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PRECISION DEBURRING OF MINIATURE PARTS

PDO 6984405, Final Report

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**Kansas City
Division**

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Final Report

Communications Services

**Kansas City
Division**

MASTER

PRECISION DEBURRING OF MINIATURE PARTS

BDX-613-1697 (Rev.), UNCLASSIFIED Final Report, Published
June 1977

Prepared by L. K. Gillespie, D/822, under PDO 6984405

An investigation of the capabilities of 35 deburring processes has aided in defining techniques for minimizing burr-related problems for the assurance of part-edge sharpness in the production of components for miniature precision mechanisms. Approaches for maintaining the required part-edge quality consist of utilizing available methods for preventing the formation of burrs, minimizing burr size by using proper machining conditions, designing parts to minimize deburring problems, and defining and extending the capabilities of existing deburring techniques.

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SUMMARY

The components of miniature precision mechanisms typically require burr-free, nearly sharp edges to assure their dependable operation. In the past, the reliable removal of machining burrs and the assurance of part-edge sharpness have dictated that deburring be performed only by hand. This method is inherently time-consuming and operator-variable.

Small burrs can be easily removed by many deburring processes. Because the time required for burr removal and the repeatability of the process are directly related to the size of the burr, this study was initiated to determine how deburring repeatability could be achieved in a minimum length of time. To accomplish this objective, the capabilities of the 35 major deburring processes were analyzed, and techniques for minimizing deburring problems were developed, studied, and improved. The results of the investigation are based on more than 50,000 measurements of burrs, a review of more than 1800 publications pertaining to deburring, an analysis of the deburring products of more than 400 manufacturers, and discussions with more than 100 persons involved in deburring.

Conclusions from the investigation indicate that burr-related problems in assuring part-edge sharpness in the production of miniature precision mechanisms can be resolved by the following four approaches.

- Employ available methods for preventing the formation of burrs.
- Minimize burr size by using proper machining conditions.
- Design parts to minimize deburring problems.
- Define and extend the capabilities of existing deburring techniques.

DISCUSSION

SCOPE AND PURPOSE

This project was initiated to develop, improve, and define processes and techniques required to produce controlled deburring of miniature metal parts.

PRIOR WORK

Five previous deburring studies have been conducted at Bendix Kansas City, and reports of the results have been published: Vibratory Deburring;¹⁻³ Thermal Shock Deburring;⁴ and Mechanical Deburring of Plastics.⁵

ACTIVITY

The following six approaches were utilized to meet the objectives of this project:

- Define the state-of-the-art of deburring;
- Extend the capabilities of certain deburring processes;
- Empirically define the effect of machining conditions on burr size;
- Analytically define the manner in which burrs are formed;
- Define techniques for preventing burrs; and
- Define other approaches for providing controlled deburring.

An initial summary defining the state-of-the-art of deburring was prepared in 1973⁶ on the basis of in-house experience and a review of over 1100 references on the subject. Since that time, two additional state-of-the-art summaries have been prepared,^{7,8} and four bibliographies containing 1800 references on burrs and deburring have been compiled.⁹⁻¹²

Empirical studies were made to define and improve the capabilities of the following processes:

- Vibratory Deburring;
- Centrifugal Barrel Tumbling;
- Brush Deburring;

- Extrude Hone Deburring;
- Hand Deburring;
- Electrochemical Deburring;
- Electropolish Deburring; and
- Chemical Deburring.

The results of several of these studies have been reported.¹³⁻²²

Burrs from seven machining processes were analyzed to determine how burr height, thickness, and radius vary with the machining conditions.²³⁻³⁰ Theories of burr formation have been described in six reports,³¹⁻³⁶ techniques that can be used to prevent burrs have been described in two reports,^{37,38} and international trends in burr technology have been summarized in two reports.^{39,40} Other design and manufacturing techniques for providing controlled deburring have been described in five reports,^{37,38,41-43} and factors to be considered in measuring burrs and calculating the economics of deburring have been summarized in four reports.^{38,44-47}

In compiling these studies, over 50,000 measurements were taken of burr sizes, edge radius, and effects of deburring on workpiece size and surface finish. High-speed movies were utilized to analyze burr formation and removal. Over 900 companies were contacted for information about available deburring equipment, supplies, and services.

Observations on the State-Of-The-Art of Deburring

In preparing the summaries of the various deburring processes, the significant observation was made that defining the state-of-the-art requires a knowledge of how the processes are affected by the thickness, height, and location of the burrs. Also required is a knowledge of how the processes affect the size, surface finish, and edge radii of the parts. Comparing the processes by the size of the burrs removed is insufficient, since any process can remove any burr if allowed enough time, stock loss, edge radius, and change in surface finish.

Another significant observation is that different results can be obtained by altering the conditions of any deburring process. Thus the capabilities of the standard vibratory deburring process differ from those of vibratory deburring using part fixturing, and electropolish deburring with a wand produces different results than those obtained from conventional electropolish deburring. Any attempt to provide condensed comparisons of the processes therefore must be made with respect to the standard process usage.

While this approach often produces the impression that a certain process will not meet the required conditions, a suitable variation of the process may prove effective. For this reason, comparisons between processes provide only basic guidelines when the entire range of process variations is considered.

Process Capabilities

The five basic approaches to deburring and the 35 process variations that they embrace are shown in Figure 1. As previously stated, detailed discussions of deburring-process capabilities have been reported,^{1-7,13-22} and a summary has been published.⁸ The highlights of these reports are presented in Tables 1 through 4. As shown by the data, when a stock loss of no more than $2.54\text{ }\mu\text{m}$ (0.0001 inch) can be tolerated in deburring operations, the burrs must be thin in order for most processes to work. Because of workpiece geometry, material, size, and surface finish limitations that are encountered in the manufacture of miniature precision metal parts, burr thickness must be maintained at $25.4\text{ }\mu\text{m}$ (0.001 inch) or less. Burr size can be somewhat larger if edge radii of $127.0\text{ }\mu\text{m}$ (0.005 inch) or greater are allowable. When maximum edge radii of $50.8\text{ }\mu\text{m}$ (0.002 inch) are required, the burr size must be kept to less than $25.4\text{ }\mu\text{m}$. In some cases, this may require extra machining operations or the use of two deburring processes. If two deburring processes are used, the first operation removes all heavy burrs and the second finishes the edges.

Deburring processes such as vibratory, barrel, and centrifugal-barrel finishing are sensitive to workpiece size. Small parts receive much less deburring action than do larger parts.

Many of the deburring processes are not as repeatable as the workpieces require. For example, centrifugal-barrel finishing has a standard deviation in the order of $0.51\text{ }\mu\text{m}$ (0.000025 inch) for some simple shapes. This indicates that 95 percent of the parts will experience a size-change variation of $\pm 1.27\text{ }\mu\text{m}$ ($\pm 0.00005\text{ inch}$). While this variation is very small, it is large when the total part tolerance is $\pm 2.54\text{ }\mu\text{m}$ ($\pm 0.0001\text{ inch}$). The variation in the size-change of the part is considerably greater for most other processes.

Because the repeatability of deburring and edge radiusing is a function of the repeatability of the burr size, burrs must be kept uniform. Unfortunately, conventional machining processes do not produce consistent burrs unless very "gentle" machining conditions are employed.

While hand-deburring always can be used to remove burrs, in many situations, it does not produce consistent edge radii smaller than

Table 1. Basic Capabilities of Deburring Processes--Stock Loss*

Deburring Process	Typical Working Range, Stock Loss (μm , Inch)			
	0.25 (0.00001)	2.54 (0.0001)	25.40 (0.001)	254.00 (0.010)
ABRASIVE				
Abrasive Jet				
Abrasive Flow				
Semisolid Carriers				
Liquid Carriers				
Water Jet				
Loose Abrasive				
Barrel				
Centrifugal Barrel				
Magnetic				
Spindle Finishing				
Vibratory				
Recipro Finishing				
Flow Finishing				
Sanding (Edges Only)				
MECHANICAL				
Mechanized				
Hand				
Brushing				

Table 1 Continued. Basic Capabilities of Deburring Processes--Stock Loss*

Deburring Process	Typical Working Range, Stock Loss (μ m, Inch)			
	0.25 (0.00001)	2.54 (0.0001)	25.40 (0.001)	254.00 (0.010)
THERMAL				
Flame	████████			
Thermal Energy (TEM)	████████			
Plasma	████████			
Hot Wire	████████			
CHEMICAL				
Chemical			████████	
Ultrasonic			████████	
Chlorine Gas			████████	
Chemical Loose Abrasive				
Barrel			████████	
Centrifugal Barrel			████████	
Spindle Finishing			████████	
Vibratory			████████	
ELECTROCHEMICAL				
Electrochemical	████████			
Electropolish			████████	
Electrochemical Brush	████████			

Table 1 Continued. Basic Capabilities of Deburring Processes--Stock Loss*

Deburring Process	Typical Working Range, Stock Loss (μm , Inch)			
	0.25 (0.00001)	2.54 (0.0001)	25.40 (0.001)	254.00 (0.010)
Electrochemical Loose Abrasive				
Barrel
Centrifugal Barrel
Spindle
Vibratory

*Based on the removal of 76.2- μm -thick (0.003 inch) burrs from the edges of 303Se stainless steel directly exposed to the deburring process. These capability estimates assume that surface finishes of 0.81 μm (32 micro-inches) are required and exist on the workpiece prior to deburring. Stock losses are defined as size changes which occur on exposed surfaces; the values are overall size changes of diameters or thicknesses. These estimates assume a maximum allowable edge break of 254 μm (0.010 inch). Less stock loss will occur if smaller burrs are present.

Table 2. Basic Capabilities of Deburring Processes--Part Size

Deburring Process	Typical Working Range, Workpiece Outside Dimensions (mm, Inch)				
	0.25 (0.010)	2.54 (0.100)	25.4 (1.00)	254.0 (10.00)	2540.00 (100.00)
ABRASIVE					
Abrasive Jet					
Abrasive Flow					
Semisolid Carriers					
Liquid Carriers					
Water Jet					
Loose Abrasive					
Barrel					
Centrifugal Barrel					
Magnetic					
Spindle Finishing					
Vibratory					
Recipro Finishing					
Flow Finishing					
Sanding (Edges Only)					
MECHANICAL					
Mechanized					
Hand					
Brushing					

Table 2 Continued. Basic Capabilities of Deburring Processes--Part Size

Deburring Process	Typical Working Range, Workpiece Outside Dimensions (mm, Inch)				
	0.25 (0.010)	2.54 (0.100)	25.4 (1.00)	254.0 (10.00)	2540.00 (100.00)
THERMAL					
Flame					
Thermal Energy (TEM)					
Plasma					
Hot Wire					
CHEMICAL					
Chemical					
Ultrasonic					
Chlorine Gas					
Chemical Loose Abrasive					
Barrel					
Centrifugal Barrel					
Spindle Finishing					
Vibratory					
ELECTROCHEMICAL					
Electrochemical					
Electropolish					
Electrochemical Brush					

Table 2 Continued. Basic Capabilities of Deburring Processes--Part Size

Deburring Process	Typical Working Range, Workpiece Outside Dimensions (mm, Inch)				
	0.25 (0.010)	2.54 (0.100)	25.4 (1.00)	254.0 (10.00)	2540.00 (100.00)
Electrochemical Loose Abrasive					
Barrel					
Centrifugal Barrel					
Spindle					
Vibratory					

Table 3. Basic Capabilities of Deburring Processes--Feature Size*

Deburring Process	Typical Working Range, Feature Size (mm, Inch)					
	0.025 (0.001)	0.25 (0.010)	2.54 (0.100)	25.4 (1.00)	254 (10.00)	2540 (100.00)
ABRASIVE						
Abrasive Jet	████████████████████	-----	████████████████████	-----	-----	-----
Abrasive Flow	████████████████████	-----	████████████████████	-----	-----	-----
Semisolid Carriers	████████████████████	████████████████████	-----	-----	-----	-----
Liquid Carriers	████████████████████	████████████████████	-----	-----	-----	-----
Water Jet	████████████████████	-----	████████████████████	-----	-----	-----
Loose Abrasive	████████████████████	-----	████████████████████	-----	-----	-----
Barrel	████████████████████	████████████████████	-----	-----	-----	-----
Centrifugal Barrel	████████████████████	████████████████████	-----	-----	-----	-----
Magnetic	████████████████████	████████████████████	-----	-----	-----	-----
Spindle Finishing	████████████████████	████████████████████	████████████████████	-----	-----	-----
Vibratory	████████████████████	████████████████████	████████████████████	-----	-----	-----
Recipro Finishing	████████████████████	████████████████████	████████████████████	-----	-----	-----
Flow Finishing	████████████████████	████████████████████	████████████████████	-----	-----	-----
Sanding (Edges Only)	████████████████████	████████████████████	████████████████████	████████████████████	-----	-----
MECHANICAL						
Mechanized	████████████████████	████████████████████	████████████████████	████████████████████	-----	-----
Hand	████████████████████	████████████████████	████████████████████	████████████████████	-----	-----
Brushing	████████████████████	████████████████████	████████████████████	████████████████████	-----	-----

Table 3 Continued. Basic Capabilities of Deburring Processes--Feature Size*

Deburring Process	Typical Working Range, Feature Size (mm, Inch)					
	0.025 (0.001)	0.25 (0.010)	2.54 (0.100)	25.4 (1.00)	254 (10.00)	2540 (100.00)
THERMAL						
Flame						
Thermal Energy (TEM)						
Plasma						
Hot Wire						
CHEMICAL						
Chemical						
Ultrasonic						
Chlorine Gas						
Chemical Loose Abrasive						
Barrel						
Centrifugal Barrel						
Spindle Finishing						
Vibratory						
ELECTROCHEMICAL						
Electrochemical						
Electropolish						
Electrochemical Brush						

Table 3 Continued. Basic Capabilities of Deburring Processes--Feature Size*

Deburring Process	Typical Working Range, Feature Size (mm, Inch)					
	0.025 (0.001)	0.25 (0.010)	2.54 (0.100)	25.4 (1.00)	254 (10.00)	2540 (100.00)
Electrochemical Loose Abrasive						
Barrel						
Centrifugal Barrel						
Spindle						
Vibratory						

*Feature size indicates the size of holes, slots, and related features that can be deburred by a process without special effort.

Table 4. Basic Capabilities of Deburring Processes--Applicable Workpiece Materials

Deburring Process	Steels	Stainless Steels	Copper Alloys	Aluminum	Space Age Metals	Plastics
ABRASIVE						
Abrasive Jet	x	x	x		x	x
Abrasive Flow	x	x	x	x	x	x
Semisolid Carriers	x	x	x	x	x	x
Liquid Carriers	x	x	x	x	x	x
Water Jet	x		x	x		x
Loose Abrasive						
Barrel	x	x	x	x	x	x
Centrifugal Barrel	x	x	x	x	x	x
Magnetic	Non-magnetic	Non-magnetic	x	x	x	x
Spindle Finishing	x	x	x	x	x	x
Vibratory	x	x	x	x	x	x
Recipro Finishing	x	x	x	x	x	x
Flow Finishing	x	x	x	x	x	x
Sanding (Edges Only)	x	x	x	x	x	x
MECHANICAL						
Mechanized	x	x	x	x	x	x
Hand	x	x	x	x	x	x
Brushing	x	x	x	x	x	x
THERMAL						
Flame	x	x	x	x	x	x
Thermal Energy (TEM)	x	Some	Some		x	Some
Plasma	x	x			x	
Hot Wire						x
CHEMICAL						
Chemical	x	x	x	x		
Ultrasonic	x	x	x			
Chlorine Gas	x					

Table 4 Continued. Basic Capabilities of Deburring Processes--Applicable Workpiece Materials

Deburring Process	Steels	Stainless Steels	Copper Alloys	Aluminum	Space Age Metals	Plastics
Chemical Loose Abrasive						
Barrel	x	x	x			
Centrifugal Barrel	x	x	x			
Spindle Finishing	x	x	x			
Vibratory	x	x	x			
ELECTROCHEMICAL						
Electrochemical	x	x		Some	x	
Electropolish	x	x	x	Some	Some	
Electrochemical Brush	x	x	x	x	x	
Electrochemical Loose Abrasive						
Barrel	x	x	x		x	
Centrifugal Barrel	x	x	x		x	
Spindle	x	x	x		x	
Vibratory	x	x	x		x	

101.6 μm (0.004 inch). As smaller workpieces are deburred, the consistency of the hand-deburring operations diminishes.

In general, centrifugal-barrel finishing and hand-deburring can meet the following requirements:

- Dimensional changes of 2.5 μm (0.0001 inch) or less;
- Surface finishes of 0.813 μm (32 microinches) or better; and
- Maximum edge breaks of 76.2 μm (0.003 inch).

Hand-deburred parts typically will have a few edges or portions of edges with radii exceeding 76.2 μm . Centrifugal-barrel finishing is more sensitive to burr size than is hand-deburring.

For the removal of small burrs, chemical, electropolish, and electrochemical deburring have the potential for maintaining the previously stated requirements, but the control of these processes is more difficult, and the attending personnel must be familiar with electrochemistry. Mechanized deburring also has the potential for meeting the requirements, but the commercially available equipment is unsatisfactory. The use of miniature brushes helps radius edges, but large burrs cannot be removed without generating large radii. The other processes are, in general, unsatisfactory for meeting the requirements stated.

If dimensional changes of 12.7 μm (0.0005 inch) or more, and radii of 127.0 μm (0.005 inch) or greater are allowable, abrasive-flow with semisolids (Extrude Hone and Dynetics processes), all the loose-abrasive processes, and sanding can be used. The thermal energy method can be used if burrs are no greater than 1/15 the thickness of the thinnest section of the part.

Burrs Produced by Machining

The studies of burrs produced by machining operations revealed several significant facts.

- All conventional machining operations produce burrs.
- Burr size can vary significantly along a single edge.
- A single pass with a cutting tool can produce burrs on eight edges with different burr properties on each edge.
- Feedrates, speeds, and tool geometries affect the burr size in complex ways.

The formation of burrs cannot be prevented by changing feeds and speeds; while this approach can minimize burrs along one edge, it may increase the size of the burrs along another edge. For the conventional speeds and feeds used at Bendix Kansas City for the production of miniature precision metal parts, typical burrs are 76.2 μm thick by 127.0 μm high (0.003 by 0.005 inch). Screw-machine parts which have tolerances of $\pm 5.08 \mu\text{m}$ (± 0.0002 inch) tend to have burrs that are 25.4 μm thick by 25.4 μm high (0.001 by 0.001 inch).

The fact that an end mill which slots a part produces eight different edges indicates some measure of the difficulty in making general statements concerning the burrs that are produced. These eight edges contain burrs produced by three different mechanisms, and each edge reacts differently to changes in the machining conditions. The effects of machining variables have been defined in several reports.^{2 3-3 6}

Analyses of Burr Formation

Burrs, flash, and other related protrusions are formed by the six physical principles shown in Table 5. Of the six, the first three involve plastic deformation of the workpiece material and represent the underlying basic mechanisms which form protrusions that generally are defined as burrs. The remaining three principles are responsible for burr-like protrusions which also are described as burrs by many investigators. The fourth principle of burr formation produces a burr-like projection as a result of the solidification of material on the working edges. The fifth type of burr occurs when the workpiece is allowed to fall from the part before the cut has been completed. Flash, the final type of burr-like projection, forms whenever the pressure on the molten molding material is sufficient to force it between the halves of a die. The basic theories of burr formation and their mathematical descriptions have been presented in several previous reports.^{2 3-3 6}

The following three basic facts appear in all of the equations which describe the formation and properties of burrs.

- Any factor which increases the cutting forces, other than the length of the edge in the cut, increases the size of the burr.
- Burr size is a function of the ratio between the cutting force (or pressure) and the effective yield strength of the workpiece.

Table 5. Burr Definitions

Physical Principle of Burr Formation	Name of Protrusion
Lateral Flow of Material	Poisson Burr
Bending of Material (Such as Chip Roll-Over)	Roll-Over Burr
Tearing of Chip From Workpiece	Tear Burr
Redeposition of Material	Recast Burr
Incomplete Cutoff	Cutoff Burr
Flow of Material Into Cracks	Flash

- Burr size increases as the strain-hardening exponent of a material increases. The strain-hardening exponent (n) is defined by the following equation for the true-stress-true-strain curve:

$$\sigma = \sigma_0 \Sigma^n; \quad (1)$$

where

σ = true stress for the true strain;

σ_0 = a constant; and

Σ = the true strain value.

Empirical data also indicate that ductile materials will form larger burrs than brittle materials. While this is obvious from a consideration of the manner in which burrs are formed, it often is forgotten. The basic equations for burr formation agree with empirical-result patterns, although the magnitudes of the results vary by a factor of 2 or 3.

Burr Prevention

Burrs and other related protrusions can be prevented by the use of chemical or electrochemical machining processes. With the exception of edges having an included angle greater than 150 degrees, conventional machining processes which produce chips by plastic deformation always produce burrs when the cutter passes over the edges of the part. Only edges having an included angle of at least 150 degrees typically do not produce burrs. The edges of most machined parts, however, have 90-degree included angles.

Other Approaches to Controlled Deburring

The following approaches can be used to overcome the deburring limitations previously described:

- Minimizing burr size;
- Designing parts for economical deburring;
- The use of two or more deburring processes;
- Masking of parts put in deburring processes;
- Utilizing special adaptations of standard deburring processes;
- Developing special hand tools for specific part configurations; and
- Choosing more effective sequences for machining operations.

Minimizing Burr Size

Parts which can be allowed to change in size by $2.5\text{ }\mu\text{m}$ (0.0001 inch) in the deburring process and which have burrs that are $25.4\text{ }\mu\text{m}$ (0.001 inch) or less in thickness can be deburred rather easily by simple, rapid techniques. As the burr thickness becomes greater, deburring time, complexity, and limitations increase. Reaming after drilling, grinding after milling, and sanding after blanking are techniques that typically reduce the burr size while improving the finish or the dimensions of the part.

Although miniature precision parts often have smaller burrs than do bulky parts having large tolerances, the belief that precision parts are synonymous with small burrs is unrealistic. In some cases, the burrs may be as large as the part. The use of sacrificial backup material and specially designed fixtures can be effective techniques for minimizing the burr size.

Designing Parts for Economical Deburring

Recent research^{4,8} indicates that product configuration plays an important role in determining burr size and deburring capabilities. In addition to considering part configuration, specifying actual edge requirements, as opposed to the use of blanket standards for edge quality, can minimize deburring problems. These techniques have been discussed more fully elsewhere.^{13,36,38,43} At the present time, however, knowledge of the influence of product configuration upon deburring is still rudimentary.

Multiple Deburring Processes

For many parts, two sequential burr-removal processes can be used more effectively than a single process. Removing large burrs by hand and then vibrating the parts to remove all other burrs is a common example. The sanding of blanked or machined parts prior to vibratory deburring can reduce the total deburring time and minimize the effects on surface finish, edge radii, and dimensions. Many commercial miniature precision watch components go through a three-step deburring process consisting of bright-dipping (chemical deburring), brushing, and centrifugal-barrel tumbling.

Masking of Parts

The effects of the deburring process on the size and surface finish of the parts can be minimized by masking the critical features. This method, however, requires additional time for the preparation and removal of the masking and, in some cases, increases the flow time. The fact that additional process operations are involved may create other deburring and cleaning problems.

Nonstandard Deburring Processes

For every deburring process, there is at least one process adaptation. Localized electropolish deburring, as opposed to total immersion in a solution, is one such example. The fixturing of parts for loose-abrasive processes and the use of flow restrictors to concentrate abrasive-flow deburring action represent other approaches. Each adaptation extends the capability of the basic process. At the present time, however, the various process adaptations have not been cataloged, nor have their capabilities been defined. This approach to improving deburring-process capabilities therefore exists only in the minds of individuals who have worked for many years in the field of deburring.

Few of the available mechanical deburring processes can be used for miniature precision parts because commercial equipment has not been designed for use with small parts having close tolerances. Specially designed equipment often is required for this type of application. While sanding is an obvious approach to the deburring of miniature flat parts, commercial sanders will not deburr such parts consistently on a small-lot basis. Simonton⁴⁹ has described a specially designed machine for producing 50.8- by 50.8- μm (0.002 by 0.002 inch) chamfers on extremely small tubes.

Specially Designed Hand Tools

Designing special tools for hand-deburring hard-to-reach areas can also help to provide controlled deburring. Although several hundred hand-deburring tools are commercially available, they

often are inadequate for use on some components; this is particularly true if the part is small enough to become lost beneath a fingernail.

Bendix Kansas City has designed over 50 hand-held tools for special deburring needs. Figure 2 shows a simple tool that is used to remove burrs from special-drilled allen-head screws. While tools of this type may produce burrs on the part, these secondary burrs are small enough to be easily removed by other faster, more readily controlled processes.

Sequence of Machining Operations

A judicious choice of the machining-operation sequence can help to minimize the burr size and the burr-removal problems. For example, when small holes intersect with a large hole, the large hole generally should be drilled first. This permits the use of a reamer or broach to shear in a single operation the burrs resulting from drilling the small holes. In addition, burrs produced by the large tool generally will be larger than those produced by the small tool.

If the opposite drilling sequence were used, the deburring tool would have to be placed in each of the small holes instead of in only the large hole. This sequence has an advantage only if burrs are allowed in the small holes but not in the large hole.

These same principles apply to all machining processes. Depending upon the part geometry and the processes involved, some combination of processes (without regard to speed, feed, and tool-geometry effects) will minimize the size of the burrs remaining on the part.

The machining sequence also can be planned to place burrs in locations that are easy to attack for the purpose of burr removal. As shown in Figure 3, feeding the cutter in one direction causes the burr to form over the shaft. In this position, the burr is difficult to remove uniformly by any deburring process. If the direction of the cut is reversed, the burr is placed in a position where it readily can be removed. This determination of the burr location must be made before tooling is ordered, however, to provide appropriate support for the workpiece. Any changes made at a later time may involve additional tool-design and fabrication expenses.

In many instances, the part can be made larger than specified by the part drawing with the knowledge that the deburring process will remove the excess material. For stamped parts, this approach may necessitate making the die cavity larger than it traditionally is made. Again, deburring must be considered before the tooling is designed.

Figure 2. Broaching Tool Used for Deburring

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 3. Typical Burr-Location Options

ACCOMPLISHMENTS

This project has fulfilled the goals of developing, improving, and defining the processes and techniques required for the controlled deburring of miniature precision metal parts. Specific accomplishments include compiling state-of-the-art summaries, documenting the available literature on deburring, analyzing the deburring products available from more than 400 manufacturers, and defining in depth the capabilities and limitations of eight deburring processes.

Comprehensive theories of burr formation were developed and then substantiated in eight major studies of the effects of machining

processes on burr size. Techniques for burr minimization and prevention were examined and defined, as were other design and manufacturing approaches which minimize burrs and result in better burr control. The economics of the various deburring processes have been mathematically defined.

The results of this study have helped to provide a better control of production-part edges during a period in which part and edge tolerances were becoming significantly smaller. In addition, this work has helped to establish an international appreciation of the fact that deburring problems can be solved in a rational, scientific manner.

FUTURE WORK

Although no further studies of deburring are planned at this time, several aspects warrant additional investigation. The deburring of threaded features, particularly those with miniature threads, is still difficult to accomplish. Practically no data exist on the deburring of plastics. Additional investigations of the influence of part geometry on burr size and formation have a potential for eliminating some problem areas. The need for convenient tools to measure burr thickness became obvious during this study. Additional investigation of the effects of the various deburring processes on part tolerances would be useful, as would improved techniques for handling and sorting parts during the deburring operations.

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