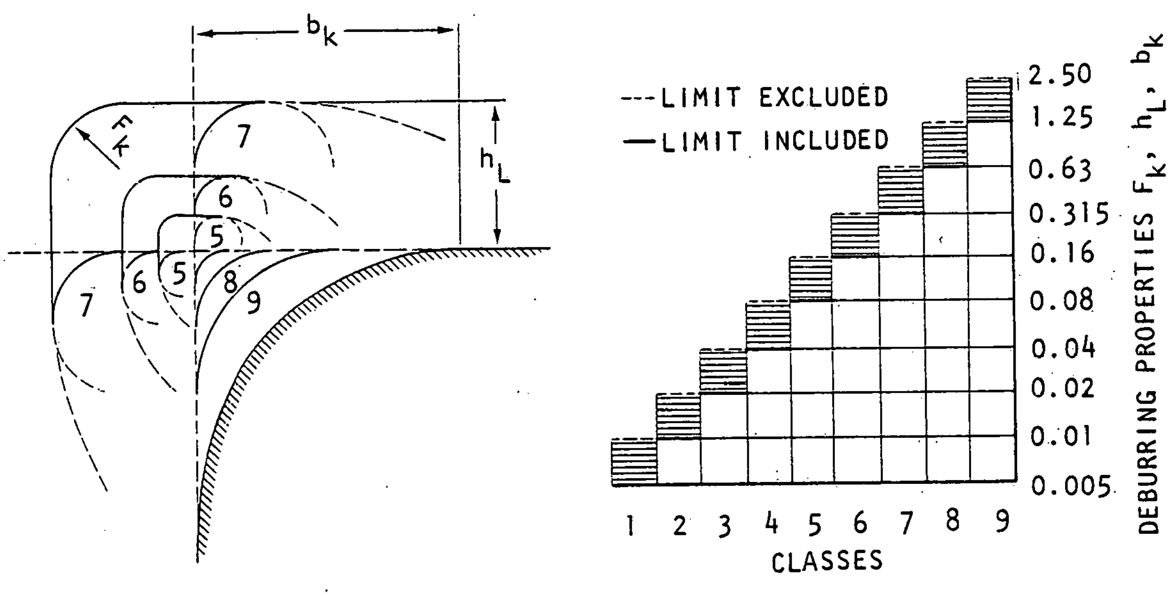


Figure 68. Classes of Allowable Edge Quality Proposed by Schafer[61]

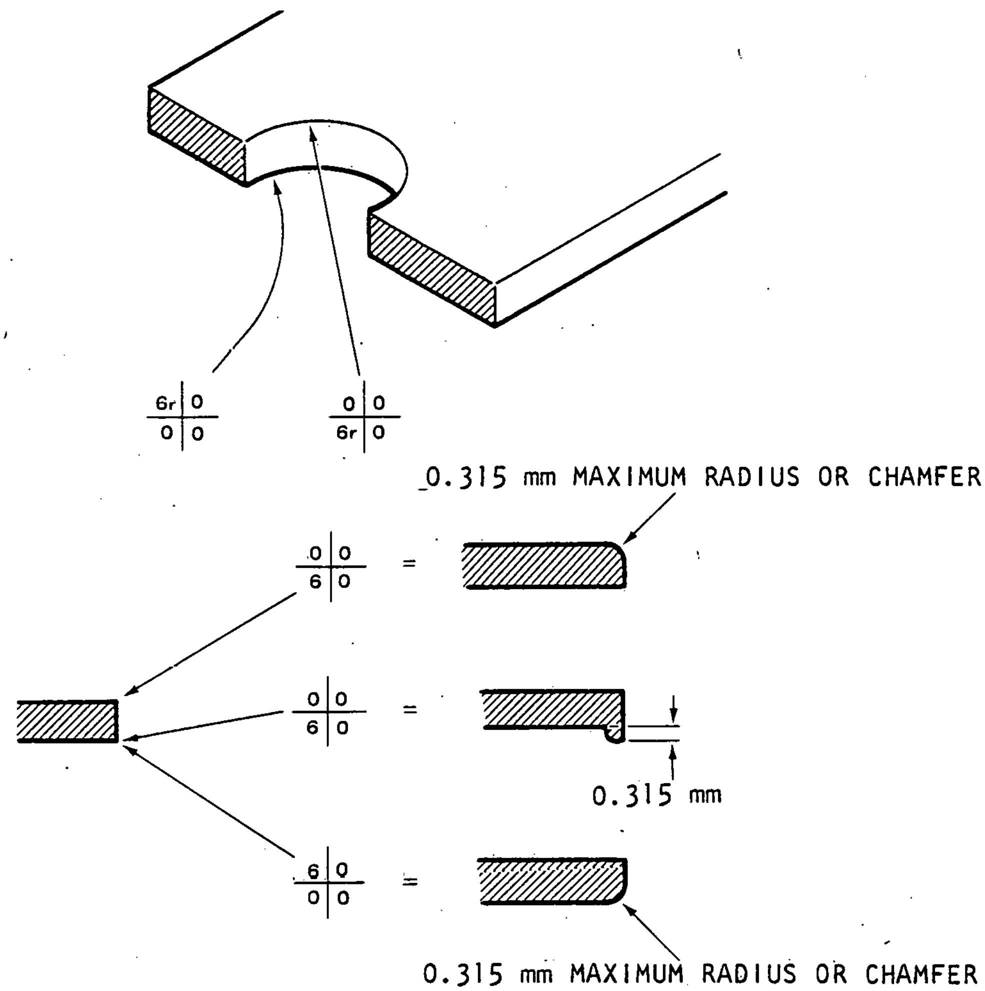


Figure 69. Schafer's Burr Notation as a Function of View Used

1. *Burrs need not be removed except as noted.*

2. *Tightly adhered burrs need not be removed. A sufficient check for adherence is defined in Standard XXXXX.*

3. *Sharp edges not permitted. Sharpness will be checked with Underwriters Laboratories sharpness monitor.*

Note 1 applies to parts in which burr measurements are not required. This, of course, eliminates the need for the proposed system except on specified edges. Note 2 applies when loose burrs or chips will cause malfunction of the assemblies. Note 3 normally is placed on most prints or in-plant standards.

Note that when burr height and thickness must be controlled, the system shown in Figure 65 must be used. When a radius rather than a chamfer is desired, an *r* can be added after the class number, or *radii* can be called out. When a chamfer is allowable, in-plant standards must indicate whether or not a small burr on the chamfer is allowable.

Standards For Burrs

As previously mentioned, no universal standards exist for burrs: industry has not been able to define what a burr is.

Sheared sheet stock can be purchased by an AISI edge condition number. Edge Number 3 indicates that the shearing burr remains on the sheet. Edge Number 5 indicates a burr-free sharp edge, and Edge Number 1 indicates chamfered or rounded edges. The National Screw Machine Products Association has a standard which indicates its supporting members do not deburr screw machine parts unless specifically agreed upon between buyer and seller. The edge quality standard proposed by Schafer[61] is the closest approach to a universal or international standard yet proposed. A national committee within the Society of Manufacturing Engineers is, however, investigating the possibility of some national standard on burrs.

Bendix does have several in-plant standards on burrs. The general workmanship requirements standard[62] indicates parts must be burr-free. As a result of the data generated in this project, existing process engineering standards have been upgraded[63-68] and a general process instruction standard has been prepared describing good workmanship practices related to burrs.[69]

While design standards of some form are necessary, they may not provide all the information needed by the machinist. If in-process deburring is required, for example, which edges to deburr at what time must be indicated, and if no blanket standard exists, the final edge condition must be specified. Figures 70 through 74 illustrate techniques which have been used. In some cases, the workmanship standard defined the required final edge condition. In others, the standard defined several levels of allowable quality on an individual part. To minimize confusion, specific edge requirements were specified to the production department. The technique shown in Figure 74 provides a method of identifying the edges to be deburred, the size of the final edge break, and the equipment to be used to remove the burr.

Burr Prevention

Deburring will not be required if burrs can be prevented from forming. Unfortunately, altering speeds, feeds, and tool geometries will not prevent burrs. Both analytical and empirical

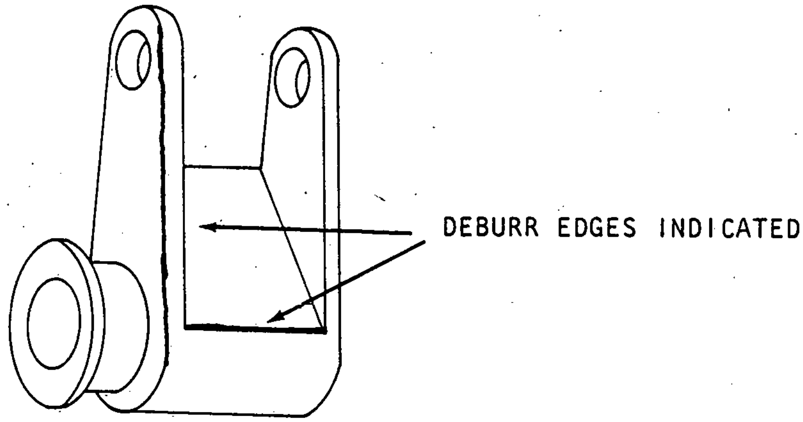


Figure 70. Shop Instructions on Deburring Simple Parts

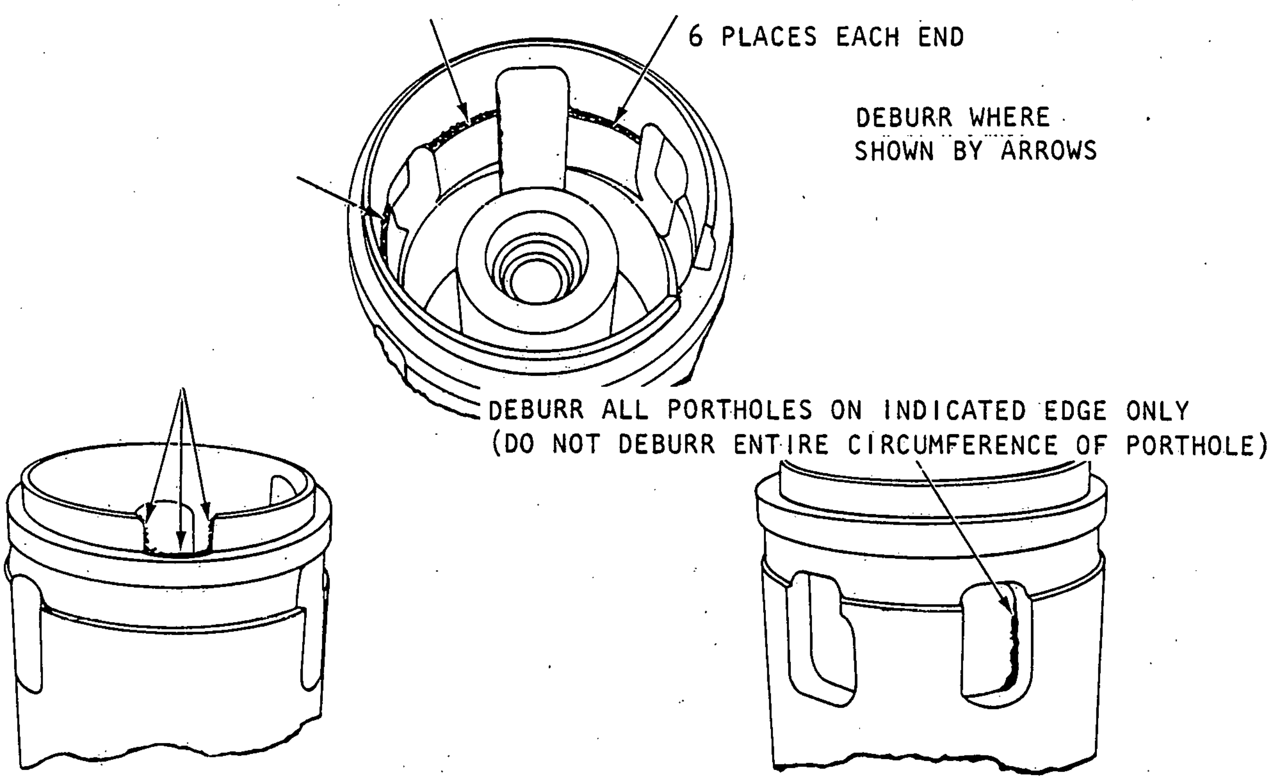


Figure 71. Shop Instructions on Deburring Complex Parts

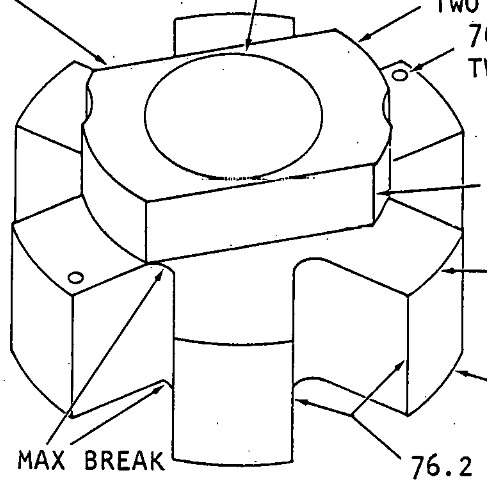
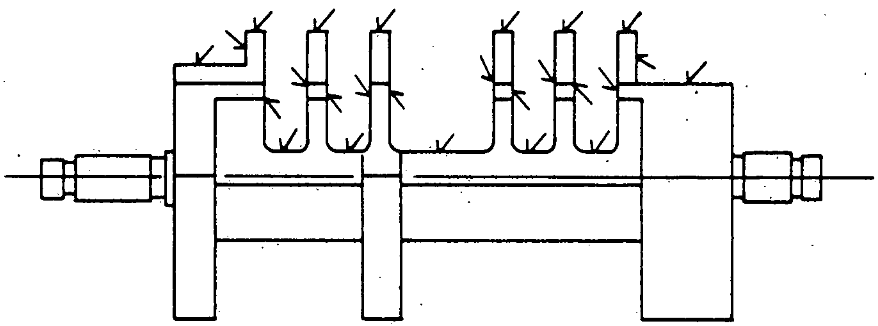


Figure 72. Shop Instructions on Allowable Edge Breaks

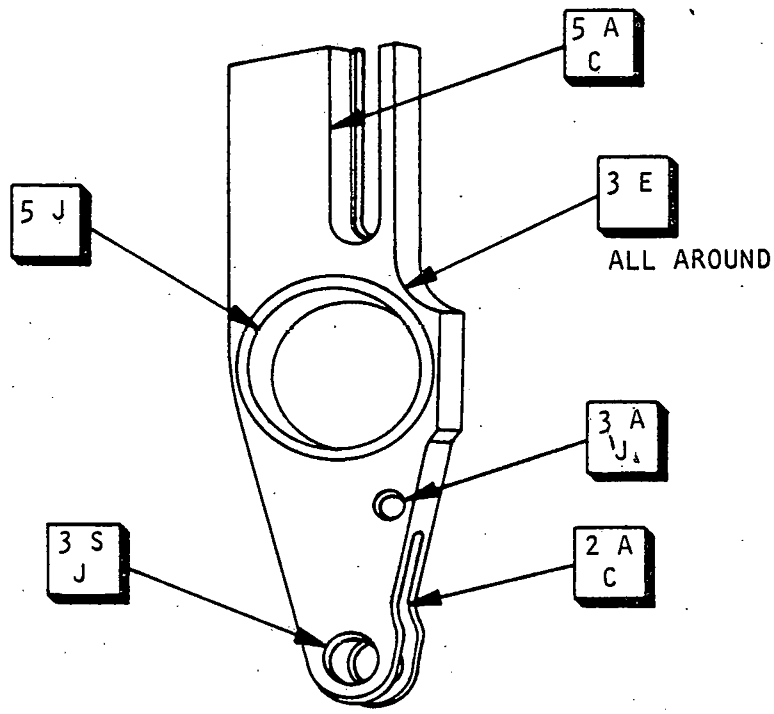


CHECKMARKS INDICATE EDGES TO BE DEBURRED

Figure 73. Identify Edges to be Deburred

studies[24-27] have shown that while tool sharpness and cutting conditions can *minimize* burr size and control burr repeatability, they cannot *prevent* burrs. Conventional machining techniques always produce burrs.

Theoretically, supporting the workpiece with a piece of backup material should prevent burrs, but from a practical standpoint backup material only helps minimize burrs. This can be seen by



CODE	INSTRUCTION
1	DEBURR A BREAK EDGE 381 TO 635 μm (0.015 TO 0.025 IN.) RADIUS
2	DEBURR A BREAK EDGE 127 TO 254 μm (0.005 TO 0.010 IN.) RADIUS
3	DEBURR A BREAK EDGE 127 μm (0.005 IN.) MAX RADIUS
4	DEBURR A BREAK EDGE 50.8/76.2 μm (0.002/0.003 IN.) RADIUS
5	DEBURR A BREAK EDGE 50.8 μm (0.002 IN.) MAX RADIUS
11	REMOVE HEAVY BURR ONLY
12	REMOVE FEATHER EDGE
13	CHAMFER FIRST AND LAST THREAD
A	BURR KNIFE
B	WIRE BRUSH
C	NYLON BRUSH WITH AL_2O_3
D	240 GRIT PAPER
E	STRING BRUSH WITH AL_2O_3
G	FILE
J	CRATEX "BULLET"
S	BURR BALL

Figure 74. Shop Instructions on Edge Requirements

Table 18. Non-Traditional Machining Capabilities

Process		Typically Makes Burr?*	Typical Edge Radius Produced μm (in.)	Typical Machining Tolerance μm (in.)
AJM	Abrasive Jet Machining	No	76.2 (0.003)	--
CHM	Chemical Machining	No	Unknown	±50.8 (±0.002)
EBM	Electron-Beam Machining	Yes	--	±25.4 (±0.001)
ECDM	Electro-Chemical Discharge Machining	Unknown	Unknown	Unknown
ECG	Electro-Chemical Grinding	No	76.2 (0.003)	±50.8 (±0.002)
ECM	Electro-Chemical Machining	No	25.4 (0.001)	±50.8 (±0.002)
ECH	Electro-Chemical Honing	No	12.7 (0.0005)	±5.1 (±0.0002)
EDM	Electrical Discharge Machining	Yes	--	±15.2 (±0.0006)
ELP	Electropolishing	No	25.4 (0.001)	±12.7 (±0.0005)
ESM	Electro Steam Machining	No	50.8 (0.002)	±25.4 (±0.001)
HCG	Hot Chlorine Gas	No	50.8 (0.002)	±76.2 (±0.003)
IBM	Ion Beam Machining	No	1.3 (0.00005)	± 2.5 (±0.0001)
LBM	Laser Beam Machining	Yes	--	±25.4 (±0.001)
PAM	Plasma Arc Machining	Yes	--	±76.2 (±0.003)
USM	Ultrasonic Machining	No	25.4 (0.001)	±25.4 (±0.001)
WJM	Water Jet Machining	No	Unknown	±76.2 (±0.003)

*Where burr is visible under 30X magnification

looking closely at a workpiece. Most operations produce burrs at more than one location. In drilling, for example, a burr is produced at both hole entrance and hole exit. In a milling operation burrs can be produced on up to 10 edges. At best, then, burrs are minimized on only one side of the workpiece. (Theoretically it would be possible to completely cover a part with backup material and prevent all burrs. From a practical standpoint this is not very realistic because the backup material must have the same properties as the workpiece to prevent burr formation.) While minimizing burr size is a distinct advantage, it is not as desirable as burr prevention.

Burrs can be prevented by employing some of the nontraditional processes. As seen in Table 18, most of the nontraditional processes do not produce burrs. Despite many statements to the contrary, EDM, EBM, and Laser Machining (LBM) do produce burr-like projections. While little test data is available on edge quality, two sources provide some insight. McBride's study[70] documents the effects of EDM parameters on EDM burr size, and the book *Non-Traditional Machining Processes*[71] discusses the edge conditions produced by EBM and LBM. Recent research on LBM, however, indicates that when a high velocity air blast is synchronized with the laser, the majority of the burr is blown out before it can solidify on the workpiece. In the future, then, LBM may fall in the category of a non-burr-producing process.

Processes such as CHM, ECG, ECM, ECH, ELP, and ESM should be used whenever possible. They not only eliminate deburring costs but they provide excellent surface finishes and minimize welding, brazing, and plating problems caused by media impregnation or improper cleaning. In addition, the elimination of unnecessary operations reduces paperwork costs and shortens production flow time.

The disadvantages of using non-traditional processes include high equipment costs, limitations to certain geometries and workpiece materials, and workpiece tolerance and surface integrity problems.[69]

Checklist for Minimizing Deburring Costs

There are 4 important rules to remember and 17 questions to answer on every part.

Rules

1. If you do not make a burr, you do not have to remove it.
2. Every conventional machining operation produces some burr.
3. If you do not have to remove the burr, do not remove it.
4. The machining conditions affect the deburring costs.

Questions

1. Does it have to be deburred?
2. Does it have to be deburred now?

3. What burr must be removed?

4. How much edge break is allowed (required)?

5. Does it have to be done by hand?

6. Will fixturing or hand tools help?

7. Can it be done on machine time?

8. Can two deburring techniques be combined to minimize total deburring cost?

9. Will backup material make deburring more economical?

10. Can fixtures be designed with burr clearance?

11. How can the burr be minimized?

12. Can the part or process be redesigned to reduce deburring?

13. Will the burr be cut off in a later machining operation? If the machining sequence were changed, would the burr be cut off?

14. Is the burr accessible? Should I change the sequence of operations? Should I change the direction of cut?

15. Can I choose a cutter that gives a smaller burr?

16. Do I know the feedrate which gives the smallest burr?

17. Can I use a subsequent heat treat or anodize to make the burr brittle?

ACCOMPLISHMENTS

Formulas for calculating deburring costs have been given as have formulas for evaluating effects of speed and feed changes. The effects of machining variables on burr size have been summarized for several processes. Practical techniques for minimizing burr size and deburring costs have been identified. Design techniques for minimizing deburring costs have also been described as have standards and burr prevention. The information compiled in this report constitutes a manual for minimizing deburring costs.

FUTURE WORK

No additional work is currently planned on this subject beyond the publishing of reports already in work. Additional work on centrifugal barrel finishing, extrude hone deburring, electropolishing, and chemical deburring would provide additional useful information. The effect of product geometry on burr size deserves additional study as does the effect of cutting tool geometry. In any future extensive study of deburring, it is essential to relate results to product configuration. A system such as that by Opitz is one approach to classifying parts by shape.

An extensive compilation of ideas for using deburring equipment which also describes tools and techniques is a necessity for widespread improvements in deburring. While such compilations have been made by the Production Engineering Research Association (PERA) of Great Britain, they are available only to members of that institution. A single exception is PERAs report on the use of power tools for deburring.[72]

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