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DRILLING MINIATURE HOLES, PART I

Topical Report

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Published July 1978

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Topical Report

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DRILLING MINIATURE HOLES, PART I

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July 1978

Prepared by L. K. Gillespie, D/822

Miniature components for precision electromechanical mechanisms, such as switches, timers, and actuators, typically require a number of small holes. Because of the precision required, the workpiece materials, and the geometry of the parts, most of these holes must be produced by conventional drilling techniques. The use of such techniques is tedious and often requires considerable trial and error to prevent drill breakage, and to minimize hole mislocation and hole diameter variations. An initial study of drill geometries and drilling techniques for producing 0.66-mm-diameter holes in stainless steel and brass indicates that positional tolerances of $50.8 \mu\text{m}$ can be maintained. With appropriate drills, a size repeatability of $\pm 2.54 \mu\text{m}$ can be maintained. Centerdrilling is not required if printed circuit board drills are used. Hole quality depends upon the particular combination of feedrate, drilling technique, and drill geometry used. Spindle speed does not affect hole size or location. Additional research is being performed on this subject.

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SUMMARY

Precision miniature electromechanical mechanisms typically require a number of precision miniature holes for rotating shafts and press-fit pins. Because of the tolerances required, the hole depth, and the materials involved, conventional drilling approaches must be utilized. These approaches are tedious and require great care to prevent drill breakage and to ensure high quality holes.

This study was initiated to determine which types of equipment, commonly used to drill small holes, would minimize hole drilling problems, and how drill geometry, feeds, and speeds would affect the accuracy of location and size of these holes.

The results of this study in 303Se stainless steel and half hard brass are summarized in the following observations for 0.66-mm-diameter drills.

- In most instances centerdrilling *did not* improve hole location or size.
- Printed circuit board drills, spiral-flute pivot drills, and bore-size drills produced distinctly more consistent size and location.
- Feedrate did not influence hole location except for some drills in brass workpieces.
- In 303Se stainless steel the location of 95 percent of the holes produced by the three best drills would fall within a 50.8- μ m-diameter circle.
- For the three best drill designs, 95 percent of hole sizes produced *without reaming* would fall within ± 2.54 μ m of the nominal hole size.
- A chip clearing (pecking) operation may influence hole location unless centerdrilling is used.
- Spindle speed did not affect hole size or location.
- Some combinations of feedrate, technique, and drill geometry were distinctly better or worse than others. (The best combination of feedrate and drilling technique may be different for each drill.)

The feedrates used ranged from 2.5 to 12.5 μ m per revolution (μ m/rev), and the spindle speeds ranged from 2200 to 6800 revolutions per minute (rpm).

A bibliography of reports on small hole drilling is included in this report.

DISCUSSION

SCOPE AND PURPOSE

The objective of this study was to determine which drilling variables and tool geometries result in minimum mislocation of holes and maximum consistency of hole size. Specifically, the study evaluated the effects of three types of drilling machines and the effects of drill geometry, feeds, and speeds.

PRIOR WORK

Small-hole drilling has been performed for several years at Bendix Kansas City, but no formal effort has been made to document the effects on size and location as a result of speed, feed, geometry, material hardness, and sequence-of-cuts. More than 100 different pieceparts in production have required the use of drills 0.79 mm in diameter, or smaller. These pieceparts were produced on 13 different types of equipment, each having separate limitations.

ACTIVITY

Study Phases

This study was performed in three phases. The first phase utilized a single machine to evaluate the basic capabilities of eight different drill configurations. In this phase, only one hole was produced in each specimen.

In the second phase, analytical and empirical analyses were made of drill rigidity and its effect on consistency of hole location and size. Typical drilling torques and thrusts were also evaluated and compared to hole location and size trends.

In the third phase, patterns of holes were drilled with the more successful drills from the first phase. These patterns were then evaluated by computer techniques to determine the optimum positional locations one could expect with the equipment used.

Because of the large number of observations made, this study is reported in three parts, with each part corresponding to the phases just described. The third report includes the final conclusions of this study. The following list describes in more detail the emphasis in each part.

Study Objectives

Pertinent Part of Report

- To determine the effects of speed and feed on location and quality of small holes. Part I (BDX-613-1785)
- To determine which drill geometries and techniques produce the minimum variance in hole size and location. Part I (BDX-613-1785) and Part II (BDX-613-1786)¹
- To determine the relative abilities of (1) N/C Eight Spindle Drill, and (2) N/C Jig Bore for maintaining 7.6 μm total size tolerance while producing holes 0.25 to 0.76 mm in diameter to positional tolerances of 25.4 μm RFS, and interior surface finishes of 0.41 μm AA. Part III (BDX-613-1787)²

Effects of Drilling Variables and Drill Geometry

In these tests eight different designs of commercially available *off-the-shelf standard drills* were studied to determine the most precise and the fastest method of drilling 0.66-mm-diameter holes. The workpiece materials included half hard alloy 8 brass (R_B 70) and annealed 303Se or 302 stainless steel (R_B 80). A precision copy drilling machine, which has mechanized feedrates and the capability for a chip clearing or pecking action, was used. The specimens (Figure 1) were placed in a special collet placed directly below the spindle. No table motion was used; therefore, any variation in hole location was not caused by table positioning capabilities.

The drills used are shown in Figures 2 through 7. The fact that these eight different geometries are available as standards in this small-size range indicates the lack of unanimity in small-hole drilling. Typical properties of each drill are listed in Appendix Tables A-1 through A-3. All drills were inspected prior to use. Angles were measured to the nearest 1.0 minute, and lineal dimensions were measured to the nearest 2.54 μm .

Table 1 indicates the many factors that must be considered when drilling holes smaller than 0.81 mm in diameter. Although the major problems are those of maintaining the rigid size and locational accuracies, hole straightness, surface finish, and burr

DIMENSIONS ARE IN MILLIMETERS.
SINGLE-HOLE SPECIMEN.
BRASS AND 303 STAINLESS STEEL.

Figure 1. Drill Specimen Geometry

removal are also significant areas of concern on many parts. Lubricity of the coolant can be a problem. Recent tests indicate that water will not enter a 0.30-mm-diameter hole unless it is forced in. Holes of this size require special low meniscus fluids such as *Cadet 2*, or Houghton's *Cut-max 105* (E. F. Houghton and Company, Philadelphia).

The selection of initial speeds and feeds was made from a computer analysis of torsional stress as a function of drill diameter and feedrate. The resulting values indicated that feedrates should be lower than $5.08 \mu\text{m/rev}$ for a 0.66-mm-diameter drill. This is considerably slower than the operating capability of most equipment at Bendix. An analysis of feeds and speeds successfully used on Bendix automatic screw machines indicated that feedrates of $7.62 \mu\text{m/rev}$ would not cause breakage in 303Se stainless steel for this sized drill. Appendix Table A-4 lists conditions used on automatic screw machines at Bendix. Tables A-5 and A-6 list values recommended by one screw machine manufacturer.³ Drills 0.64 mm in diameter, however, broke in recent tests when fed at $20.32 \mu\text{m/rev}$ into brass workpieces. The equations used for breaking strengths are presented in Part II.¹

Figure 2. Tool Geometries Studied

Test 1. Effects of Technique. The initial test used the master drills to determine how much the following techniques influenced hole size and location:

- Drill only,
- Centerdrill, and drill, and
- Centerdrill, drill, and ream.

The effects of feedrate and spindle speed on hole size and location were also explored. The conditions used, which represents a 3^3 factorial design, are given in Tables 2 and 3. All nine combinations of feed and speed were used. The master drill was chosen because it appeared to be stiffer than other drills.

The actual tools used and the resulting effects on hole size and location are presented in Appendix Tables A-7 and A-8 respectively. Brass specimens only were used in this test. Most drills extended roughly 12.7 mm from the drill chuck.

As implied by the name of the method, *drill* or *drill only* indicate that the hole was produced without any centerdrilling or reaming. *Centerdrill*, *drill* indicates that the hole was produced by centerdrilling, followed by drilling. Two specimens were drilled at each of the 27 possible combinations.

Text continued on page 19.

3A. MASTER DRILL

3B. MASTER BORE-SIZE DRILL

3C. STRAIGHT-FLUTE PIVOT DRILL

3D. SPIRAL-FLUTE PIVOT DRILL

3E. GOLD-HEAD DRILL

3F. PRINTED CIRCUIT BOARD DRILL

Figure 3. Enlarged View of Master Drill, Master Bore-Size, Straight-Flute Pivot, Spiral-Flute Pivot, Gold-Head, and Printed Circuit Board Drills

4A. STANDARD CHISEL-POINT DRILL

4B. PRINTED CIRCUIT BOARD DRILL

4C. BORE-SIZE DRILL

4D. CENTER DRILL

Figure 4. End View of Used Standard Chisel-Point, Printed Circuit Board, Bore-Size, and Center Drills

5A. SPIRAL-FLUTE PIVOT DRILL

5B. GOLD-HEAD DRILL

5C. FLAT-PIVOT DRILL

Figure 5. End View of Used Spiral-Flute Pivot, Gold-Head, and Flat-Pivot Drills

6A. MASTER DRILL

6B. CHISEL-POINT DRILL

6C. PRINTED CIRCUIT BOARD DRILL

6D. BORE-SIZE DRILL

Figure 6. Overall View of Used Master Drill, Chisel-Point, Printed Circuit Board, and Bore-Size Drills

7A. SPIRAL-FLUTE PIVOT DRILL

7B. FLAT-SPADE DRILL

7C. GOLD-HEAD DRILL

Figure 7. Overall View of Used Spiral-Flute Pivot, Flat-Spade, and Gold-Head Drills

Table 1. Hole Quality Parameters, Factors Affecting Quality, and Specific Problems in Drilling Small Holes

Hole Quality Parameters

1. Locational accuracy and consistency
 2. Size accuracy and repeatability
 3. Hole concentricity
 4. Hole straightness
 5. Size and ease of removal of burrs
 6. Interior surface finish
 7. Machining time and cost per hole
-

Factors Affecting Quality

1. Feedrate
2. Speed
3. Drill geometry
4. Vendor variables in geometry
5. Drill material
6. Workpiece material
7. Machine design and condition
8. Workpiece geometry
9. Hole geometry

Table 1 Continued. Hole Quality Parameters,
Factors Affecting Quality,
and Specific Problems in
Drilling Small Holes

Specific Problems in Drilling Small Holes

1. Inability to get coolant in the hole
 - Shortens tool life
 - Affects chip formation
 2. Chip Packing
 - Causes tool breakage
 - Poor surface finish
 - Frequent drill clearing
 3. Small geometry variations greatly influence drill life
 4. Inability to observe cutting action due to smallness
-

In this and all other cases after drilling, parts were deburred by hand, visually inspected at 20X to verify complete burr removal, and then inspected for location and size. All location measurements were made from the locating edges used to position the parts during drilling. A Zeiss toolmakers microscope was used to inspect the specimens. After inspection, analyses of variance were performed on differences between hole size and tool size, X mislocation, Y mislocation, and radial mislocation.

The fixture used to position these specimens during drilling located the diameter of the part in a tightly fitting cavity. The flat was then oriented with a sliding bumper. In practice, this orienting bumper did not always produce the desired orientation; consequently, the radial mislocation analysis of variance is a more realistic measure of location variances than either X or Y mislocations alone. All statistical analyses were made for a confidence level of $\alpha = 0.90$. As seen in Table 4, only the technique used to produce the holes affected hole size, although some combinations of feed and speed, and speed and technique, produced noticeably different results than did others. Hole location depended upon which combination of feed and technique were used.

Table 2. Comparison of Techniques and Test Conditions for Single-Hole Test, Using Power Feed

Variable	Low	Medium	High
Method	Drill	Centerdrill, Drill	Centerdrill, Drill, Ream
Feedrate ($\mu\text{m}/\text{rev}$)	2.5	7.6	12.5
Speed (rpm)	2200	4200	6800

From Figure 8, on the average, reaming produced almost $25.4 \mu\text{m}$ less overcut than did drilling. Figure 9 shows that faster feedrates resulted in slightly less overcut when all techniques were averaged together. The minimum hole mislocation occurred by centerdrilling, and then drilling at the faster feedrates (Figure 10). At the slower feedrates, the other techniques were better.

Using the master drills under these conditions, the following effects were apparent.

- Reaming produces typically $5.08 \mu\text{m}$ overcut, while drilling results in an overcut of $25.4 \mu\text{m}$.
- Centerdrilling does not improve overcut.
- Adjusting feed or speed reduced overcut a maximum of $5.08 \mu\text{m}$.
- At feedrates of $7.62 \mu\text{m}/\text{rev}$, or above, centerdrilling does improve hole mislocation.
- Under the best conditions, the holes were mislocated by $12.7 \mu\text{m}$.
- Spindle speed did not affect hole locations, and feedrate had little effect on the average, although a slight trend is visible when averages are plotted.

Test 2. Effects of Chip Clearing. To determine the effects of chip clearing operations, a second test was performed. In this test, half of the specimens were drilled under constant feed and the remainder were drilled with interruptions of feed every 0.25 mm of depth. A 0.67-mm master drill was used in these tests in conjunction with the Posalux machine. The data from this test are presented in Appendix Tables A-9 and A-10.

Table 3. Feedrates Used

Speed (rpm)	Feedrate ($\mu\text{m}/\text{rev}$)		
	2.5	7.6	12.5
	($\mu\text{m}/\text{s}$)		
2200	93	279	466
4200	178	529	889
6800	288	889	1439

An analysis of the data indicated that no significant differences in overcut or mislocation occur as the result of chip clearing. The standard deviation of hole size was $3.81 \mu\text{m}$ in both this and the previous test. The repeatability of mislocation was $19.2 \mu\text{m}$ in this test and $12.7 \mu\text{m}$ in the previous test.

Test 3. Effects of Drill Geometry. To examine the effects of drill geometry on hole size and location, the six drill geometries shown earlier were used at two feedrates on the copy drilling machine. Appendix Tables A-11 through A-14 present the inspection results of this test.

An analysis of variance of the data indicated that typically neither feedrate nor technique affected the results of size, but gross differences existed between drills. Tables 5 and 6 summarize the analysis of variance results on hole size. The data for drill G is taken from the results of the first two tests.

As shown in these two tables, the feedrate and technique used did affect hole size for some drills. Figure 11 indicates that centerdrilling reduces hole overcut at high speeds when the printed circuit board drill is used, but the opposite is true when the bore-size drill is used (Figure 12). Very similar trends occurred in the 303Se stainless steel samples (Figures 13 and 14).

The printed circuit board drill A and the gold head drill D produced the least variation from the drill size (Tables 5 and 6). In interpreting the results, one should bear in mind that the data are significant only to the nearest $2.54 \mu\text{m}$, although sizes were estimated to the nearest $0.25 \mu\text{m}$. While the differences shown in Figures 11 through 14 are relatively small, they are significant both statistically and physically. If overcut can be controlled closely, many reaming operations can be eliminated. The most significant results of this study are the standard deviation

Table 4. ANOVA Results for Single-Hole Brass Specimen

Factors	Measured Variable	
	Radial Mislocation	Hole Size
Spindle Speed		
Technique		*
Feedrate		
Speed x Technique		
Speed x Feedrate		*
Technique x Feedrate	*	*
Speed x Feedrate x Technique		
*Indicates significance at the 99-percent confidence level.		

estimates which indicate the repeatability of each drill. Table 7, which ranks all the drills studied by their estimated standard deviation, shows that drills A and C are the most consistent in addition to producing the least overcut. Even with these low values of standard deviation, $\pm 3 \sigma$ limits result in $\pm 2.54 \mu\text{m}$ variations in hole size.

Hole locations were also greatly affected by the drill geometry used. The feedrate and technique also affected some of the results (Tables 8 and 9). Figures 15 through 18 indicate the effects of feedrate and drilling technique on hole location. For these four conditions, centerdrilling did result in better hole location than just drilling alone. As indicated in Tables 8 and 9, in the majority of cases neither adversely affected the hole location.

As shown in Table 9, the printed circuit board drill (Code A), the spiral-flute pivot drill (Code B), and the bore-size drill (Code C) had the least amount of radial mislocation in stainless steel and the smallest standard deviation. It is significant to note that these three drills also typically produced the best size repeatability. In addition, the repeatability of locational accuracy was typically twice as good in brass as in stainless steel.

Figure 8. Effect of Feedrate and Drilling Technique on Hole Oversize

Figure 9. Effect of Feedrate and Speed on Hole Oversize

Figure 10. Hole Location as a Function of Feedrate and Technique for 0.66-mm Master Drill in Brass

In reviewing these results the following observations appear to be most significant.

- In most instances centerdrilling *did not* improve hole location or size.
- The standard chisel-point drill buckled in stainless steel when centerdrilling was not used.
- Drills A, B, and C (printed circuit board, spiral-flute pivot, and bore-size) are distinctly superior in maintaining both consistent size and location.
- Feedrate did not influence hole location except for some drills in brass workpieces.
- In stainless steel 95 percent of the holes produced by Drills A, B, or C would fall within a 50.8-μm-diameter circle. Only 54 percent would fall within a 25.4-μm-diameter circle.
- For drills A, B, and C, hole size on 95 percent of the specimens should fall within 2.5 μm of the nominal hole size; that is, if a 0.662-mm drill typically produces a 0.665-mm-diameter hole, 95 percent of the holes should fall within a diameter range of 0.662 to 0.668 mm.

Text continued on page 29.

Table 5. Effects of Drill Geometry, Feedrate, and Technique on Hole Overcut in Brass

Drill Code	Drill Type	Factor			Mean ΔS^* (μm)	Standard Deviation** (μm)
		Feed Technique		Feed x Technique		
A	Printed circuit board	S	S	S	-1.02	0.254
B	Spiral-flute pivot	N	N	N	+8.13	1.067
C	Bore-size	N	S	S	+25.65	0.940
D	Gold-head	N	N	N	-2.29	3.099
E	Chisel-point	N	N	N	+7.37	1.194
F	Flat-pivot	N	N	N	+24.89	1.956
G	Master drill	N	S	S	+25.91	2.794

"S" implies the indicated factor had a statistically significant effect on hole overcut.

"N" implies the indicated factor did not have a statistically significant effect on hole overcut.

* ΔS is the hole diameter minus the drill diameter.

**Standard Deviation is the standard deviation of the hole size measurements.

Table 6. Effects of Drill Geometry, Feedrate, and Technique on Hole Overcut in 303Se Stainless Steel

Drill Code	Drill Type	Factor			Mean ΔS^* (μm)	Standard Deviation** (μm)
		Feed Technique		Feed x Technique		
A	Printed circuit board	N	N	S	-1.78	0.559
B	Spiral-flute pivot	N	N	N	+2.29	0.864
C	Bore-size	N	N	S	+3.05	0.737
D	Gold-head	N	N	N	+19.05	3.632
E	Chisel-point	N	N	N	Tool buckles	---
F	Flat-pivot	N	N	N	+21.08	4.978
G	Master drill	N	N	N	+23.11	3.912

"S" implies the indicated factor had a statistically significant effect on hole overcut.

"N" implies the indicated factor did not have a statistically significant effect on hole overcut.

* ΔS is the hole diameter minus the drill diameter.

**Standard Deviation is the standard deviation of the hole size measurements.

Figure 11. Effect of Feedrate and Drilling Technique When Using Printed Circuit Board Drill 48701022-1 in Brass

Figure 12. Effect of Feedrate and Drilling Technique When Using Bore-Size Drill BSD-026-3 in Brass

Figure 13. Effect of Feedrate and Drilling Technique When Using the Printed Circuit Board Drill 48701022-1 in Stainless Steel

Figure 14. Effect of Feedrate and Drilling Technique When Using the Bore-Size Drill in Stainless Steel

Table 7. Drill Performance Ranked by Standard Deviation

Rank	303Se		Brass	
	Drill	σ_S (μm)	Drill	σ_S (μm)
1	A Printed circuit	0.559	A	0.254
2	C Bore-size	0.737	C	0.940
3	B Spiral-flute	0.864	B	1.067
4	D Gold-head	3.632	E	1.194
5	G Master drill	3.912	F	1.956
6	F Flat-pivot	4.978	G	2.794
7	E Chisel-point	---	D	3.099

Production Implications

The results of the three tests described above show that drill geometry plays a significant role in determining drill accuracy. While this observation has long been known, actual data did not exist to an appreciable extent except on very large holes.

The printed circuit board drill, the spiral-flute pivot drill, and the bore-size drill typically outperformed, by a significant margin, drills of the other geometries tested. The repeatability of size was good with these drills. But the combined effects of geometry variations among drills of the same kind, size variations in drills of the *same* size, the overcutting effect, and the repeatability of overcutting make it impractical to produce holes having tolerances of 5.08 μm without reaming after drilling. Centerdrilling, however, was not required for the printed circuit, spiral-flute pivot, and bore-size drills used in this study.

If the standard deviation of radial mislocation is σ , then P percent of all holes drilled will fall within a radius r of the mean location where

$$P = 1 - e^{-r^2/2\sigma^2}, \quad (1)$$

or

$$r = [-2\sigma^2 \ln (1 - P)]^{\frac{1}{2}}. \quad (2)$$

Text continued on page 34.

Table 8. Effects of Drill Geometry, Feedrate, and Technique on Hole Mislocation in Brass

Drill Code	Drill Type	Factor			Mean R* (μm)	Standard Deviation** (μm)
		Feed Technique		Feed x Technique		
A	Printed circuit board	N	N	N	24.89	6.35***
B	Spiral-flute pivot	N	S	N	20.57	6.60
C	Bore-size	N	N	N	24.38	14.22
D	Gold-head	S	N	S	26.92	3.56
E	Chisel-point	S	S	S	21.59	13.97
F	Flat-pivot	N	N	N	25.91	9.65
G	Master drill	N	N	S	22.61	12.70

"N" implies the indicated factor did not have a statistically significant effect on hole overcut.

"S" implies the indicated factor did have a statistically significant effect on hole overcut.

*R indicates the average radial mislocation of the hole.

**Standard Deviation is the standard deviation of radial mislocation.

***One outlier was excluded from the data used in obtaining this value.

Table 9. Effects of Drill Geometry, Feedrate, and Technique on Hole Mislocation in 303Se Stainless Steel

Drill Code	Drill Type	Factor			Mean R* (μm)	Standard Deviation** (μm)
		Feed Technique		Feed x Technique		
A	Printed circuit board	N	N	N	23.88	11.18
B	Spiral-flute pivot	N	N	N	21.34	11.68
C	Bore-size	N	N	N	17.78	10.16
D	Gold-head	N	N	N	26.42	19.56
E	Chisel-point	N	N	N	Drill buckled	---
F	Flat-pivot	S	N	N	34.80	26.67
G	Master drill	N	S	N	28.45	19.05

"N" implies the indicated factor did not have a statistically significant effect on hole overcut.

"S" implies the indicated factor had a statistically significant effect on hole overcut.

*R indicates the average radial mislocation of the hole.

**Standard Deviation is the standard deviation of radial mislocation.

Figure 15. Effect of Feedrate and Technique on Accuracy of Hole Location, Using Spiral-Flute Pivot Drill in Brass

Figure 16. Effect of Feedrate and Technique on Accuracy of Hole Location, Using Gold-Head Drill in Brass

Figure 17. Effect of Feedrate and Technique on Accuracy of Hole Location, Using Chisel-Point Drill in Brass

Figure 18. Effect of Feedrate and Technique on Accuracy of Hole Location, Using Flat-Pivot Drill in Stainless Steel

Thus, 95 percent of the holes produced should fall within a radius of

$$r = \sqrt{5.991\sigma^2} = 2.448\sigma. \quad (3)$$

If $\sigma = 11.4 \mu\text{m}$, as was typical for the better drills, 95 percent of all holes would fall within a radius of $27.9 \mu\text{m}$. Thus, if the machine tool, the workpiece, and the drill were perfectly aligned, a true position locational tolerance of at least $55.8 \mu\text{m}$ in diameter would be required, using the best tools under the best operating conditions.

If the drill enters the hole with the drill point slightly off center from the spindle, the location at the exit side of the hole will be significantly worse. Galloway⁴ indicates that the mislocation will be

$$q = q_0 \exp\left(\frac{3t}{2L}\right), \quad (4)$$

where

q = mislocation at distance t from the hole entrance,

q_0 = mislocation at hole entrance, and

L = length of fluted portion of drill projecting from the colleting device.

For a tool drilling off axis by $7.6 \mu\text{m}$ to a depth of 2.54 mm with a drill length of 3.81 mm , the mislocation will be $20.8 \mu\text{m}$.

Based on the data described in this report, the most economical techniques for producing holes of a given size and positional tolerance would be those indicated by X in Table 10. The positional tolerance shown is true position diametral tolerance. Data in Table 10 agree with general production experience. Such factors as work hardening, depth of hole, and material hardness can necessitate other approaches, however.

Table 10. Initial Estimate of Most Economical Technique for Producing Small Holes

Technique*	Size Tolerance							
	$\pm 2.5 \mu\text{m}$				$\pm 7.5 \mu\text{m}$			
	Positional Tolerance (μm)				Positional Tolerance (μm)			
	25	50	75	125	25	50	75	125
Centerdrill, Drill, Bore, Ream	X				X			
Centerdrill, Drill, Ream		X				X		
Drill, Bore, Ream								
Drill, Ream			X	X			X	X
Centerdrill, Drill								
Drill Only								

Table 10 Continued. Initial Estimate of Most Economical
Technique for Producing Small Holes

Technique*	Size Tolerance							
	$\pm 12.5 \mu\text{m}$				$\pm 25.0 \mu\text{m}$			
	Positional Tolerance (μm)				Positional Tolerance (μm)			
	25	50	75	125	25	50	75	125
Centerdrill, Drill, Bore, Ream								
Centerdrill, Drill, Ream		X			X			
Drill, Bore, Ream	X							
Drill, Ream								
Centerdrill, Drill								
Drill Only			X	X		X	X	X

*Assumes a 0.64-mm through-hole in 1.91-mm-thick stock.

A bibliography of articles related to small drill performance or the finishing and inspection of small holes is presented in this report. The majority of these references describe the machining techniques used but do not discuss the problem of defining the accuracy of drilling.

ACCOMPLISHMENTS

This study has identified three drill geometries which provide better size and positional repeatability than standard chisel-point drills when small diameters are required. For at least one drill design (printed circuit board) at low feedrates, center-drilling does not improve hole location. Drilling alone can produce hole locations repeatable within a 50.8- μm diameter of the mean location when printed circuit board, spiral-flute pivot, or bore-size drills are used on precision equipment. Hole size for these drills was within $\pm 2.54 \mu\text{m}$ of the drill diameter. These observations have provided a quantitative basis for recommended drilled hole production techniques for small drills. A bibliography of publications describing the drilling, finishing, or inspection of small holes has also been prepared.

FUTURE WORK

An analysis of drill rigidity and strengths as related to operating conditions remains to be reported as does a final report on the effect of equipment on the accuracy of hole patterns.

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³*Automatic Screw Machine Cam and Tool Design*, Training Manual. Providence, Rhode Island: Brown and Sharpe, March, 1962, pp 10-10B.

⁴D. F. Galloway, "Some Experiments on the Influence of Various Factors on Drill Performance," *Transactions of the ASME*, February, 1957, pp 191-231.

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Appendix

TOOL INSPECTION DATA, TOOL
DESCRIPTION, AND COMMERCIAL
FEEDRATES

Table A-1. Typical Properties of Tools Studied

Drill Code Number	Description	Drill Diameter (μm)	Included Point Angle (Degrees)	Lip Height Difference (μm)
50101607	Chisel-Point	0.65	138	10.16
50900090	Drill/Countersink	0.38	112	12.70
MD-022	Master Drill	0.56	140	7.60
MD-0263-L	Master Drill	0.67	140	7.60
MD-0263-S	Master Drill	0.67	140	5.08
BSD-026	Master Bore-Size Drill	0.67	122	7.60
GHD-0260	Gold-Head Drill	0.66	118	25.40
48701022	Four-Facet Drill	0.66	123	12.70
R0264	Reamer	0.67	135*	
R0262	Reamer	0.67	131*	
FPD-026	Flat-Pivot Drill	0.68	107	15.20
SFPD-026	Spiral-Flute Pivot Drill	0.66	138	5.08
50311190	Reamer*	0.88	130*	
50310990	Reamer*	0.78	131	

*These tools have 45-degree chamfers for entering holes.

Table A-2. Characteristics of Tools Studied

Drill Code Number	Drill Material	Helix Angle (Degrees)	Flute Length or Bore Depth (mm)	Web Thickness (μm)	Lip Relief or End Clearance (Degrees)	Concentricity* Diameter (μm)
50101607	Cobalt HSS	20	9.37	203.2	19	17.78
50900090	Cobalt HSS	4	0.69	101.6	23	12.70
MD-022	Solid Carbide	0	4.75	152.4	12	--
MD-0263-L	Solid Carbide	0	8.74	203.2	12	--
MD-0263-S	Solid Carbide	0	4.75	127.0	14	--
BSD-026		0	3.96	101.6	18	--
GHD-0260	Solid Carbide	32	4.57	152.4	18	7.62**
48701022	Solid Carbide	32	4.39	127.0	27	2.54
R0264		0	17.53		22	25.40
R0262		0	14.27		7	10.16
FPD-026	Cobalt HSS	0	4.75	228.6	20	5.08
SFPD-026	Cobalt HSS	22	3.96	177.8	27	2.54
50311190	High-Speed Steel	0	12.70		16	7.62
50310990	Cobalt HSS	0	12.70		16	5.08

*Dashes indicate that shank diameter and cutting diameter are the same. The concentricity is shown for all instances where the diameters were different.

**The value shown is for the drill margin to brass shank concentricity. The concentricity between the drill margin and the shank of the carbide drill was less than 2.54 μm .

Table A-3. Commercial Descriptions of Tools Used

Bendix Drill Code Number	Drill Description
50101607	Number 71, 0.066-mm-diameter, cobalt HSSS, regular RHS, jobbers length, special purpose drill, with 135-degree point for stainless steel; 9.53-mm flute length and 31.75-mm OAL.
50900090	Number 0000 miniature center drill; 0.38-mm drill diameter; 1.98-mm body diameter.
MD-022	Special 0.56-mm-diameter solid carbide master drill; 2.38 $\pm$ 0.40-mm flute length; 38.10-mm OAL.
MD-0263-L	6.68 +0.0 -0.01-mm-diameter, solid carbide master drill; 7.94-mm flute length; 31.75-mm OAL.
MD-0263-S	Special 0.67 +0 -0.01-mm-diameter, solid carbide master drill; 2.38 to -0.40-mm flute length; 38.10-mm OAL.
BSD-026	Special 0.67 +0 -0.01-mm-diameter master bore-size drill; 31.75-mm minimum OAL.
GHD-0262	0.066-mm-diameter gold-head, RHC, drill; 2.38-mm shank; 38.10 mm long.
48701022	0.66-mm four-facet printed circuit board drill; solid carbide; 25.4-mm OAL.
R0264	0.67 +0 -0.01-mm-diameter HSSS chucking reamer, List Number 533.
R0262	0.67 +C -0.01-mm-diameter HSSS chucking reamer, List Number 533.
FPD-026	Number 71 0.066-mm-diameter, Cobalt HS, flat-pivot drill, 1.0-mm-diameter shank. Micro G514.

Table A-3. Continued... Commercial Descriptions of Tools Used

Bendix Drill Code Number	Drill Description
SFPD-026	Number 71 0.066-mm-diameter, Cobalt HS, R.H. spiral-flute pivot drill, 1.0-mm-diameter shank. Micro G511.
50311190	0.88 ± 0.005 -0.000-mm-diameter, HS, SS, RHC, 3 str. flutes chucking reamer. 12.7-mm F.L.; 63.5-mm OAL.
50310990	0.78 ± 0.002 -0.000-mm-diameter, HS cobalt, full diameter str. shank, RHC, 4 str. flutes, chucking reamer; 12.7-mm flute length; 63.5-mm OAL. To cut 303 stainless, Lav-Idé Style L or equivalent.

Table A-4. Screw Machine Feeds and Speeds Used for Small Hole Drilling at Bendix

Workpiece Material	Hole Diameter (mm)	Hole Depth (mm)	Depth/Dia Ratio (Maximum)	Feedrate ($\mu\text{m}/\text{rev}$)	Speed (rpm)
303Se SST (Cold-Worked Cond.)	0.229/0.279	0.635	2.8	7.6	6135
	0.406/0.457	0.445	1.1	5.1	8050
	0.457/0.508	0.635	1.4	7.6	1880
	0.508/0.584	0.889	1.7	7.6	6135
	0.584/0.686	0.889	1.5	7.6	4935
	0.635/0.762	0.445	0.7	7.6	3625
	0.635/0.762	0.445	0.7	7.6	7500
	0.635/0.762	1.000	1.6	5.1	5570
	0.686/0.737	1.270	1.8	7.6	4935
17-4 PH SST (H-1150 Cond.)	0.330/0.381	0.762	2.3	2.5	6135
	0.724/0.749	1.143	1.6	2.5	3380
BeCu, Cond. H	0.597/0.660	3.048	5.1	7.6	4510
	0.635/0.686	5.080	8.0	12.7	3000
	0.787	5.563	7.0	10.2	3070
	1.000/1.041	3.048	3.0	7.6	5550

Table A-5. Approximate Cutting Speeds and Feeds Recommended for Standard Twist Drills*

Material	Feedrate ($\mu\text{m}/\text{rev}$)	Drill Diameter (mm)
Free Cutting Brass. Use maximum spindle speed available on machine.	43.2	0.50
	61.0	1.00
	121.9	1.59
	182.9	2.38
	279.4	3.18
2011-ST Aluminum (4.1 m/s).	30.5	0.50
	43.2	1.00
	63.5	1.59
	78.7	2.38
	111.8	3.18
2017-ST Aluminum and 5053-ST Aluminum (2.8 m/s).	27.9	0.50
	38.1	1.00
	55.9	1.59
	68.6	2.38
	96.5	3.18
2024-ST Aluminum (2.0 m/s); 6061 Aluminum (Naval Brass) (1 m/s); Copper (Tobin Bronze) (1.5 m/s).	25.4	0.50
	35.6	1.00
	50.8	1.59
	63.5	2.38
	88.9	3.18
High Sulphur Steel (B-1113) (X-1112) (B & S 12A) (1.15 m/s); (C-1113) (1.0 m/s); (B-1112) (0.84 m/s).	22.9	0.50
	30.5	1.00
	43.2	1.59
	53.3	2.38
	76.2	3.18
Type 416 and 430F Stainless Steel (0.66 m/s).	22.9	0.50
	30.5	1.00
	45.7	1.59
	55.9	2.38
	78.7	3.18

Table A-5 Continued. Approximate Cutting Speeds and Feeds
Recommended for Standard Twist Drills*

Material	Feedrate ($\mu\text{m}/\text{rev}$)	Drill Diameter (mm)
Steels Rated at 0.57 m/s.	20.3	0.50
	27.9	1.00
	40.6	1.59
	50.8	2.38
	68.6	3.18
Steels Rated at 0.48 m/s.	17.8	0.50
	22.9	1.00
	35.6	1.59
	45.7	2.38
	61.0	3.18
All Other Stainless Steels. Tool Steel (0.38 m/s); Monel (0.31 m/s); Phosphor A, B, and D Bronze and HS Steel (0.33 m/s).	15.2	0.50
	20.3	1.00
	30.5	1.59
	40.6	2.38
	50.8	3.18

*From Reference 3.

Table A-6. Recommended Chip Clearing Procedure

Ratio Between Diameter of Drill and Depth of Hole	Number of Chip Clearing Pullouts Required*
(All Materials Except Brass)	
Up to 3.5	None
3.5 to 4.75	One
4.75 to 5.85	Two
5.85 to 6.95	Three
6.95 to 8.05	Four
8.05 to 9.15	Five
9.15 to 10.25	Six
10.25 to 11.35	Seven
11.35 to 12.45	Eight

*From Reference 3.

Table A-7. Hole Size Data From Test 1, Using Master Drill* in Brass Specimens

Specimen	Operation			Feedrate ($\mu\text{m}/\text{rev}$)	Speed (rpm)	Size (mm)	Tool Diameter (mm)	Δ Size (mm)
	C'drill†	Drill	Ream					
58	yes	yes	yes	2.5	2200	0.6668	0.06655	0.0013
106						0.6668		0.0013
90	yes		yes	7.6		0.6668		0.0013
32								0.0008
88	yes		yes	12.5		0.6668		0.0013
77						0.6668	0.06655	0.0013
7	yes		-	2.5		0.6990	0.6680	0.0310
17						0.6998		0.0318
61	yes		-	7.6		0.6972		0.0292
78						0.6891		0.0211
15	yes		-	12.5		0.6972		0.0292
107						0.6939		0.0259
75	-		-	2.5		0.6947		0.0267
49						0.6998		0.0292
13	-		-	7.6		0.6947		0.0267
68						0.6972		0.0292
45	-		-	12.5	2200	0.6972		0.0292
92						0.6922	0.6680	0.0241
91	yes		yes	2.5	4200	0.6688	0.6655	0.0033
79						0.6668		0.0013
19	yes		yes	7.6		0.6668		0.0013
54						0.6668		0.0013
16	yes	yes	yes	12.5		0.6668		0.0013
8					4200	0.6668	0.6655	0.0013

Table A-7 Continued. Hole Size Data From Test 1, Using Master Drill* in Brass Specimens

Specimen	Operation			Feedrate ($\mu\text{m}/\text{rev}$)	Speed (rpm)	Size (mm)	Tool Diameter (mm)	Δ Size (mm)
	C'drill†	Drill	Ream					
80 64	yes	yes	-	2.5	4200	0.7023 0.06998	0.6680	0.0089 0.0318
85 101	yes		-	7.6		0.6962 0.6781		0.0282 0.0165
63 62	yes		-	12.5		0.6861 0.6871		0.0180 0.0191
87 104	-		-	2.5		0.6988 0.6985		0.0318 0.0305
86 57	-		-	7.6		0.6988 0.6939		0.0307 0.0259
34 39	-		-	12.5	4200	0.6922 0.6947	0.6680	0.0241 0.0165
83 108	yes		yes	2.5	6800	0.6668 0.6668		0.0013 0.0013
36 5	yes		yes	7.6		0.6668 0.6668		0.0013 0.0013
73 76	yes		yes	12.5		0.6668 0.6668	0.6655	0.0013 0.0013
56 35	yes		-	2.5		0.6998 0.6965	0.6680	0.0318 0.0284
114 27	yes		-	7.6		0.6947 0.6972		0.0267 0.0292
60 22	yes	yes	-	12.5	6800	0.6922 0.6947	0.6680	0.0241 0.0267

Table A-7 Continued. Hole Size Data From Test 1, Using Master Drill* in Brass Specimens

Specimen	Operation			Feedrate ($\mu\text{m}/\text{rev}$)	Speed (rpm)	Size (mm)	Tool Diameter (mm)	Δ Size (mm)
	C'drill†	Drill	Ream					
98	-	yes	-	2.5	6800	0.6947	0.6680	0.0267
94						0.6911		0.0231
4	-		-	7.6		0.6965		0.0284
72						0.6972		0.0292
112	-	yes	-	12.5	6800	0.6845	0.6680	0.0165
95						0.6891		0.0211

*A master drill 0.66 mm was used except with reaming operations, for which a 0.56-mm master drill was used.

†Centerdrill.

Table A-8. Hole Location Data From Test 1, Using Master Drill*
in Brass Specimens

Specimen	Operation			Feedrate ($\mu\text{m}/\text{rev}$)	Speed (rpm)	Radial Mislocation (mm)
	C'Drill†	**	Ream			
58 106	yes	yes	yes	2.5	2200	0.0124 0.0094
90 32	yes		yes	7.6		0.0132 0.0379
88 77	yes		yes	12.5		0.0381 0.0086
7 17	yes		-	2.5		0.0958 0.0227
61 78	yes		-	7.6		0.0099 0.0099
15 107	yes		-	12.5		0.0285 0.0271
75 49	-		-	2.5		0.0199 0.0136
13 68	-		-	7.6		0.0301 0.0261
45 92	-		-	12.5	2200	0.0280 0.0215
91 79	yes		yes	2.5	4200	0.0182 0.0048
19 54	yes		yes	7.6		0.0280 0.0370
16 8	yes		yes	12.5		0.0278 0.0493
80 64	yes		-	2.5		0.0217 0.0324
85 101	yes		-	7.6		0.0109 0.0090
63 62	yes		-	12.5		0.0209 0.0083
87 104	-		-	2.5		0.0102 0.0171
86 57	-	yes	-	7.6	4200	0.0183 0.0155

Table A-8 Continued. Hole Location Data From Test 1, Using
Master Drill* in Brass Specimens

Specimen	Operation			Feedrate ($\mu\text{m}/\text{rev}$)	Speed (rpm)	Radial Mislocation (mm)
	C'Drill†	**	Ream			
34	-	yes	-	12.5	4200	0.0097
39						0.0119
83	yes		yes	2.5	6800	0.0156
108						0.0163
36	yes		yes	7.6		0.0382
5						0.0317
73	yes		yes	12.5		0.0142
76						0.0297
56	yes		-	2.5		0.0292
35						0.0256
114	yes		-	7.6		0.0163
27						0.0174
60	yes		-	12.5		0.0147
22						0.0169
98	-		-	2.5		0.0131
94						0.0297
4	-		-	7.6		0.0228
72						0.0232
112	-	yes	-	12.5		0.0515
95					6800	0.0279

*A master drill 0.66 mm was used except with reaming operations,
for which a 0.56-mm master drill was used.

†Centerdrill.

**Drilling operation was used on all specimens.

Table A-9. Effects of Chip Clearing on Hole Overcut

Specimen	Material	Operation		Feed Pecking	Size (mm)	Δ Size (mm)
		C'drill*	Drill			
29	B	yes	yes	yes	0.6962	0.0282
52	B				0.6965	0.0361
109	B	--			0.6947	0.0267
44	B				0.6939	0.0259
47	S	yes			0.6861	0.0180
58	S				0.6939	0.0259
69	S	--			0.6886	0.0206
29	S			yes	0.6937	0.0257
99	B	yes		no	0.6998	0.0318
97	B				0.6972	0.0292
48	B	--			0.6937	0.0257
2	B				0.6962	0.0282
11	S	yes			0.6962	0.0282
61	S				0.6871	0.0191
42	S	--	yes	no	0.6922	0.0241
14	S				0.6916	0.0237

Test Conditions:

Pecking cycle...~ 0.25 mm per cycle (5 to 7 cycles per hole).

Feedrate for steady feed...0.531 mm/s.

Machine...Posalux.

Drill...Masterdrill.

B...Brass.

S...302 Stainless Steel.

Speed...4200 rpm.

*Centerdrill.

Table A-10. Effects of Chip Clearing on Hole Mislocation

Specimen	Material	Operation		Feed Pecking	Radial Mislocation (mm)
		C'drill*	Drill		
29	B	yes	yes	yes	0.0108
52	B				0.0317
109	B	-			0.0356
44	B				0.0801
47	S	yes			0.0229
58	S				0.0179
69	S	-			0.0682
29	S				0.0126
99	B	yes			0.0168
97	B				0.0112
48	B	-			0.0105
2	B				0.0139
11	S	yes			0.0156
61	S				0.0249
42	S	-			0.0333
14	S				0.0192

Test Conditions:

Pecking cycle...~ 0.25 mm per cycle (5 to 7) cycles per hole).

Feedrate for steady feed...0.531 mm/s.

Machine...Posalux.

Drill...Masterdrill.

B...Brass.

S...302 Stainless Steel.

Speed...4200 rpm.

*Centerdrill.

Table A-11. Effects of Drill Geometry on Hole Overcut in Brass

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Size (mm)	Δ Size (mm)
	C'drill*	Drill			
21	yes	A	2.5	0.6530	0.0003
1				0.6535	0.0008
96	-	A		0.6515	0.0013
66				0.6515	0.0013
50	yes	B		0.6632	0.0079
113				0.6642	0.0089
111	-	B		0.6632	0.0079
41				0.6632	0.0079
33	yes	C		0.6812	0.0208
28				0.6819	0.0216
10	-	C		0.6894	0.0290
110				0.6896	0.0292
102	yes	D		0.6667	0.0013
20				0.6634	0.0046
31	-	D		0.6632	0.0048
93				0.6667	0.0013
65	yes	E		0.6617	0.0089
18				0.6591	0.0064
23	-	E		0.6616	0.0089
42				0.6604	0.0076
53	yes	F		0.7074	0.0267
11				0.7041	0.0234
81	-	F	2.5	0.7048	0.0241
43				0.7074	0.0267
26	-	F	13.5	0.7066	0.0259
70				0.7041	0.0234
25	yes	F		0.7041	0.0234
74				0.7066	0.0259
30	yes	A		0.6507	0.0020
89				0.6515	0.0013
12	-	A	12.5	0.6515	0.0013
67				0.6515	0.0013

Table A-11 Continued. Effects of Drill Geometry on Hole Overcut in Brass

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Size (mm)	Δ Size (mm)
	C'drill*	Drill			
3	yes	B	12.5	0.6629	0.0076
82				0.6642	0.0089
71	-	B		0.6617	0.0064
47				0.6642	0.0089
100	yes	C		0.6871	0.0267
103				0.6871	0.0267
38	-	C		0.6845	0.0241
51				0.6871	0.0267
69	yes	D		0.6711	0.0030
14				0.6642	-0.0038
6	-	D		0.6668	-0.0013
46				0.6642	-0.0038
9	yes	E		0.6591	0.0064
105				0.6591	0.0064
59	-	E	12.5	0.6591	0.0064
37				0.6609	0.0081

Test Conditions:

Speed...4200 rpm.

Δ Size...Hole size minus drill size.

Coding of Drills...See Table 9 in text.

*Centerdrill.

Table A-12. Effects of Drill Geometry on Hole Overcut in 303Se Stainless Steel

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Size (mm)	Δ Size (mm)
	C'drill*	Drill			
6	yes	A	2.5	0.6515	-0.0013
34				0.6515	-0.0013
35	-	A		0.6490	-0.0038
7				0.6505	-0.0023
19	yes	B		0.6581	0.0028
43				0.6566	0.0013
27	-	B		0.6566	0.0013
20				0.6566	0.0013
26	yes	C		0.6629	0.0025
57				0.6617	0.0013
54	-	C		0.6632	0.0028
75				0.6642	0.0038
67	yes	D		0.6922	0.0241
70				0.6871	0.0191
16	-	D		0.6871	0.0191
62				0.6845	0.0165
55	yes	E		0.6558	0.0046
39				0.6541	0.0013
Buckled	-	E		---	---
				---	---
46	yes	F		0.7049	0.0241
36				0.6988	0.0025
59	-	F	2.5	0.6967	0.0160
3				0.7066	0.0259
73	-	F	12.5	0.6995	0.0102
9				0.7015	0.0208
15	yes	F		0.7069	0.0262
79				0.6993	0.0185
33	yes	A		0.6507	-0.0020
8				0.6510	-0.0018
25	-	A		0.6515	-0.0013
48				0.6515	-0.0013
22	yes	B		0.6566	0.0013
77				0.6584	0.0030

Table A-12 Continued. Effects of Drill Geometry on Hole
Overcut in 303Se Stainless Steel

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Size (mm)	Δ Size (mm)
	C'drill*	Drill			
18	-	B	12.5	0.6584	0.0030
64	-	B		0.6591	0.0038
72	yes	C		0.6657	0.0053
80	-	C		0.6657	0.0053
12	-	C		0.6629	0.0025
44	-	C		0.6617	0.0013
49	yes	D		0.6833	0.0152
52	-	D		0.6911	0.0231
82	-	D		0.6838	0.0157
24	-	D		0.6871	0.0191
53	yes	E		0.6541	0.0013
56	-	E		0.6591	0.0064
Did Not Try	-	E	12.5	---	---

Speed...4200 rpm.

Coding of drills...See Table 9 in text.

*Centerdrill.

Table A-13. Effects of Drill Geometry on Hole Mislocation in Brass

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Radial Mislocation (mm)
	C'drill*	Drill		
21	yes	A	2.5	0.0227
1				0.0225
96	-	A		0.0236
66				0.0109
50	yes	B		0.0117
113				0.0153
111	-	B		0.0190
41				0.0149
33	yes	C		0.0301
28				0.0142
10	-	C		0.0137
110				0.0096
102	yes	D		0.0257
20				0.0204
31	-	D		0.0144
93				0.0170
65	yes	E		0.0235
18				0.0089
23	-	E		0.0290
42				0.0554
53	yes	F		0.0214
11				0.0350
81	-	F	2.5	0.0369
43				0.0253
26	-	F	12.5	0.0069
70				0.0274
25	yes	F		0.0176
74				0.0149
30	yes	A		0.0321
89				0.0254
12	-	A		0.0365
67				0.1326
3	yes	B	12.5	0.0083
82				0.0141

Table A-13 Continued. Effects of Drill Geometry on Hole Mislocation in Brass

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Radial Mislocation (mm)
	C'drill*	Drill		
71	-	B	12.5	0.0198
47				0.0369
100	yes	C		0.0173
103				0.0339
38	-	C		0.0442
51				0.0114
69	yes	D		0.0162
14				0.0231
6	-	D		0.0397
46				0.0347
9	yes	E		0.0310
105				0.0304
59	-	E	12.5	0.1165
37				0.1422

Speed...4200 rpm.

Coding of Drills...See Table 9 in text.

*Centerdrill.

Table A-14. Effects of Drill Geometry on Hole
Mislocation in 303Se Stainless Steel

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Radial Mislocation (mm)
	C'drill*	Drill		
6	yes	A	2.5	0.0131
34				0.0089
35	-	A		0.0257
7				0.0051
19	yes	B		0.0105
43				0.0165
27	-	B		0.0084
20				0.0200
26	yes	C		0.0346
57				0.0159
54	-	C		0.0250
75				0.0074
67	yes	D		0.0165
70				0.0149
16	-	D		0.0284
62				0.0059
55	yes	E		0.0290
39				0.0390
Buckled	-	E		---
46	yes	F		0.0127
36				0.0167
59	-	F	2.5	0.0202
3				0.0410
73	-	F	12.5	0.1390
9				0.0620
15	yes	F		0.0269
79				0.0384
33	yes	A		0.0341
8				0.0112
25	-	A		0.0128
48				0.0091
22	yes	B	12.5	0.0075
77				0.0393

Table A-14 Continued. Effects of Drill Geometry on
Hole Mislocation in 303Se
Stainless Steel

Specimen	Operation		Feed ($\mu\text{m}/\text{rev}$)	Radial Mislocation (mm)
	C'drill*	Drill		
18	-	B	12.5	0.0223
64				0.0232
72	yes	C		0.0075
80				0.0132
12	-	C		0.0176
44				0.0060
49	yes	D		0.0358
52				0.0033
82	-	D		0.0633
24				0.0248
53	yes	E		0.0124
56				0.0230
Did Not Try	-	E	12.5	---

Speed...4200 rpm.

Coding of drills...See Table 9 in text.

*Centerdrill.

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minimize hole mislocation and hole diameter variations. An initial study of drill geometries and drilling techniques for producing 0.66-mm-diameter holes in stainless steel and brass indicates that positional tolerances of 50.8 μm can be maintained. With appropriate drills, a size repeatability of $\pm 2.54 \mu\text{m}$ can be maintained. Centerdrilling is not required if printed circuit board drills are used. Hole quality depends upon the particular combination of feedrate, drilling technique, and drill geometry used. Spindle speed does not affect hole size or location. Additional research is being performed on this subject.

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