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HAND DEBURRING OF PRECISION
MINIATURE PARTS

PDO 6984405, Topical Report

L. K. Gillespie, Project Leader

Project Team:
W. H. McDaniel

November 1975

MASTER

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**Kansas City
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**HAND DEBURRING OF PRECISION
MINIATURE PARTS**

November 1975

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PDO 6984405
Topical Report

Technical Communications

**Kansas City
Division**

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HAND DEBURRING OF PRECISION MINIATURE PARTS

BDX-613-1443
November 1975

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

Small precision mechanisms such as timers, switches, and actuators require burr-free, sharp-edged parts to operate well. This study indicated that the smallest edge-radius which can be reliably produced by skilled operators, while deburring with hand tools, is 0.004 inch (101.6 μm). Fifty percent of the radii produced while trying to maintain a 0.002 inch (50.8 μm) maximum edge-radius were 0.002 inch or smaller. Hand-deburring time increases as burr thickness increases and as accessible space around the burrs decreases. Ten to 60 percent of the time spent in hand deburring precision miniature parts is consumed in checking edges to be sure they are burr-free. Maintaining edge radii requirements on short-run precision miniature parts requires a combination of hand and mechanized deburring on many parts.

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SUMMARY

Component parts of small precision mechanisms have typically required near-sharp edges to assure reliable component operation. A burr-free condition is also needed to minimize possible jamming of the mechanism if burrs should break loose during operation. In the past, reliable removal of machining burrs, combined with protection of the near-sharp edge requirements, has dictated that deburring be done only by hand, which is time consuming and inherently operator-variable.

This study was initiated to determine how burr size, workpiece material, and accessibility influence deburring. Two specific objectives were to determine how small an edge radius could be repeatedly produced while removing a burr, and how burr accessibility affects deburring time.

Hand-deburring workers, experienced in deburring precision miniature parts, could not maintain maximum radii smaller than 0.004 inch (101.6 μm). While 50 percent of the edge measurements indicated a radius of 0.002 inch (50.8 μm) after deburring, a 0.004-inch maximum radius specification would be required to accommodate 95 percent of the measurements. Increasing the number of edges to be deburred and the complexity of the deburring increase the likelihood that at least one edge will exceed the maximum edge radius requirement.

The time required for deburring was a nonlinear function of burr thickness. Burrs thicker than 0.004 inch require considerably more time to remove than do thinner burrs. Deburring time also appears to be a function of the strain-hardening exponent of the workpiece material. Materials with large strain-hardening exponents require more deburring time. This result, however, is strongly influenced by the machining conditions used.

The accessibility of burrs influences deburring time. When there is little room to maneuver deburring tools, deburring time increases sharply. This is particularly evident when openings around burr-laden edges are smaller than 0.062 inch (1.57 mm) in diameter or width. Because workers shift deburring techniques as accessibility decreases, deburring time as a function of accessibility does not follow a smooth curve.

Ten to 60 percent of the time spent in hand deburring precision miniature parts is consumed in checking edges to be sure they are burr-free.

In some cases hand deburring and mechanized deburring can be combined to assure that special requirements, such as a 0.002-inch maximum radius, are maintained.

DISCUSSION

SCOPE AND PURPOSE

The objective of this study was to determine the repeatability of hand deburring, to determine how deburring time and techniques vary with burr size and accessibility, and to determine how hand deburring can be improved.

PRIOR WORK

No prior studies of hand deburring have been reported by Bendix, although many time studies have been made on individual piece-parts.

Bendix studies on vibratory, brush, thermal shock, and extrude hone deburring have been published,¹⁻⁷ in addition to a general summary of the capabilities of the 20 major deburring processes.⁸ Related studies on burr formation and properties, minimization, and the minimization of deburring costs have also been reported,⁹⁻²¹ and two bibliographies on these subjects have been compiled^{22,23} An overview of international research on burrs and deburring has also been reported.²⁴

ACTIVITY

Background

The removal of burrs by hand-held deburring tools is a practice employed to some degree by almost every manufacturing plant in the world. Hand (or manual) deburring in this study includes parts hand-held against a moving deburring tool, as well as parts in which a hand-held deburring tool is used. It is an undesirable (albeit, often necessary) practice for at least two reasons.

- Since each part is handled individually, it is inherently time-consuming.
- Since it relies upon operator skill and visual acuity, it is inherently operator-variable.

While many studies have been performed within individual plants with the goal of reducing hand-deburring time or improving the quality of the edges, no formal reports have been published which provide background information on such aspects as the following:

- Repeatability of burr removal/edge radiusing;
- Effect of burr properties on deburring time;
- Effect of product size and geometry on deburring time; and
- The capability of the various deburring tools for removing burrs.

The magnitude of a comprehensive study that would provide data for evaluating hand deburring without actual in-plant observation on each part, becomes obvious when one considers that an estimated 500 deburring tools are available. As will be discussed later, operator technique can create an equal number of variables in the process.

In this study seven tests were performed, using techniques and tools commonly used on precision miniature metal components. Some tests explored the final edge condition after the burr was removed, in an attempt to ascertain the smallest repeatable edge break which could be maintained on parts. Other tests explored the effect of product geometry and burr properties on deburring time. More specifically, the product geometry tests analyzed how the accessibility of burrs affect deburring time.

Tests of Deburring Repeatability

In the initial tests of deburring repeatability, four production workers whose principal job duties are burr removal, were given six specimens each to deburr. Each worker was told that the final edge break, or radius, must be maintained at 0.005 inch (127.0 μm) or less.

A statistical analysis of the data indicated that the average radius produced was 0.0022 inch (55.9 μm), and the standard deviation of the data was 0.0015 inch (38.1 μm). There was no difference in the results produced by the four operators. Statistically, for these values, 95 percent of the radii should be 0.0052 inch (132.1 μm), or less. An examination of the test measurements revealed that 95 percent of the edge radii were in fact 0.0050 inch (127.0 μm), or less. From these results and production experience, it is clear that trained operators can maintain a 0.005-inch maximum edge break while removing burrs. Statistically, less than 50 percent of the edges produced under these conditions would have radii of 0.002 inch (50.8 μm), or less.

The specimens used in this test were 0.5-inch (12.7 mm) cubes, with a milled step in one edge (Figure 1a). The workpiece material was 303 Se stainless steel, and the burrs which were produced by an end mill were up to 0.0098 inch (248.9 μm) long

1a

1b

Figure 1. Specimen Geometry Used to Assess Edge Break Repeatability

and 0.0037 inch (94.0 μm) thick. Each of the machining conditions and burrs produced is typical of those produced on precision, miniature, metal pieceparts.

Edge radii were measured on the top and bottom lip of the milled cutout. These measurements were made by sectioning the specimen, mounting in a metallurgical mount, polishing, and then inspecting, using a Zeiss inspection machine. In several cases, the edge radius produced was not a uniform blend; but all sharp edges were removed. Figure 2 shows some typical edge conditions.

Figure 2. Common Edge Conditions Produced by Hand Deburring

In the second study burrs had to be removed from thin slots as well as from exposed edges (Figure 1b). In this test one individual deburred 10 specimens each of four workpiece materials. A 0.005-inch (127 μm) maximum edge radius was also the goal of this study. Table 1 summarizes the results of this study.

As shown in Table 1, typical average ($\bar{r}$) values for edge radii ranged from 0.0025 inch (63.5 μm) to 0.0042 inch (106.7 μm). For 17-4 PH stainless steel, 95 percent of the edges ($\bar{r} + 2\sigma$) produced under these conditions had radii of 0.0043 inch (109.2 μm), or smaller. While this is, in general, true also of the other metals, on some edges the allowable edge radii would have to be 0.0071 inch (180.3 μm) to accommodate 95 percent of the radii on that edge. While the required 0.005-inch (127.0 μm) maximum radii was maintained on most edges, 4.5 percent of the edges measured exceeded the requirement.

The hand deburring in this study tended to be consistent in that the standard deviation was typically 0.0007 inch (17.8 μm). Table 1 shows that the 303 Se stainless steel specimen required almost twice the time to deburr as did the aluminum specimen. The burrs in this test, which were produced by slitting saws and an end mill, were quite small, typically 0.0008 inch thick (20.3 μm) and 0.0039 inch long (99.1 μm).

A statistical analysis of the data indicates that the time required to remove these burrs was not proportional to their length nor to the final radius; neither was final edge radius a function of burr length. There was not sufficient data to be

Table 1. Results of Hand Deburring Test

Test Parameters	Workpiece Material			
	6061-T6 Aluminum	BeCu	17-4 PH Stainless (H-900 Condition)	303 Se Stainless
Average Time Required to Remove Burrs (Minutes)	2.51	3.28	3.07	4.66
Results (inch) (μm)				
Edge Number 1				
Avg Radius ($\bar{r}$)	0.0031 (78.7)	0.0025 (63.5)	0.0025 (63.5)	0.0021 (53.3)
Std Deviation (σ)	0.0007 (17.8)	0.0005 (12.7)	0.0006 (15.2)	0.0008 (20.3)
$\bar{r} + 2\sigma$	0.0045 (114.3)	0.0035 (88.9)	0.0037 (94.0)	0.0037 (94.0)
Edge Number 2				
Avg Radius ($\bar{r}$)	0.0038 (96.5)	0.0039 (99.1)	0.0032 (81.3)	0.0042 (106.7)
Std Deviation (σ)	0.0007 (17.8)	0.0013 (33.0)	0.0004 (10.2)	0.0012 (30.5)
$\bar{r} + 2\sigma$	0.0052 (132.1)	0.0065 (165.1)	0.0040 (101.6)	0.0066 (167.6)
Edge Number 3				
Avg Radius ($\bar{r}$)	0.0026 (66.0)	0.0022 (55.9)	0.0016 (40.6)	0.0025 (63.5)
Std Deviation (σ)	0.0009 (22.9)	0.0007 (17.8)	0.0010 (25.4)	0.0007 (17.8)
$\bar{r} + 2\sigma$	0.0044 (111.8)	0.0036 (91.4)	0.0036 (91.4)	0.0039 (99.1)

Table 1 Continued. Results of Hand Deburring Test

Test Parameters	Workpiece Material			
	6061-T6 Aluminum	BeCu	17-4 PH Stainless (H-900 Conditions)	303. Se Stainless
Edge Number 4				
Avg Radius ($\bar{r}$)	0.0026 (66.0)	0.0045 (114.3)	0.0029 (73.7)	0.0023 (58.4)
Std Deviation (σ)	0.0009 (22.9)	0.0013 (33.0)	0.0007 (17.8)	0.0008 (20.3)
$\bar{r} + 2\sigma$	0.0044 (111.8)	0.0071 (180.3)	0.0043 (109.2)	0.0039 (99.1)

checked to provide a relationship between deburr time and burr thickness. Since knives were used to cut off burrs, it is logical to believe that deburring time is a function of burr thickness. The time required for deburring appears to be proportional to the strain-hardening exponent of the workpiece (Figure 3).

For the third test, an operator was asked to produce an edge radius no larger than 0.002 inch (50.8 μm). In this case, only three materials were studied; but radii were measured on 11 edges (Figure 1b). More than one measurement was made on some edges, since the radius is not always constant along edges. A total of 330 edges were measured.

Average edge radii values were calculated for each of the 11 edges on the workpiece. As shown in Table 2, on the beryllium copper workpieces only six of the 11 edges had an average radius of 0.002 inch (50.8 μm), or less. The objective of this test was to deburr such that all edges (not just 50 percent) had radii of 0.002 inch, or less. On only one of the 11 edges would 95 percent ($\bar{r} + 2\sigma$) of the radii be 0.002 inch, or less.

Table 3 provides some numerical values of the edge radii. If one had to select a typical radius ($\bar{r}$) for any one edge, that radius would be 0.0020 inch (50.8 μm) in beryllium copper. Ninety-five percent of the parts ($\bar{r} + 2\sigma$) measured at that edge would tend to have a radius of 0.003 inch, or less. If one were concerned that all 11 edges on 95 percent of the parts had a radius equal to or less than r , then r would have to be 0.0039 inch (99.1 μm) for beryllium copper (Table 3).

The following implications result from this and the two previous tests. It has been found that these results also generally apply to production parts.

- Maintaining 0.002-inch (50.8 μm) maximum edge radius by existing hand-deburring techniques is not usually feasible without 50-percent fallout. It is possible, however, to produce an average radius of 0.002 inch. While the majority of edges on a part may have radii of 0.002 inch or less, a significant portion of the total length of edges will have radii greater than 0.002 inch.
- There is little difference in the results obtained by trying to maintain 0.005 inch (127.0 μm) maximum edge radius or 0.002 inch (50.8 μm) maximum edge radius.
- Increasing the number of edges to be deburred and the complexity of the deburring increases the variability in results.

Figure 3. Relationship Between Deburring Time and Strain Hardening Exponent

There was little difference in the results produced by experienced operators in this study. In production situations, however, a notable difference does exist. Repeatability is a function of burr size and location. These variations affect some operators more than others. In production, it is not always possible to guarantee that the most highly capable individuals are assigned to deburr workpieces having small allowable edge breaks. The time required to deburr specimens will vary considerably among operators.

Effects of Part Geometry and Burr Size on Deburring Time

In the second series of tests an attempt was made to determine how burr size and the accessibility of the burr affected deburring time. Four brief tests were performed. As discussed in the previous section, deburring time is a function of workpiece material properties. Short but very wide burrs occur in some materials, while long but very thin burrs occur in others. For any given material, the conditions that produced the burr greatly affected the burr size and, therefore, also the deburring time.

The accessibility of the burr also influences the time required for deburring, and the quality of the resulting edge. For example, if one had to deburr the intersection of two holes, one would reasonably expect the time required to deburr the intersection to be a function of the hole sizes (Figure 4). As will be shown, actual deburring times are a function of accessibility, but they do not follow the regular pattern shown in Figure 4.

Table 2. Hand-Deburring Results

Workpiece Material	Edges With Average Radius ($\bar{r}$) of 0.002 in. (50.8 μ m), or Less		Edges for Which $\bar{r} + 2\sigma$ Would be 0.002 in., or Less	
	Number	Percent	Number	Percent
BeCu	6	55	1	9
Aluminum	7	63	3	27
17-4 PH Stainless	6	55	2	18

For the first study in this series of tests, a round washer-like part (Figure 5) was deburred. Some of these parts had drilling burrs and some had reaming burrs. These parts were made from 303 Se and 17-4 PH stainless steel, 1018 steel, and 6061-T6 aluminum. Typical properties of the burrs on these specimens are shown in Table 4. Burr thickness and length were measured on the side where the drill entered the workpiece, as well as on the side where it exited.

Five specimens were deburred at each of the eight material/machining combinations. Table 5 shows the time required, and that the typically thinner reaming burrs required less time for deburring than did the drilling burrs. The procedure used to deburr these specimens follows.

1. Rub both sides of part on 600-grit paper to remove raised metal.
2. Cut off burr with burr knife on both sides.
3. Rub both sides of part on 600-grit paper.

A very large burr occurred on the drill and reamed specimen of 17-4 PH stainless steel because rapid drill wear generated high temperatures which caused an extruded burr. Reaming did not remove all of this burr. The 17-4 PH drill specimen in this test was made before the drill became dull, and therefore does not exhibit the extruded burr. Nippers were used to remove the majority of the extruded burr; then the above procedure was followed.

Table 3. Analysis of Edge Radii

Results	Workpiece Material		
	BeCu	Aluminum	17-4 Stainless Steel
Average Deburr Time (Minutes)	2.36	2.39	1.89
Typical Values of Radii (in.)			
$\bar{r}$	0.0020	0.0017	0.0021
σ	0.0005	0.0004	0.0004
$\bar{r} + 2\sigma$	0.0030	0.0025	0.0029
Mean and Standard Deviation for all Edges (in.)			
$\bar{r}$	0.0020	0.0017	0.0018
σ	0.0009	0.0008	0.0008
$\bar{r} + 2\sigma$	0.0039	0.0034	0.0036

NOTE: To convert inches to μm , multiply by 0.0254.

As shown in Figure 6, which is a plot of the data in Table 5, once burr thickness increases beyond 0.004 inch (101.6 μm), deburring time increases sharply. While only a few points were available from which to construct Figure 6, the basic shape and the 0.004 *breaking* point are consistent with conditions observed in production. Although the graph is useful to illustrate the significance of burr size, using the data predicted by the equation describing this curve (Equation 1) can provide some misleading estimates of production deburring time.

$$T = \frac{\ln(A_1 - b_t) - \ln A_2}{A_3} \quad 1/c \quad (1)$$

A_1 , A_2 , A_3 are constants.

b_t = Burr thickness.

T = Time required to manually remove burr.

c = Constant.

Figure 4. Conceptual Model of Burr Removal Time as a Function of Aperture Size

Figure 5. Specimen Used for Analysis of Deburring Time

There is a point, undefined as yet, at which each deburring worker will change his or her approach to deburring. For example, nippers were used to cut off the major portion of the 0.005-inch-thick (127 μ m) burr. Another worker might have used a file, then followed this procedure with sand paper; still another might have used a file, a reamer, then sand paper. In short, because of the wide variety of tools and techniques available, actual times required for deburring will not follow a smooth curve, such as shown in Figure 6.

Figure 6 ignores the time spent on deburring the smaller entrance burr, and it ignores the impact of burr length. A more realistic estimate than Equation 1 of deburring time or deburring difficulty would be expressible by an equation of the form shown in Equation 2.

$$\text{Time} = C_1 (h_e f_e + h_x f_x) \sigma_u, \quad (2)$$

Where h_e is the height of the entrance burr.

h_x is the height of the exit burr.

f_e is Equation 1, evaluated for the entrance burr thickness.

f_x is Equation 1, evaluated for the exit burr thickness.

σ_u is the tensile strength of the workpiece material.

C_1 is a constant.

Table 4. Typical Drilling and Reaming Burr Properties

Workpiece Material	Entrance Burr		Exit Burr	
	Length (inch) (μm)	Thickness (inch) (μm)	Length (inch) (μm)	Thickness (inch) (μm)
Drilled Hole				
303 Se	0.0033 (83.8)	0.0022 (55.9)	0.0066 (167.6)	0.0020 (50.8)
17-4 PH	0.0007 (17.8)	0.0009 (22.9)	0.0088 (223.5)	0.0036 (91.4)
6061-T6	0.0026 (66.0)	0.0034 (86.4)	0.0065 (165.1)	0.0042 (106.7)
1018	0.0044 (111.8)	0.0043 (109.2)	0.0096 (243.8)	0.0042 (106.7)
Drilled and Reamed Hole				
303 Se	0.0024 (61.0)	0.0013 (33.0)	0.0068 (172.7)	0.0025 (63.5)
17-4 PH	0.0044 (111.8)	0.0031 (78.7)	0.0409 (1038.9)	0.0051 (129.5)
6061-T6	0.0040 (101.6)	0.0034 (86.4)	0.0097 (246.4)	0.0030 (76.2)
1018	0.0026 (66.0)	0.0017 (43.2)	0.0056 (142.2)	0.0017 (43.2)

Table 5. Time Required to Deburr Washer-Like Parts

Material	Time Required (Minutes)	
	Drill Only	Drill and Ream
303 Se	1.464	1.115
17-4 PH	1.800	3.545
6061-T6	1.190	0.973
1018	1.276	1.105

Even this equation is inaccurate for large values of burr length, because a burr 0.500 inch long (12.7 mm) and 0.0005 inch thick (12.7 μ m) does not require 50,000 percent more deburring time than a 0.001-inch-long (25.4 μ m) burr of the same thickness. Since the majority of burrs produced in metal vary from 0.001 to 0.005 inch thick, and 0.001 to 0.015 inch (381 μ m) high, the above equation does offer a reasonable and logical baseline for estimating deburring time. Its use, however, requires a knowledge of the constants in both Equations 1 and 2.

In the second test in this series, three different hole sizes were produced in flat plates of four different materials. The hole sizes used were 0.125-, 0.0625-, and 0.03125-inch diameter (3.175, 1.588, and 0.792 mm). The operator was instructed to maintain a 0.002-inch edge break around both sides of each hole.*

Figure 7 shows that holes smaller than 0.125 inch (3.2 mm) do require more time to deburr than do 0.125-inch diameter burrs. The effect of hole size, however, does not follow a smooth curve, as shown in Figure 4. Part of the reason is that it is not possible to produce the same burr properties (Table 6) with three different drill sizes. The major reason, however, is that when accessibility of the burr restricts the use of one deburring approach, a different approach is tried. While this introduces a nonuniform test condition, it does reflect actual shop practice.

*Throughout this report it is assumed that the edges after deburring must be free of any material extending past the two 90-degree surfaces which form the edge. In other words, both sharp fragments and bulging material must be removed.

Figure 6. Effect of Burr Thickness on Deburring Time

In this test, the 0.125-inch-diameter (3.2 mm) holes were deburred by the following procedure:

1. Wiping both sides of the hole on 400-grit emery paper;
2. Cutting off burr with a burr knife; and
3. Removing slivers produced by the knife by polishing with a 1-inch-diameter (25.4 mm) motor-driven nylon wheel.

In the case of the two smaller holes, a reamer was used in place of a burr knife. For all practical purposes, the thickness of the exit burr was the same for all these holes (Table 6). As a result, this variable is not influencing the trends shown in Figure 7.

Figure 7. Effect of Hole Size on Deburring Time

It is interesting to note that 10 percent of the time spent in deburring these samples was actually devoted to scrutinizing the holes to assure that the burrs were removed. On more complex and on more critical parts, the portion of the time for scrutinizing increases. On some miniature parts, the operator spends more time checking for a burr-free condition than he does in actually removing the burrs.

In the third test, the intersection of four 0.062-inch-diameter (1.57 mm) holes with a larger cross-hole was deburred. The cross-hole was varied from 0.062-inch to 0.500-inch-diameter (12.7 mm) (Figure 8). This particular geometry reflects one of the most difficult types of situations to deburr by hand. There is essentially no room to maneuver the deburr tools.

It proved impossible to deburr the intersection of holes when the cross-hole was only 0.062 inch in diameter. As expected, the larger the cross-hole, the shorter the time required for deburring (Figure 9). As the cross-hole becomes smaller, the effectiveness of a deburring knife diminishes. One essentially has to depend upon reamers to remove the burrs. By alternately reaming the large hole, then the small holes, and then repeating this

Table 6. Properties of Burrs Produced on Three Different Hole Sizes

Workpiece Material	Hole Diameter	Entrance Burr		Exit Burr	
		Length	Thickness	Length	Thickness
6061-T6 Aluminum	0.03125	0.0026	0.0016	0.0054	0.0029
		0.0022	0.0012	0.0051	0.0023
	0.0625	0.0007	0.0006	0.0081	0.0014
		0.0010	0.0009	0.0102	0.0017
	0.125	0	0	0.0064	0.0010
		0	0	0.0096	0.0012
303 Se Stainless	0.03125	0.0008	0.0005	0.0034	0.0019
		0.0015	0.0010	0.0022	0.0014
	0.0625	0	0	0.0050	0.0014
		0.0007	0.0015	0.0059	0.0020
	0.125	0.0035	0.0007	0.0037	0.0014
		0	0	0.0072	0.0021
17-4 PH Stainless	0.03125	0	0	0.0026	0.0017
		0	0	0.0019	0.0020
	0.0625	0.0015	0.0005	0.0028	0.0012
		0	0	0.0028	0.0012
	0.125	0.0021	0.0009	0.0018	0.0012
		0.0003	0.0009	0.0025	0.0011
1018	0.03125	0.0017	0.0004	0.0036	0.0011
		0.0016	0.0007	0.0044	0.0010
	0.0625	0.0005	0.0002	0.0004	0.0011
		0	0	0	0
	0.125	0	0	0	0
		0	0	0.0043	0.0008

NOTE:

Values shown are in inches; 0.001 inch equals 25.4 μm . Holes were produced by HSS drills (Bendix 50112301, 50105400, and 50102101) at 1200 rpm and 1.2 IPM (0.51 mm/sec). A water soluble coolant was used on all holes. No drill produced more than 21 holes.

Figure 8. Geometry of Intersecting Hole Specimen

sequence, it is possible to remove the large flexible portion of the burr. This approach, however, will not guarantee that a small burr is not left on hole intersections, nor will it radius the intersecting edges. Thus, for manual deburring, the quality of deburring decreases as the effective working area decreases. No attempt was made, however, to measure the edge break on the intersecting holes. It should be noted that measuring small edge radii becomes extremely difficult for small features and three dimensional intersections.

In the final study, slotted workpieces were deburred. Half of the workpieces had 0.032-inch-wide (0.81 mm) slots, while the other half had 0.250-inch-wide (6.35 mm) slots (Figure 10). The time required to deburr the four slots manually on both sets of workpieces was recorded and divided by the total edge length deburred. As illustrated in Figure 11, the 0.032-inch-wide slots

Figure 9. Effect of Cross-Hole Diameter on Deburring Time

Figure 10. Geometry of Milled Slot Specimen

Figure 11. Effect of Slot Width on Hand-Deburring Time

required more time to deburr per inch of edge than did the wider slot. It appears that below 0.032 inch, deburring time would increase sharply.

As previously indicated, deburring techniques vary as a function of part geometry, feature size, and workpiece material. In this study, a file was used to remove the majority of the burr from the stainless steel workpieces. Because of the restricted access, it could not be used on the narrow slots. In 1018 steel and in aluminum, the burr was thin enough that a burr knife was the most effective tool on slots of both widths. Burr properties were not recorded in this study.

As a point of interest, it is much easier to remove a burr from the flat side of the part than one of the same size on the L side of the part. The addition of the ledge can increase deburring time by 50 percent on this particular workpiece. Since the location of the large cutter exit burr is a function of setup or fixturing, deburring time can be influenced by both the manufacturing engineer and the machine operator.

General Observations

Hand deburring is an economic necessity on many parts in many industries. This is particularly true of low-volume, high-precision parts having complex geometries. In some materials burr properties are consistent part after part. In this case, some form of mechanized or mass deburring can be substituted for hand deburring.

Unfortunately, burrs produced in most materials are not very repeatable. As a consequence, subjecting these to a fixed deburring process will produce varying edge conditions. This is not permissible on parts which have to be burr-free, yet have edge radii of 0.002 inch (50.8 μm), or less. Theoretically, hand-deburring workers can react to varying burr conditions to produce consistent edge quality better than would a fixed deburring process. Based on these tests, this is true down to requirements of 0.005-inch (127 μm) maximum edge radii. For many geometries, it may also be true down to 0.002-inch maximum edge radii requirements.

In the tests reported here most of the deburring was performed with triangular deburring knives, abrasive paper, reamers, file, abrading laden rubber wheels, and miniature brushes. These represent only a small portion of the estimated 500 tools commercially available that are used for deburring. At this time, however, there is no single reference in the published literature which even lists the tools which are available. More importantly, there are no references at all which indicate for which situation a particular type of tool is best suited. One type of tool may

be well suited to deburring and producing a radius of 0.015 inch (381 μm), while another may produce a 0.005-inch (127 μm) chamfer. Some may remove a very short burr without affecting part size, and others may be very aggressive. The efficiency of hand deburring will always be lower than it needs to be until the capabilities of the deburring tools are described. While this information will improve hand-deburring efficiency, hand deburring will always be dependent upon the skill and dexterity of the worker.

As mentioned earlier, 10 percent of the time spent in deburring the test samples was actually devoted to determining if all of the burr was removed. On precision miniature production parts, this scrutinization time can exceed 60 percent of the total hand-deburring time. While 10 percent does not seem excessive, it occurs on every single part deburred. At this rate, on 200 parts requiring 3 minutes each to hand deburr, 1 hour would be devoted to just checking edge quality. That scrutinization time alone is longer than used for some mechanized processes in deburring 200 parts.

High-speed movies of workers hand-deburring production parts also indicate that some motions of the workers are more habitual than essential. For example, operators develop a certain rhythm for *polishing* an edge with sand paper. On many, the natural wrist motion is to make three passes over an edge; however, on many edges only one pass would be sufficient. These little habitual actions are beneficial on some workpieces, and merely time consuming on others.

Effective Utilization of Hand Deburring

The comments made thus far in this report generally assumed that deburring on the part was done by hand and to precision tolerances. In most instances, it is more efficient to use hand deburring as only a part of the deburring sequence. The basic approaches to utilizing hand deburring are the following.

- Hand deburr entire part to print requirements.
- Hand deburr only certain edges on part to print requirements, to allow part to locate in a fixture, and to deburr edges not reached by mechanized processes.
- Hand deburr to remove only the big or loose portion of the burrs.

In the second and third approaches to hand deburring, a faster or mechanized deburring process is used to produce the final edge quality required on a part. Most deburring processes can maintain radii requirements of 0.002 inch (50.8 μm) maximum if the burr to be removed is not large. The majority of time spent in

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- On easy-to-reach edges, it may be possible to maintain smaller edge radii. Increasing the number of edges to be deburred and the complexity of the deburring, increases the variability of results.
- Deburring time appears to be a function of burr thickness, which in turn is a function of the strain-hardening exponent. No relationship was observed between burr height and deburring time.
- Deburring techniques vary among workers and also vary as a function of burr accessibility. This makes it difficult to predict deburring time. Openings around burr-laden edges less than 0.060 inch (1.52 mm) in diameter or width increase deburring time significantly.
- Although hand deburring is an economic necessity on many short-run precision miniature parts, it is possible to minimize the time spent and to maintain 0.002-inch (50.8 μ m) maximum edge radii by utilizing both hand- and mechanized-deburring.
- The development of improved hand-deburring results and times requires a knowledge of the tools which are available and the situations in which they work best.

ACCOMPLISHMENTS

The edge radii which can be produced reliably while hand deburring miniature parts, have been determined. The effect of burr size on hand-deburring time has been recorded for a specific workpiece configuration. The effect of burr accessibility on deburring time has been noted, as have approaches to minimizing hand-deburring time.

FUTURE WORK

The only additional work planned at this time on hand deburring is the compilation of the descriptions of tools commercially available for hand deburring. Additional in-depth studies of hand-deburring techniques will be required to improve the edge radiusing capabilities, to minimize hand-deburring time, and to define the most appropriate tool for a given situation. Such studies are not planned at this time, however.

Tests on such mechanized or mass deburring processes as *Extrude Hone*, *Centrifugal Barrel Tumbling*, *Electropolish*, and *Chemical Deburring* are currently being performed.

REFERENCES

- ¹G. V. Robbins, *Radius Generation in Vibratory Deburring*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-85, September, 1966.
- ²L. K. Gillespie, *Vibratory Deburring*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-735, August, 1973.
- ³L. K. Gillespie, *The Effect of Edge Angle on the Radius Produced by Vibratory Finishing*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1279, February, 1975.
- ⁴L. K. Gillespie, *Brush Deburring*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1056, March, 1974.
- ⁵L. K. Gillespie, "Brush Deburring of Precision Miniature Parts," SME Paper, MR 74-994, 1974.
- ⁶J. H. Kuehnle, *Thermal Shock Deburring*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-642, 1972.
- ⁷L. H. Luebbert, Jr. and L. K. Gillespie, *Extrude Hone Deburring*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-948, August, 1973.
- ⁸N. S. Ajlouny and L. K. Gillespie, "State of the Art of General Deburring," SME Paper, MR 74-116, 1974.
- ⁹L. K. Gillespie, "The Formation and Properties of Machining Burrs," M. S. Thesis, Utah State University, Logan, Utah, 1973.
- ¹⁰L. K. Gillespie and P. T. Blotter, "The Formation and Properties of Machining Burrs," Paper pending publication by ASME, June, 1975.
- ¹¹L. K. Gillespie, "The Formation and Properties of Burrs," SME Paper, MRR 75-03, April, 1975.
- ¹²L. K. Gillespie, "The Effect of Cutting Edge Radius on Poisson Burr Properties," SME Paper, MR 74-990, 1974.
- ¹³L. K. Gillespie, *The Effects of Reaming Variables on Burr Properties*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1083 (rev) September, 1974.
- ¹⁴L. K. Gillespie, *Properties of Burrs Produced by Ball Broaching*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1084 (rev) December, 1974.

¹⁵L. K. Gillespie, *The Burrs Produced by Drilling*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1248, to be published.

¹⁶L. K. Gillespie, *The Burrs Produced by Side Milling Cutters*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1303, September, 1975.

¹⁷L. K. Gillespie, *The Burrs Produced by Grinding*, (Topical Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1372, to be published.

¹⁸L. K. Gillespie, "The Measurement of Burrs," SME Paper, MR 74-993, 1974.

¹⁹L. K. Gillespie, "Effects of Measurement Technique and Experimental Design in the Analysis of Burrs," SME Paper, MR 75-985, 1975.

²⁰L. K. Gillespie, "The Burr--Manufacturing's Perennial Thorn," SME Paper, MR 74-992, 1974.

²¹L. K. Gillespie, "Towards a Rational Approach to Deburring," SME Paper, MR 74-996, 1974.

²²L. K. Gillespie, "Deburring--An Annotated Bibliography," SME Bibliography Series, 1974.

²³L. K. Gillespie, "Deburring--An Annotated Bibliography, Volume II," SME Paper, MRR 75-04, 1974.

²⁴L. K. Gillespie, "An Overview of International Activities in Burr Prevention and Removal," SME Paper, MRR 75-02, 1975.

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