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ELECTROCHEMICAL GRINDING

PDO 6984757, Topical Report

R. W. Stiles, Project Leader

Project Team:
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Published August 1976

MASTER

Prepared for the United States Energy
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ELECTROCHEMICAL GRINDING

BDX-613-1159, UNCLASSIFIED Topical Report, Published August 1976

Prepared by R. W. Stiles, D/822, under PDO 6984757

Cutting tests performed with an electrochemical surface grinder on 17-4 PH stainless steel, 303 Se stainless steel, 6061-T6 aluminum, and beryllium copper have established process standard deviations for dimensional variation, overcut, parallelism, flatness, and surface finish. Depths-of-cut studied were 0.001, 0.005, 0.010, 0.020, and 0.050 inch (0.025, 0.127, 0.254, 0.508, and 1.270 mm).

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SUMMARY

Cutting tests were performed to establish process standard deviations for electrochemical grinding (ECG) on 17-4 PH stainless steel, 303 Se stainless steel, 6061-T6 aluminum, and beryllium copper. Bars measuring 0.750 by 0.750 by 6.000 inches (19.050 by 19.050 by 152.400 mm) were used to determine overcut, dimensional variation, parallelism, flatness, and surface finish for each depth-of-cut within each material group. Depths-of-cut studied were 0.001, 0.005, 0.010, 0.020, and 0.050 inch (0.025, 0.127, 0.254, 0.508, and 1.270 mm).

The overcut on the bars generally increased as the depth-of-cut increased. The dimensional variation increased with the depth-of-cut for each material group except beryllium copper. Dimensional variation of the beryllium copper bars was greater for the shallower depths-of-cut.

The variation in parallelism and flatness generally increased with the depth-of-cut. Again, the exception was beryllium copper for which the variation in parallelism remained relatively constant.

Except for the aluminum bars, surface finish worsened with increased depth-of-cut. The surface finish of the aluminum bars was generally worse for the shallower depths-of-cut. The range of surface finish for all depths-of-cut was less on the stainless steel bars than on either the beryllium copper or the aluminum bars.

Additional tests showed that overcut is proportional to the machining voltage and inversely proportional to feed rate. The workpiece size was also found to affect the total dimensional variation of the bars since the electrolysis time and the machining current increase with the area of the workpiece.

Electrochemical grinding produces reasonably good results over small areas, but variations in surface effect occur with larger areas. The electrochemical grinding action varies from the entrance edge to the center and again to the exit edge as the wheel passes over the workpiece. The electrolyte flow conditions, the current density, and the mechanical pressure are variables which contribute to the lack of uniformity in tolerances and surface finish.

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DISCUSSION

SCOPE AND PURPOSE

Cutting tests were performed with the electrochemical surface grinder to determine tolerance capabilities for the electrochemical grinding (ECG) of 17-4 PH stainless steel, 303 Se stainless steel, 6061-T6 aluminum, and beryllium copper. Test bars were inspected for overcut, dimensional variation, parallelism, flatness, and surface finish. From the data obtained, a process standard deviation was established for each variable.

Separate tests were conducted to determine the effect of machining voltage and feed rate upon overcut.

PRIOR WORK

Before the cutting tests were started, optimum machine settings were established, problem areas were isolated, and the machine was configured for best performance. A flow meter was installed in the electrolyte line to provide repeatable control of the electrolyte flow, and a nozzle holder was developed to allow grinding of the plexiglass nozzles while in place, and to provide rapid nozzle adjustment. Proper fitting of the nozzle to the wheel for the best electrolyte flow is essential.

ACTIVITY

Machine Description

The electrochemical surface grinder (Figure 1), built for the Bendix Kansas City Division by Anocut Engineering Company, consists of a modified Brown and Sharpe Model 824 surface grinder, an electrical power supply, and an electrolyte system. The power supply is an ac/dc power-rectifier unit which delivers from 0 to 1000 A at 4 to 15 Vdc. The electrolyte system is a 200-gallon (0.757 m³) unit. The nozzle holder is shown in Figure 2, and the method for properly fitting it to the grinding wheel is shown in Figure 3.

The control panel of the electrochemical grinder allows the operator to set the voltage, the spark sensitivity, and the feed rate in inches per minute. The indicators allow him to monitor the input voltage, the machining voltage, the spindle load, and the machining current amperage. For stainless steel, settings from 7 to 8 V are recommended for heavy cuts and 5 to 6 V for light cuts; for aluminum, 6 to 7 V are recommended for heavy cuts and 2 to 3 V for light cuts. Electrolyte flow rates from 20 to 30 gallons per

Figure 1. Electrochemical Surface Grinder

Figure 2. Grinding Wheel With Nozzle Holder in Position

Figure 3. Positioning of Nozzle Holder

hour (21.040 to 31.560 cm³/s) worked well for all materials and most depths-of-cut. Spark-sensitivity-circuit settings ranged from 75 to 80 percent. A reference feed-rate chart which was developed is shown in Figure 4.

The grinding wheel used for the tests was a copper-resin-bonded aluminum oxide abrasive wheel having a diameter of 12 inches (304.800 mm) and a width of 1 inch (25.400 mm). The electrolyte consisted of 2 pounds per gallon of water (239.653 kg/m³) of Anocut Solution 90 (50 per KC1, 50 percent KNO₃).

Test Procedure

Cutting tests were performed on 17-4 PH stainless steel, 303 Se stainless steel, 6061-T6 aluminum, and beryllium copper. The test bars measured 0.750 by 0.750 by 6.00 inches (19.050 by 19.050 by 152.400 mm). The depths-of-cut studied were 0.001, 0.005, 0.010, 0.020, and 0.050 inch (0.025, 0.127, 0.254, 0.508, and 1.270 mm).

Each test involved the grinding of 25 bars. Overcut, dimensional variation, parallelism, flatness, and surface finish were determined for each depth-of-cut within each material group to establish a process standard deviation for each variable. The bars were surface-ground between tests to provide a consistent volume of metal removal from bar to bar. The amount of material removed was determined by setting the distance from the chuck to the grinding wheel.

Variables which affected the amount of material removed (after the height of the wheel had been set) included the chemical composition of the electrolytic solution, the surface condition of

Figure 4. Feed-Rate Chart for 12-Inch-Diameter (304.800 mm) Wheel

the grinding wheel, the feed rate, the amperage, the spark suppression, the flow rate of the electrolyte, and the speed of the wheel. Once the setup was complete and optimum cutting conditions were achieved, further adjustments were minimized during the cutting tests in order to reduce the variables affecting the test results to those inherent in the machine-tool-workpiece-electrolyte system. The machine settings are shown, according to the material tested, in the Appendices.

The test specimens were inspected and the data from 21 data points were analyzed to compare the depths- and lengths-of-cut (Figure 5). The following lengths-of-cut, using the data points indicated, were considered.

- The 6-inch (152.400 mm) lengths used all 21 data points from each bar.
- The 1-inch (25.400 mm) lengths used 6 data points covering 1-inch areas at the entry, center, and exit of each bar.
- The 2-inch (50.800 mm) lengths used 9 data points covering 2-inch areas at the entry, center, and exit of each bar.
- The 4-inch (101.600 mm) middle lengths used 15 data points from the middle of each bar (excluding the 3 points at the entry and exit of the bar).
- Area B of the 4-inch (101.600 mm) middle lengths used 5 data points (points 5, 8, 11, 14, and 17) through the center of each bar.

The surface opposite the electrochemically ground surface of each bar was placed on the surface plate and height measurements were recorded at the positions shown in Figure 5. The parallelism readings were obtained by determining the differences between the maximum and minimum height measurements taken over the specified lengths-of-cut.

An air probe was mastered (set to zero) flush with the surface plate. The electrochemically ground surface of each bar was then placed in contact with the surface plate and the following measurements were taken at the 21 points used for flatness readings:

- Bar height;
- Overcut/undercut across the bar;
- Parallelism measurements;
- Flatness readings; and

Figure 5. Typical Test Bar Showing Areas Measured

- Surface-finish readings.

The measurements were then analyzed and recorded in the following manner:

- Height measurements listed the average part size, the upper and lower limits bounding 95 percent of the part readings, and the minimum tolerance for 95 percent of the readings 95 percent of the time;
- Parallelism measurements and flatness measurements listed averages, standard deviations, and minimum tolerances;
- Surface-finish measurements listed averages, standard deviations, and confidence intervals; and
- Standard deviations and confidence statements were listed for the different depths-of-cut.

Separate tests were conducted using machining voltage and feed rate as independent variables to study their effect on overcut. The bars used for these studies consisted of 1-, 2-, and 3-inch (25.400, 50.800, and 76.200 mm) lengths of 0.750-inch square (19.050 mm) 17-4 PH stainless steel.

Test Results

The data obtained for dimensional variation, overcut, parallelism, flatness, and surface finish for the different depths-of-cut in the different material groups are plotted in Figures 6 through 25.

For the 17-4 PH stainless steel, the 303 Se stainless steel, and the 6061-T6 aluminum samples, the dimensional variation on the 0.010-inch (0.254 mm) depth-of-cut generally was greater than on the other depths-of-cut. An analysis of the data revealed that the current density for the 0.010-inch samples was greater than that for the 0.001-, 0.005-, 0.020-, and 0.050-inch (0.025, 0.508, and 1.270 mm) depths-of-cut and, in all cases, it was greater than the values recommended (Figure 4).

17-4 PH Stainless Steel

Data obtained for 17-4 PH stainless steel are shown in Figures 6 through 10.

- The minimum dimensional variation for the height measurements was approximately the same for all depths-of-cut.
- A significant reduction occurred in the within-part dimensional variation for bars that had the entry and exit conditions removed.
- Overcut or undercut along the length of the bar became more uniform if the entry and exit conditions were removed.
- The amount of overcut on the deeper cuts increased as the distance along the length of the bar increased.
- Minimum parallelism tolerances decreased as the depth-of-cut decreased, except for the 0.001-inch (0.025 mm) depth.
- Flatness tolerances decreased as the depth-of-cut decreased.
- The center portions of the bars were much flatter than the entry and exit portions.

Figure 6. Dimensional Variation for 95 Percent of the Readings 95 Percent of the Time for 17-4 PH Stainless Steel

Figure 7. Average Overcut/Undercut for 17-4 PH Stainless Steel

Figure 8. Parallelism Measurements for 17-4 PH Stainless Steel

Figure 9. Flatness Measurements for 17-4 PH Stainless Steel

Figure 10. Average Surface Finish for 17-4 PH Stainless Steel

303 Se Stainless Steel

Data obtained for 303 Se stainless steel are shown in Figures 11 through 15.

- The minimum dimensional variation for the height, parallelism, and flatness measurements increased for depths-of-cut between 0.001 and 0.010 inch (0.025 and 0.254 mm), and were about the same for the 0.010-, 0.020-, and 0.050-inch (0.254, 0.508, and 1.270 mm) depths.
- The dimensional variation for the 6-inch (152.400 mm) length required considerably more tolerance than the 1- and 2-inch (25.400 and 50.800 mm) centers (with the entry and exit conditions removed).
- There was little difference between the 1- and 2-inch (25.400 and 50.800 mm) centers.
- Within-part dimensional variation was significantly less when the entry and exit conditions were removed.
- When the part-to-part dimensional variation and the entry and exit conditions were removed, the dimensional variation was reduced by approximately 50 percent at each depth-of-cut.
- The average amount of overcut or undercut was more for the greater depths-of-cut: 0.010, 0.020, and 0.050 inch (0.254, 0.508, and 1.270 mm).

Figure 11. Dimensional Variation for 95 Percent of the Readings 95 Percent of the Time for 303 Se Stainless Steel

- Average overcut or undercut for the 0.001- and 0.005-inch (0.025 and 0.127 mm) depths-of-cut were relatively constant as compared to the greater depths-of-cut.
- The average surface-finish measurements increased as the depth-of-cut increased.

Figure 12. Average Overcut/Undercut for 303 Se Stainless Steel

Figure 13. Parallelism Measurements for 303 Se Stainless Steel

Figure 14. Flatness Measurements for 303 Se Stainless Steel

Figure 15. Average Surface Finish for 303 Se Stainless Steel

6061-T6 Aluminum

Data obtained for 6061-T6 aluminum are shown in Figures 16 through 20.

- For depths-of-cut of 0.010 inch (0.254 mm) and greater, the dimensional variation for the height measurements was more on the 6-inch (152.400 mm) length than on the 1- and 2-inch (25.400 and 50.800 mm) centers.
- There was little difference between the dimensional variation for the 1- and 2-inch (25.400 and 50.800 mm) centers.

Figure 16. Dimensional Variation for 95 Percent of the Readings 95 Percent of the Time for 6061-T6 Aluminum

Figure 17. Average Overcut/Undercut for 6061-T6 Aluminum

- Height measurements on the 4-inch (101.600 mm) middle had a significantly smaller dimensional variation than those for the 6-inch (152.400 mm) length.
- When the variation perpendicular to the path of the grinding wheel was removed, a significant reduction occurred in the dimensional variation, except for the 0.005-inch (0.127 mm) depth.
- The 0.020- and 0.050-inch (0.508 and 1.270 mm) depths-of-cut had more overcut than the 0.001-, 0.005-, and 0.010-inch (0.025, 0.127, and 0.254 mm) depths.
- The removal of the entry and exit measurements, that is the 0- and 6-inch (0 and 152.400 mm) points from the serial number end, provided a more uniform, flatter bar.

Figure 18. Parallelism Measurements for 6061-T6 Aluminum

- A general increase in the dimensional variation of both the parallelism and flatness measurements occurred as the depth-of-cut increased.
- The dimensional variation for the 6-inch (152.400 mm) length was approximately twice that of the 1- and 2-inch (25.400 and 50.800 mm) centers for the parallelism and flatness measurements.
- Except for the 0.005-inch (0.127 mm) depth-of-cut, the average surface-finish measurement increased with an increase in depth.

Figure 19. Flatness Measurements for 6061-T6 Aluminum

Figure 20. Average Surface Finish for 6061-T6 Aluminum

Beryllium Copper

Data obtained for beryllium copper are shown in Figures 21 through 25.

- The dimensional variation for the height measurements for all depths-of-cut was within a 0.002-inch (50.8 μ m) band.
- The 1- and 2-inch (25.400 and 50.800 mm) centers had approximately the same estimates, and the 6-inch (152.400 mm) length was approximately 0.001 inch (0.025 mm) higher.
- Plots of the dimensional variation using the within-part variation indicated small reductions when the entry and exit points were removed, except for the 0.010-inch (0.254 mm) depth which indicated approximately a 50-percent reduction.
- A small reduction also was noted for the dimensional variation when the variation perpendicular to the grinding-wheel path was removed.
- The 0.020-inch (0.508 mm) depth had more overcut than the other depths-of-cut.
- When the entry and exit points were removed, the average overcut or undercut was flat within 0.0006 inch (0.01524 mm).
- The parallelism and flatness measurements required approximately one-half of the tolerance when the entry and exit conditions were removed, except for the flatness measurements on the 0.001- and 0.005-inch (0.025 and 0.127 mm) depths-of-cut.
- Flatness measurements for the 0.005-inch (0.127 mm) depth-of-cut included one part that made the averages high; when this data was removed, the averages were similar to those for the other depths-of-cut.
- The average-surface-finish measurements increased with increases in the depths-of-cut.

Figure 21. Dimensional Variation for
95 Percent of the Readings
95 Percent of the Time for
Beryllium Copper

Figure 22. Average Overcut/Undercut for Beryllium Copper

Figure 23. Parallelism Measurements for Beryllium Copper

Figure 24. Flatness Measurements for Beryllium Copper

Figure 25. Average Surface Finish for Beryllium Copper

Effect of Process Variables on Overcut and Dimensional Variation

Cutting tests were performed to determine the effect of voltage and feed rate (or duration of electrolysis) on overcut. For this study, 0.750-inch-square (19.050 mm) 17-4 PH stainless steel bars were cut into 1-, 2-, and 3-inch (25.400, 50.800, and 76.200 mm) lengths. A depth-of-cut of 0.020 inch (0.508 mm) was used, and the grinding wheel and electrolyte were the same as were used in the previous cutting tests. The electrolyte flow-rate, the wheel speed, and the spark-suppression setting were held constant. The depth-of-cut was established by setting the grinding wheel off the chuck with gage blocks. The gage blocks were also used to measure the remaining thickness of the test bars.

In one test situation, the feed rate was held constant and the voltage was varied; in another, the voltage was held constant and the feed rate was varied. The test results shown in Figures 26 and 27 indicate that overcut is directly proportional to voltage and inversely proportional to feed rate. Figure 28 shows the effect of voltage on the dimensional variation of the bars, and Figure 29 shows the effect of feed rate. The length-of-cut also affects the total dimensional variation, as shown in Figure 30. Summaries of the test data are shown in Tables 1 and 2.

Text continued on page 48.

Figure 26. Effect of Voltage on Overcut

Figure 27. Effect of Feed Rate on Overcut

Figure 28. Effect of Voltage on Dimensional Variation

Figure 29. Effect of Feed Rate on Dimensional Variation

Figure 30. Effect of Length-Of-Cut on Total Dimensional Variation

Table 1. Total Effect of Voltage as a Process Variable

Material: 0.750-inch-square (19.050 mm) 17-4 PH Stainless Steel Depth-Of-Cut: 0.020 inch (0.508 mm) Contact Area: 0.368 in. ² (237.419 mm ²) Grinding Wheel: 12-inch diameter x 1-inch width (304.800 x 25.400 mm) A100V4CD Electrolyte: Anocut Solution 90 Machine Settings: Feed Rate, 3.8 ipm (1.607 mm/s) Wheel Speed, 3600 rpm Electrolyte Flow Rate, 28 gph (29.456 cm ³ /s) Spark Suppression, 75 Percent				
Voltage (V)	Bar Length (Inches)*	Overcut (Inch)*	Tolerance, ± (Inch)*	Parallelism** (Inch)*
4.0	1	+0.0004	0.0012	0.0011
4.0	2	+0.0005	0.0016	0.0017
4.0	3	+0.0001	0.0014	0.0016
5.0	1	+0.0002	0.0010	0.0006
5.0	2	-0.0006	0.0012	0.0011
5.0	3	-0.0011	0.0020	0.0016
6.0	1	-0.0018	0.0010	0.0010
6.0	2	-0.0024	0.0016	0.0014
6.0	3	-0.0021	0.0018	0.0018
7.0	1	-0.0020	0.0014	0.0013
7.0	2	-0.0022	0.0018	0.0015
7.0	3	-0.0030	0.0022	0.0022
*1 inch = 25.400 mm **At 4.0 V, the parts ran + material to - material, front-to-back taper; at 5.0 V, the parts ran straight front-to-back taper; at 6 and 7 V, the parts became dished in the center.				

Table 2. Total Effect of Feed Rate as a Process Variable

Material: 0.750-inch-square (19.050 mm) 17-4 PH Stainless Steel Depth-Of-Cut: 0.020 inch (0.508 mm) Contact Area: 0.360 in. ² (237.419 mm ²) Grinding Wheel: 12-inch diameter x 1-inch width (304.800 x 25.400 mm) A100V4CD Electrolyte: Anocut Solution 90 Machine Settings: Voltage, 5.0 V Wheel Speed, 3600 rpm Electrolyte Flow Rate, 28 gph (29.456 cm ³ /s) Spark Suppression, 75 Percent				
Feed Rate (ipm)*	Bar Length (Inches)**	Overcut (Inch)**	Tolerance, ± (Inch)**	Parallelism (Inch)**
0.5	1	-0.0015	0.0016	0.0014
0.5	2	-0.0017	0.0008	0.0011
0.5	3	-0.0017	0.0012	0.0010
1.0	1	-0.0008	0.0006	0.0004
1.0	2	-0.0010	0.0008	0.0007
1.0	3	-0.0004	0.0008	0.0011
2.0	1	+0.0004	0.0008	0.0008
2.0	2	0	0.0014	0.0016
2.0	3	-0.0003	0.0014	0.0015
3.0	1	+0.0004	0.0010	0.0011
3.0	2	+0.0014	0.0018	0.0020
3.0	3	+0.0014	0.0024	0.0029
*1 ipm = 0.423 mm/s. **1 inch = 25.400 mm.				

Effect of Part Size on Overcut and Dimensional Variation

Additional cutting tests were performed to determine whether part size affects overcut or dimensional variation. Three sizes of 17-4 PH stainless steel bars were selected for the test: 0.250 inch in diameter by 0.250 ± 0.001 inch long (6.350 ± 0.025 mm); 0.500 inch in diameter by 0.250 ± 0.001 inch long (12.700 ± 0.025 mm); and 0.750-inch in diameter by 0.250 ± 0.001 inch long (19.050 ± 0.025 mm). The grinding wheel was set 0.200 inch (5.080 mm) above the chuck with a gage block. A sample quantity of ten bars was machined with identical machine settings used for each size-group. The variables in the tests consisted of part size, machining current (amperage), and duration of electrolysis (cutting time). All machine settings remained constant throughout the tests.

The remaining thickness of the bars was inspected with a height gage indicator mastered to the 0.200-inch (5.080 mm) gage block used to set up the machine. Four data points were selected on the 0.250-inch bar: the entrance, two sides, and the exit end. Five points were selected for the 0.500- and 0.750-inch bars: the entrance, two sides, the center, and the exit end. The inspection data provided a basis for determining overcut, dimensional variation, and parallelism.

The tests proved that part size has a direct effect upon dimensional variation, because the electrolysis time and the machining current increase as the size of the workpiece is increased. Figures 31 through 34 show plots of the variables involved, and Table 3 summarizes the data obtained.

Figure 31. Cutting Time Versus Dimensional Variation

Figure 32. Machining Current Versus Dimensional Variation

Figure 33. Workpiece Diameter Versus Dimensional Variation

Figure 34. Workpiece Diameter Versus Overcut

Table 3. Total Effect of Part Size as a Process Variable

Characteristic	Bar Diameter		
	0.250 Inch (6.350 mm)	0.500 Inch (12.700 mm)	0.750 Inch (19.050 mm)
Machine			
Voltage (V)	7.0	7.0	7.0
Machining Current (A)	150	360	560
Feet Rate (ipm)*	1.5	1.5	1.5
Wheel Speed (rpm)	3600	3600	3600
Electrolyte Flow (gph)**	30	30	30
Cutting Duration (s)	10.2	19.8	30.0
Dimension			
Setup Height (Inch)***	0.200	0.200	0.200
Nominal Size (Inch)***	0.196	0.194	0.194
Standard Deviation	0.00062	0.00098	0.0014
Upper Limit (Inch)***	0.1972	0.1960	0.1968
Lower Limit (Inch)***	0.1948	0.1920	0.1912
Overcut**** (Inch)***	-0.004	-0.006	-0.006
Parallelism:			
Total Variation (Inch)***	0.0009	0.0018	0.0027
Front-To-Back Variation (Inch)***	0.0003	0.0008	0.0018
Side-To-Side Variation (Inch)***	0.0009	0.0018	0.0021
<p>*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm³/s. ***1 inch = 25.400 mm. ****Averaged deviation from setup height.</p>			

ACCOMPLISHMENTS

The results of the tests conducted on the electrochemical surface grinder have been disappointing in that the precision tolerances and fine surface finishes claimed by others working in this field have not been realized. One author has reported the following results.¹

It should be possible to electrolytically machine parts with essentially zero overcut, if a two step operation is used. In step 1 stock is hogged out at maximum efficient voltage consistent with maximum productivity... In step 2 a finish operation is performed at minimum voltage and maximum effective feed rate....

It is well to bear in mind that the amount of overcut is precisely reproducible, provided feed rate and voltage is constant throughout the electrolytic grinding operation.

The following results are reported by a second author.²

ECG is accurate; a large user in the electronics industry reports working to ".00004" in flat work. Form grinding to $\pm .0005$ " is now done in production.

Surface finishes obtained in the process are often in the range of 6 to 10 microinches and seldom exceed 24 microinches.

The experience at Bendix Kansas City with ECG does not substantiate the foregoing statements; to date, ECG has not proved to be a precision process. Overcut is reproducible only within the repeatability limits of the process; zero overcut is possible only by correcting the wheel-head height, and then only within the parallelism limits of the process. On light cuts, the overcut condition goes to undercut with excess material being left on the workpiece.

ECG produces a reasonably good job over small areas with a short electrolysis time, but variations in surface effect occur when larger areas are attempted. The ECG action varies from the entrance edge to the center and then from the center to the exit edge as the grinding wheel passes over the workpiece. The electrolyte flow conditions, the current densities, and the mechanical pressure variables all contribute to a lack of uniformity in tolerances and surface finish.

The following observations, made during the machining tests, explain, in part, the test results.

- Throughout each cutting test, no further adjustments were made to the setup or the machine settings once the optimum machining conditions were achieved. If this were a production situation, the operator would monitor the cutting process and make needed adjustments to better control dimensional conformity.
- During the testing period, a degradation of machining performance occurred. Arcing during cutting, sludging of the material being removed, and a noticeable voltage drop between input and machining voltage all were indicative of a loss in efficiency. Because of the low voltage and high current used in ECG, any resistance in the circuit can cause a serious loss in machining efficiency. The corrosive nature of the electrolyte necessitates a regular preventive maintenance schedule to insure the cables are in good condition and the terminals and contact surfaces are clean; otherwise, resistance will build up in the machining circuit.
- Additional experimentation with electrolytes is required to find the proper combination between performance and dimensional control.
- Operator involvement is as important to ECG as it is to any other machining process. During the cutting tests, it became apparent that any number of different approaches can be made to electrochemically remove material, and changes occur during the process for which adjustments must be made. The operator therefore must be free to use his initiative in optimizing any particular cutting situation.

The results of the tests on the 6-inch (152.400 mm) bars prompted the conducting of additional tests to determine the relationship of part size to overcut and dimensional variation. Attempts to establish tolerance levels for isolated areas on the 6-inch bars were inconclusive in that the time of electrolysis affected the inspection data. The tests, performed on three different sample sizes, proved that dimensional control is much greater on small workpieces than on large workpieces.

Once the electrolyte has been selected, the important variables in the process are voltage and feed rate. Too slow a feed rate adversely affects both overcut and dimensional variation. As voltage increases, overcut and dimensional variation also increase. While the electrolyte flow-rate has a wide tolerance range before it becomes significant, the distribution of the electrolyte on the grinding wheel is critical. The wheel speed is important only as it affects the rate at which the electrolyte is pushed through the working gap. The machine has two speeds: 1800 and 3600 rpm, which are equivalent to 6000 and 11000 surface feet per minute (30.480

and 55.880 m/s). The 3600-rpm speed produces the better results and is recommended for most applications.

The electrolyte used (Anocut Solution 90) was recommended by Anocut Engineering Company as a general-purpose electrolyte for stainless and alloy steels. The use of a general-purpose solution is important in eliminating the high cost of changing the electrolyte each time a new alloy is machined. This electrolyte, however, produced erratic cutting of the beryllium copper bars with a resultant poor surface finish. For this reason, the 0.050-inch (1.270 mm) depth-of-cut tests were not conducted on beryllium copper.

At the present stage of ECG development at Bendix Kansas City, the following process parameters are recommended.

- Tolerances

Large Areas: ± 0.002 inch (50.8 μm)

Small Areas: ± 0.001 inch (25.4 μm)

- Surface Finish

10 to 30 rms (254 to 762 nm)

- Metal Removal

Large Areas: Rough and finish.

Small Areas: Remove material in one pass.

- Current Density

Stainless steels: 1000 to 2000 A/in.² (1.55 to 3.10 A/mm²)

Aluminum: Approximately 1000 A/in.² (1.55 A/mm²)

- Voltage

Stainless Steels: Rough, 7 to 8 volts

Finish, 4 to 5 volts

Aluminum: Rough, 5 to 6 volts

Finish, 2 to 3 volts

Experience to date using the electrochemical grinder for the production of small metal parts has been good because of the small contact area and short electrolysis time.

FUTURE WORK

An appropriate preventive maintenance program will be established for the electrochemical grinder to obtain a continuously effective performance.

Additional cutting tests will be performed using $\text{NaCl}/\text{NaNO}_3$ electrolyte to compare the results with those obtained using Anocut Solution 90, particularly in the cutting of beryllium copper.

Additional cutting tests also will be performed to evaluate slotting and two-dimensional form grinding.

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Appendix A .

DATA FOR 17-4 PH STAINLESS STEEL

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Table A-1. Height Measurements, 17-4 PH Stainless Steel,
0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.5138	0.5155	0.5133	0.0042
2	Entry	0.5138	0.5153	0.5115	0.0038
	Center	0.5136	0.5151	0.5114	0.0037
	Exit	0.5138	0.5156	0.5113	0.0043
1	Entry	0.5139	0.5153	0.5116	0.0037
	Center	0.5136	0.5151	0.5115	0.0036
	Exit	0.5138	0.5157	0.5114	0.0042
*1.000 inch = 25.400 mm.					

Table A-2. Parallelism Measurements, 17-4 PH Stainless
Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0015	0.00072	0.0032
2	Entry	0.0011	0.00061	0.0025
	Center	0.0011	0.00066	0.0026
	Exit	0.0013	0.00073	0.0030
1	Entry	0.0008	0.00058	0.0022
	Center	0.0009	0.00064	0.0024
	Exit	0.0011	0.00074	0.0029
*1.000 inch = 25.400 mm.				

Table A-3. Flatness Measurements, 17-4 PH Stainless Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0007	0.00028	0.0013
2	Entry	0.0006	0.00024	0.0011
	Center	0.0003	0.00020	0.0007
	Exit	0.0006	0.00027	0.0012
1	Entry	0.0005	0.00025	0.0010
	Center	0.0003	0.00018	0.0007
	Exit	0.0005	0.00028	0.0012
*1.000 inch = 25.400 mm.				

Table A-4. Surface-Finish Measurements, 17-4 PH Stainless Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	28.4	11.0	2.7 to 54.1
Center	23.0	11.3	0 to 49.3
Exit	24.4	12.0	0 to 52.4
*1.000 inch = 25.400 mm.			

Table A-5. Height Measurements, 17-4 PH Stainless Steel,
0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.5172	0.5192	0.5154	0.0038
2	Entry	0.5173	0.5192	0.5156	0.0036
	Center	0.5171	0.5188	0.5154	0.0034
	Exit	0.5171	0.5188	0.5154	0.0034
1	Entry	0.5174	0.5192	0.5157	0.0035
	Center	0.5171	0.5188	0.5155	0.0033
	Exit	0.5171	0.5189	0.5155	0.0034
*1.000 inch = 25.400 mm.					

Table A-6. Parallelism Measurements, 17-4 PH Stainless
Steel, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0014	0.00033	0.0022
2	Entry	0.0012	0.00025	0.0021
	Center	0.0010	0.00025	0.0016
	Exit	0.0010	0.00025	0.0016
1	Entry	0.0010	0.00030	0.0017
	Center	0.0009	0.00022	0.0014
	Exit	0.0009	0.00023	0.0015
*1.000 inch = 25.400 mm.				

Table A-7. Flatness Measurements, 17-4 PH Stainless Steel, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0013	0.00022	0.0018
2	Entry	0.0011	0.00025	0.0017
	Center	0.0009	0.00013	0.0012
	Exit	0.0012	0.00021	0.0017
1	Entry	0.0010	0.00023	0.0016
	Center	0.0008	0.00017	0.0012
	Exit	0.0011	0.00016	0.0015
*1.000 inch = 25.400 mm.				

Table A-8. Surface-Finish Measurements, 17-4 PH Stainless Steel, 0.005-Inch (0.127 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	35.7	2.7	28.5 to 42.9
Center	34.3	2.1	28.6 to 40.1
Exit	35.9	2.5	29.0 to 42.7
*1.000 inch = 25.400 mm.			

Table A-9. Height Measurements, 17-4 PH Stainless Steel,
0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.5240	0.5272	0.5213	0.0060
2	Entry	0.5243	0.5276	0.5216	0.0060
	Center	0.5239	0.5262	0.5216	0.0047
	Exit	0.5238	0.5264	0.5214	0.0050
1	Entry	0.5245	0.5277	0.5218	0.0059
	Center	0.5239	0.5262	0.5217	0.0045
	Exit	0.5238	0.5263	0.5213	0.0050
*1.000 inch = 25.400 mm.					

Table A-10. Parallelism Measurements, 17-4 PH Stainless
Steel, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0026	0.00058	0.0039
2	Entry	0.0017	0.00048	0.0028
	Center	0.0011	0.00035	0.0019
	Exit	0.0013	0.00044	0.0023
1	Entry	0.0014	0.00039	0.0023
	Center	0.0009	0.00031	0.0016
	Exit	0.0011	0.00034	0.0019
*1.000 inch = 25.400 mm.				

Table A-11. Flatness Measurements, 17-4 PH Stainless Steel, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0022	0.00038	0.0030
2	Entry	0.0017	0.00042	0.0027
	Center	0.0009	0.00036	0.0018
	Exit	0.0019	0.00040	0.0028
1	Entry	0.0015	0.00043	0.0025
	Center	0.0008	0.00033	0.0016
	Exit	0.0017	0.00042	0.0027
*1.000 inch = 25.400 mm.				

Table A-12. Surface-Finish Measurements, 17-4 PH Stainless Steel, 0.010-Inch (0.254 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	32.5	9.6	10.1 to 54.8
Center	29.9	7.9	11.4 to 48.4
Exit	33.0	12.1	4.9 to 61.2
*1.000 inch = 25.400 mm.			

Table A-13. Height Measurements, 17-4 PH Stainless Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.5404	0.5432	0.5382	0.0050
2	Entry	0.5410	0.5432	0.5392	0.0040
	Center	0.5402	0.5418	0.5383	0.0034
	Exit	0.5399	0.5420	0.5382	0.0038
1	Entry	0.5412	0.5432	0.5394	0.0038
	Center	0.5404	0.5418	0.5388	0.0029
	Exit	0.5399	0.5418	0.5382	0.0036
*1.000 inch = 25.400 mm.					

Table A-14. Parallelism Measurements, 17-4 PH Stainless Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0024	0.00039	0.0033
2	Entry	0.0017	0.00034	0.0024
	Center	0.0009	0.00024	0.0015
	Exit	0.0008	0.00024	0.0013
1	Entry	0.0015	0.00031	0.0022
	Center	0.0006	0.00018	0.0010
	Exit	0.0008	0.00037	0.0017
*1.000 inch = 25.400 mm.				

Table A-15. Flatness Measurements, 17-4 PH Stainless Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0027	0.00050	0.0038
2	Entry	0.0023	0.00068	0.0038
	Center	0.0010	0.00044	0.0020
	Exit	0.0018	0.00040	0.0027
1	Entry	0.0023	0.00069	0.0038
	Center	0.0008	0.00047	0.0019
	Exit	0.0014	0.00035	0.0022
*1.000 inch = 25.400 mm.				

Table A-16. Surface-Finish Measurements, 17-4 PH Stainless Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	33.7	7.1	17.2 to 50.1
Center**	30.7	5.5	18.0 to 43.4
Exit	27.3	4.6	16.6 to 37.9
<p>*1.000 inch = 25.400 mm.</p> <p>**These values have Part 3 omitted since it was approximately 80 microinches larger than the second-largest value. The corresponding values with Part 3 included are: 34.5; 19.8; and 0 to 80.3.</p>			

Table A-17. Height Measurements, 17-4 PH Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.5654	0.5684	0.5433	0.0052
2	Entry	0.5659	0.5684	0.5634	0.0050
	Center	0.5652	0.5677	0.5631	0.0045
	Exit	0.5649	0.5670	0.5633	0.0037
1	Entry	0.5661	0.5682	0.5639	0.0044
	Center	0.5653	0.5677	0.5632	0.0045
	Exit	0.5649	0.5669	0.5632	0.0037
*1.000 inch = 25.400 mm.					

Table A-18. Parallelism Measurements, 17-4 PH Stainless
Steel, 0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0022	0.00035	0.0032
2	Entry	0.0015	0.00042	0.0027
	Center	0.0010	0.00041	0.0021
	Exit	0.0008	0.00025	0.0015
1	Entry	0.0012	0.00027	0.0019
	Center	0.0007	0.00043	0.0019
	Exit	0.0007	0.00024	0.0013
*1.000 inch = 25.400 mm.				

Table A-19. Flatness Measurements, 17-4 PH Stainless Steel, 0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0022	0.00055	0.0036
2	Entry	0.0016	0.00051	0.0030
	Center	0.0010	0.00043	0.0022
	Exit	0.0017	0.00041	0.0028
1	Entry	0.0015	0.00056	0.0030
	Center	0.0009	0.00038	0.0019
	Exit	0.0015	0.00046	0.0027
*1.000 inch = 25.400 mm.				

Table A-20. Surface-Finish Measurements, 17-4 PH Stainless Steel, 0.050-Inch (1.270 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	40.5	9.4	15.6 to 65.4
Center**	41.6	14.1	4.2 to 79.0
Exit	35.7	5.7	20.7 to 50.7
<p>*1.000 inch = 25.400 mm.</p> <p>**These values have Part 3 omitted since it was approximately 40 microinches larger than the second-largest value. The corresponding values with Part 3 included are: 45.0; 21.8; and 0 to 102.7.</p>			

Table A-21. Standard Deviations and Confidence Statements for Different Types of Cuts, 17-4 PH Stainless Steel

Depth-Of-Cut** (Inch)*	Minimum Part Tolerance**** 6-Inch Cut (Inch)*	Within-Part Standard Deviation (Confidence Statements***)		
		Total Bar, 6-Inch Cut† (Inch)*	Middle 4-Inch Cut†† (Inch)*	Middle 4-Inch Cut, Area B††† (Inch)*
0.100	0.0143	0.0012 (±0.0025)	0.0009 (±0.0019)	0.0008 (±0.0017)
0.050	0.0052	0.0006 (±0.0013)	0.0005 (±0.0009)	0.0005 (±0.0010)
0.020	0.0050	0.0007 (±0.0014)	0.0004 (±0.0009)	0.0004 (±0.0009)
0.010	0.0060	0.0007 (±0.0015)	0.0005 (±0.0010)	0.0005 (±0.0010)
0.005	0.0038	0.0004 (±0.0009)	0.0004 (±0.0008)	0.0002 (±0.0003)
0.001	0.0042	0.0005 (±0.0011)	0.0005 (±0.0010)	0.0002 (±0.0005)
<p>*1.000 inch = 25.400 mm.</p> <p>**The lengths and areas of cuts are shown in Figure 5.</p> <p>***The value listed in parentheses is the width of the tolerance interval within which 95 percent of the readings will fall 95 percent of the time.</p> <p>****Minimum Part Tolerance = The difference between the upper and lower 95-percent tolerance limits. This estimate contains both part-to-part and within-part variation.</p> <p>†Total Bar, 6-Inch Cut = The within-part variation using all 21 measurements shown in Figure 5.</p> <p>††Middle 4-Inch Cut = The within-part variation using the measurements in the middle 4-inch section shown in Figure 5. This has the entry and exit conditions removed.</p> <p>†††Middle 4-Inch Cut, Area B = The within-part variation using only those measurements in Area B of the middle 4 inches of each bar. This removes some variation across the bar perpendicular to the travel of the grinding wheel.</p>

Figure A-1. Height-Measurement Distribution for 17-4 PH Stainless Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Figure A-2. Height-Measurement Distribution for 17-4 PH Stainless Steel, 0.005-Inch (0.127 mm) Depth-Of-Cut

Figure A-3. Height-Measurement Distribution for 17-4 PH Stainless Steel,
0.010-Inch (0.254 mm) Depth-Of-Cut

17-4 PH .020 IN. CUT

Figure A-4. Height-Measurement Distribution for 17-4 PH Stainless Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Figure A-5. Height-Measurement Distribution for 17-4 PH Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Table A-22. Process Variables, 17-4 PH Stainless Steel,
0.001-Inch (0.025 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 1800 rpm Set 0.513 inch (13.030 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	6.0 ↑	25.0 ↑	80	75 ↑	18 ↑
2			100		
3			100		
4			120		
5			120		
6			100		
7			100		
8			100		
9			100		
10			100		
11			120		
12			120		
13			120		
14			110		
15			↑		
16			↓		
17			110		
18			140		
19			110		
20					
21					
22					
23	6.0 ↓	25.0 ↓	110	75 ↓	18 ↓
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

Table A-23. Process Variables, 17-4 Stainless Steel,
0.005-Inch (0.127 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.516 inch (13.106 mm)					
Part Number***	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	6.0	11.0	200	75	22
2	↑	↑	200	↑	↑
3			200		
4			200		
5			200		
6			200		
7			200		
8			250		
9			250		
10			280		
11			280		
12			280		
13			280		
14			300		
15			300		
16			300		
17			240		
18			220		
19			200		
20			200		
21			200		
22	6.0	11.0	220	75	22
23	6.0	11.0	220	75	22
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s. ***Heavy Sparking on cut but not audible and no spindle load.					

Table A-24. Process Variables, 17-4 PH Stainless Steel,
0.010-Inch (0.254 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration					
Wheel Speed, 3600 rpm					
Set 0.528 inch (13.411 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	7.5 ↑	6.0	660	75 ↑	24
2			660		24
3			660		24
4			660		22
5			660		
6			660		
7			660		
8			660		
9			680		
10			680		
11			680		
12			720		
13			720		
14			700		
15			700		
16			660		
17			660		
18			660		
19			640		
20			6.0		660
21***		4.0	480		
22		4.0	500		
23		4.0	500		
24	7.5	4.0	500	75	22

*1 ipm = 0.423 mm/s.

**1 gph = 1.052 cm³/s.

***Excessive arcing.

Table A-25. Process Variables, 17-4 PH Stainless Steel,
0.020-Inch (0.508 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.544 inch (13.818 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	7.5	4.0	660	75	22
2	7.5	↑	680	↑	20
3***	7.0	↑	680	↑	16
4	7.5	↑	660	↑	22
5	↑	↑	↑	↑	22
6	↑	↑	↑	↑	23
7	↑	↑	↑	↑	22
8	↑	↑	↑	↑	↑
9	↑	↑	↑	↑	↑
10	↑	↑	↑	↑	↑
11	↑	↑	↑	↑	↑
12	↑	↑	↑	↑	↑
13	↑	↑	↑	↑	↑
14	↑	↑	↑	↑	↑
15	↑	↑	↑	↑	↑
16	↑	↑	↑	↑	↑
17	↑	↑	↑	↑	↑
18	↑	↑	↑	↑	↑
19	↑	↑	↑	↑	↑
20	↑	↑	↑	↑	↑
21	↑	↑	↑	↑	↑
22	↑	↑	↑	↑	↑
23	↑	↑	↑	↑	↑
24	↑	↑	↑	↑	↑
25	7.5	4.0	660	75	22

*1 ipm = 0.423 mm/s.
 **1 gph = 1.052 cm³/s.
 ***Excessive arcing reduced voltage.

Table A-26. Process Variables, 17-4 PH Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration					
Wheel Speed, 3600 rpm					
Set 0.572 inch (14.529 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1†	7.5	1.2	480	75	20
2	↑	↑	480-500	↑	20
3			500		20
4			500		20
5			480		22
6			500		20
7††			500		20
8			500		22
9			500		22
10			500		22
11			480		20
12			500		22
13			480		22
14			500		20
15			480		20
16			480		20
17			500		22
18			480		20
19			480		20
20			500		20
21			500		18
22			500		22
23			↓		↓
24	500	20			
25	500	20			
*1 ipm = 0.423 mm/s.					
**1 gph = 1.052 cm ³ /s.					
†Stopped in cut.					
††Honed chuck to remove high spot, end to end.					

Appendix B

DATA FOR 303 Se STAINLESS STEEL

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Table B-1. Height Measurements, 303 Se Stainless Steel,
0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.6820	0.6831	0.6805	0.0026
2	Entry	0.6820	0.6829	0.6806	0.0024
	Center	0.6819	0.6829	0.6807	0.0022
	Exit	0.6821	0.6832	0.6808	0.0024
1	Entry	0.6820	0.6829	0.6806	0.0023
	Center	0.6819	0.6828	0.6807	0.0021
	Exit	0.6821	0.6832	0.6809	0.0023
*1.000 inch = 25.400 mm.					

Table B-2. Parallelism Measurements, 303 Se Stainless
Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0009	0.00054	0.0021
2	Entry	0.0007	0.00038	0.0016
	Center	0.0006	0.00040	0.0015
	Exit	0.0008	0.00043	0.0018
1	Entry	0.0006	0.00037	0.0015
	Center	0.0005	0.00038	0.0014
	Exit	0.0007	0.00039	0.0016
*1.000 inch = 25.400 mm.				

Table B-3. Flatness Measurements, 303 Se Stainless Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0007	0.00033	0.0015
2	Entry	0.0006	0.00027	0.0012
	Center	0.0004	0.00024	0.0010
	Exit	0.0006	0.00029	0.0013
1	Entry	0.0005	0.00030	0.0012
	Center	0.0004	0.00026	0.0010
	Exit	0.0005	0.00026	0.0011
*1.000 inch = 25.400 mm.				

Table B-4. Surface-Finish Measurements, 303 Se Stainless Steel, 0.001-Inch (0.025 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	10.1	4.2	0 to 21.3
Center	9.7	4.4	0 to 21.3
Exit	9.3	4.4	0 to 20.9
*1.000 inch = 25.400 mm.			

Table B-5. Height Measurements, 303 Se Stainless Steel,
0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.7110	0.7128	0.7089	0.0040
2	Entry	0.7112	0.7129	0.7092	0.0036
	Center	0.7106	0.7122	0.7091	0.0031
	Exit	0.7109	0.7127	0.7090	0.0036
1	Entry	0.7113	0.7132	0.7095	0.0037
	Center	0.7107	0.7121	0.7092	0.0030
	Exit	0.7111	0.7127	0.7096	0.0031
*1.000 inch = 25.400 mm.					

Table B-6. Parallelism Measurements, 303 Se Stainless Steel,
0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0020	0.00045	0.0030
2	Entry	0.0014	0.00034	0.0022
	Center	0.0012	0.00029	0.0019
	Exit	0.0014	0.00031	0.0021
1	Entry	0.0009	0.00016	0.0012
	Center	0.0011	0.00032	0.0018
	Exit	0.0010	0.00019	0.0014
*1.000 inch = 25.400 mm.				

Table B-7. Flatness Measurements, 303 Se Stainless Steel,
0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0017	0.00028	0.0024
2	Entry	0.0013	0.00023	0.0018
	Center	0.0011	0.00029	0.0017
	Exit	0.0016	0.00041	0.0026
1	Entry	0.0007	0.00015	0.0011
	Center	0.0010	0.00030	0.0017
	Exit	0.0011	0.00033	0.0019
*1.000 inch = 25.400 mm.				

Table B-8. Surface-Finish Measurements, 303 Se Stainless
Steel, 0.005-Inch (0.127 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	24.8	9.7	.0 to 50.5
Center	18.2	3.1	10.1 to 26.3
Exit	19.6	5.2	5.7 to 33.5
*1.000 inch= 25.400 mm.			

Table B-9. Height Measurements, 303 Se Stainless Steel,
0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.7200	0.7244	0.7171	0.0073
2	Entry	0.7206	0.7244	0.7173	0.0071
	Center	0.7191	0.7214	0.7171	0.0043
	Exit	0.7198	0.7225	0.7172	0.0053
1	Entry	0.7213	0.7244	0.7184	0.0060
	Center	0.7191	0.7214	0.7171	0.0044
	Exit	0.7200	0.7225	0.7176	0.0050
*1.000 inch = 25.400 mm.					

Table B-10. Parallelism Measurements, 303 Se Stainless
Steel, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0036	0.00037	0.0044
2	Entry	0.0032	0.00034	0.0040
	Center	0.0010	0.00022	0.0015
	Exit	0.0017	0.00031	0.0024
1	Entry	0.0019	0.00028	0.0025
	Center	0.0009	0.00021	0.0014
	Exit	0.0012	0.00029	0.0018
*1.000 inch = 25.400 mm.				

Table B-11. Flatness Measurements, 303 Se Stainless Steel,
0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0. (Inch)*
6	All	0.0039	0.00044	0.0049
2	Entry	0.0032	0.00055	0.0045
	Center	0.0014	0.00031	0.0021
	Exit	0.0031	0.00048	0.0042
1	Entry	0.0024	0.00052	0.0036
	Center	0.0010	0.00036	0.0018
	Exit	0.0023	0.00058	0.0037
*1.000 inch = 25.400 mm.				

Table B-12. Surface-Finish Measurements, 303 Se Stainless
Steel, 0.010-Inch (0.254 mm) Depth-Of-Cut

Position On 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	27.3	4.4	17.2 to 37.4
Center	25.5	3.4	17.6 to 33.3
Exit	29.4	5.3	17.2 to 41.6
*1.000 inch = 25.400 mm.			

Table B-13. Height Measurements, 303 Se Stainless Steel,
0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.6855	0.6898	0.6825	0.0073
2	Entry	0.6864	0.6898	0.6830	0.0068
	Center	0.6848	0.6874	0.6825	0.0050
	Exit	0.6850	0.6881	0.6818	0.0064
1	Entry	0.6870	0.6898	0.6869	0.0029
	Center	0.6849	0.6875	0.6826	0.0050
	Exit	0.6852	0.6881	0.6825	0.0057
*1.000 inch = 25.400 mm.					

Table B-14. Parallelism Measurements, 303 Se Stainless
Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0044	0.00048	0.0055
2	Entry	0.0038	0.00040	0.0047
	Center	0.0019	0.00035	0.0027
	Exit	0.0023	0.00051	0.0035
1	Entry	0.0027	0.00027	0.0033
	Center	0.0018	0.00036	0.0026
	Exit	0.0021	0.00051	0.0033
*1.000 inch = 25.400 mm.				

Table B-15. Flatness Measurements, 303 Se Stainless Steel,
0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0040	0.00044	0.0050
2	Entry	0.0030	0.00038	0.0038
	Center	0.0021	0.00031	0.0028
	Exit	0.0035	0.00046	0.0045
1	Entry	0.0026	0.0003	0.0033
	Center	0.0017	0.00026	0.0023
	Exit	0.0029	0.00041	0.0038
*1.000 inch = 25.400 mm.				

Table B-16. Surface-Finish Measurements, 303 Se Stainless
Steel, 0.020-Inch (0.508 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	36.1	10.4	8.4 to 63.8
Center	34.2	5.4	19.8 to 48.6
Exit	33.4	6.6	15.8 to 51.0
*1.000 inch = 25.400 mm.			

Table B-17. Height Measurements, 303 Se Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.6104	0.6136	0.6073	0.0063
2	Entry	0.6109	0.6135	0.6081	0.0054
	Center	0.6108	0.6133	0.6082	0.0051
	Exit	0.6097	0.6127	0.6072	0.0055
1	Entry	0.6108	0.6135	0.6081	0.0054
	Center	0.6110	0.6133	0.6087	0.0046
	Exit	0.6094	0.6119	0.6073	0.0047
*1.000 inch = 25.400 mm.					

Table B-18. Parallelism Measurements, 303 Se Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0032	0.00046	0.0044
2	Entry	0.0019	0.00057	0.0034
	Center	0.0016	0.00032	0.0025
	Exit	0.0020	0.00048	0.0033
1	Entry	0.0018	0.00058	0.0034
	Center	0.0010	0.00027	0.0018
	Exit	0.0014	0.00044	0.0026
*1.000 inch = 25.400 mm.				

Table B-19. Flatness Measurements, 303 Se Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0033	0.00076	0.0053
2	Entry	0.0032	0.00081	0.0054
	Center	0.0019	0.00042	0.0031
	Exit	0.0020	0.00050	0.0033
1	Entry	0.0030	0.00084	0.0053
	Center	0.0018	0.00049	0.0031
	Exit	0.0018	0.00057	0.0033
*1.000 inch = 25.400 mm.				

Table B-20. Surface-Finish Measurements, 303 Se Stainless
Steel, 0.050-Inch (1.270 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	37.9	3.1	29.5 to 46.3
Center	35.5	3.5	26.0 to 44.9
Exit	39.2	5.0	25.6 to 52.8
*1.000 inch 25.400 mm.			

Table B-21. Standard Deviations and Confidence Statements for Different Types of Cuts, 303 Se Stainless Steel

Depth-Of-Cut** (Inch)*	Minimum Part Tolerance**** 6-Inch Cut (Inch)*	Within-Part Standard Deviation (Confidence Statements***)		
		Total Bar, 6-Inch Cut† (Inch)*	Middle 4-Inch Cut†† (Inch)*	Middle 4-Inch Cut, Area B††† (Inch)*
0.050	0.0063	0.0009 (±0.0019)	0.0007 (±0.0015)	0.0006 (±0.0014)
0.020	0.0073	0.0013 (±0.0026)	0.0009 (±0.0019)	0.0007 (±0.0016)
0.010	0.0073	0.0012 (±0.0025)	0.0009 (±0.0018)	0.0009 (±0.0020)
0.005	0.0040	0.0006 (±0.0012)	0.0005 (±0.0011)	0.0005 (±0.0011)
0.001	0.0026	0.0003 (±0.0007)	0.0003 (±0.0006)	0.0001 (±0.0002)
<p>*1.000 inch = 25.400 mm.</p> <p>**The lengths and areas of cuts are shown in Figure 5.</p> <p>***The value listed in parentheses is the width of the tolerance interval within which 95 percent of the readings will fall 95 percent of the time.</p> <p>****Minimum Part Tolerance = The difference between the upper and lower 95-percent tolerance limits. This estimate contains both part-to-part and within-part variation.</p> <p>†Total Bar, 6-Inch Cut = The within-part variation using all 21 measurements shown in Figure 5.</p> <p>††Middle 4-Inch Cut = The within-part variation using the measurements in the middle 4-inch section shown in Figure 5. This has the entry and exit conditions removed.</p> <p>†††Middle 4-Inch Cut, Area B = The within-part variation using only those measurements in Area B of the middle 4 inches of each bar. This removes some variation across the bar perpendicular to the travel of the grinding wheel.</p>

Figure B-1. Height-Measurement Distribution for 303 Se Stainless Steel,
0.001-Inch (0.025 mm) Depth-Of-Cut

Figure B-2. Height-Measurement Distribution for 303 Se Stainless Steel, 0.005-Inch (0.127 mm) Depth-Of-Cut

Figure B-5. Height-Measurement Distribution for 303 Se Stainless Steel, 0.050-Inch (1.270 mm) Depth-Of-Cut

Table B-22. Process Variables, 303 Se Stainless Steel,
0.001-Inch (0.025 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.681 inch (17.297 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	5.0	25.0	60	75	14
2	↑	↑	60	↑	12
3	↑	↑	60	↑	↑
4	↑	↑	60	↑	↑
5	↑	↑	40	↑	↑
6	↑	↑	40	↑	↑
7	↑	↑	60	↑	↑
8	↑	↑	40	↑	↑
9	↑	↑	↑	↑	↑
10	↑	↑	↑	↑	↑
11	↑	↑	↑	↑	↑
12	↑	↑	↑	↑	↑
13	↑	↑	↑	↑	↑
14	↑	↑	↑	↑	↑
15	↑	↑	↓	↑	↑
16	↑	↑	↓	↑	↑
17	↑	↑	40	↑	↑
18	↑	↑	30	↑	↑
19	↑	↑	20	↑	↑
20	↑	↑	40	↑	↑
21	↑	↑	50	↑	↑
22	↑	↑	40	↑	↑
23	↓	↓	10	↓	↓
24	5.0	25.0	40	75	12
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

Table B-23. Process Variables, 303 Se Stainless Steel,
0.005-Inch (0.127 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.712 inch (18.085 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	5.0	10.0	140	75	22
2			200		
3			160		
4			240		
5			200		
6†			200		
7†			200		
8††			240		
9			100		
10			120		
11	5.0	10.0	140	75	22
12			180		
13†			200		
14†			240		
15			240		
16			260		
17			240		
18			240		
19			240		
20			300		
21	5.5	9.0	300	75	22
22			300		
23			280		
24			280		
25			280		

*1 ipm = 0.423 mm/s.
**1 gph = 1.052 cm³/s.
†Stopped in cut.
††Stopped four times.

Table B-24. Process Variables, 303 Se Stainless Steel,
0.010-Inch (0.254 mm) Depth-Of-Cut

Conditions: Electrolyte, Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.726 inch (18.440 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	7.5	5.0	740	75	22
2†	8.0	5.0	700	↑	24
3	8.0	4.5	620	↑	26
4	8.0	↑	600	↑	26
5	7.5	↑	660	↑	26
6	8.0	↑	620	↑	24
7	↑	↑	600	↑	22
8	↑	↓	600	↑	22
9	↑	↓	600	↑	24
10	↑	4.5	600	↑	22
11††	↑	3.5	600	↑	↑
12	↑	↑	580	↑	↑
13	↑	↑	580	↑	↑
14	↑	↑	580	↑	↑
15	↑	↑	600	↑	↑
16	↑	↑	600	↑	↑
17	↑	↑	600	↑	↑
18	↑	↑	600	↑	↑
19	↑	↑	620	↑	↓
20	↑	↑	600	↑	22
21	↑	↑	640	↑	24
22	↑	↑	580	↑	24
23	↑	↑	620	↑	24
24	↓	↓	700	↓	24
25	8.0	3.5	640	75	24
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s. †Excessive arcing. ††Excessive arcing; data shows large difference between high and low.					

Table B-25. Process Variables, 303 Se Stainless Steel,
0.020-Inch (0.508 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.688 inch (17.475 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1			620		30-26
2			660		30
3			620		22
4			640		24
5			620		
6			600		
7			600		
8			600		
9			520		
10			460		
11			540		
12			540		
13			540		
14			540		
15			540		
16			600		
17			580		
18			580		
19			580		
20			580		
21			600		
22			600		
23			600		
24			600		
25	8.0	3.0	600	75	24
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

Table B-26. Process Variables, 303 Se Stainless Steel,
0.050-Inch (1.270 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.615 inch (15.621 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1†	7.5	1.2	520	75	24-40
2	6.0	↑	500	↑	40
3	↑	↑	500	↑	↑
4††	↑	↑	520	↑	↑
5	↑	↑	520	↑	↑
6	↑	↑	520	↑	↑
7	↑	↑	520	↑	↑
8	↑	↑	540	↑	↑
9	↑	↑	↑	↑	↑
10	↑	↑	↑	↑	↑
11	↑	↑	↑	↑	↑
12	↑	↑	↑	↑	↑
13	↑	↑	↑	↑	↑
14	↑	↑	↑	↑	↑
15	↑	↑	↑	↑	↑
16	↑	↑	↑	↑	↑
17	↑	↑	↓	↑	↑
18	↑	↑	↓	↑	↑
19	↑	↑	540	↑	↑
20	↑	↑	520	↑	↑
21	↑	↑	520	↑	↑
22	↑	↑	540	↑	↑
23	↑	↑	540	↑	↑
24	↓	↓	540	↓	↓
25	6.0	1.2	540	75	40

*1 ipm = 0.423 mm/s.

**1 gph = 1.052 cm³/s.

†Surging in middle of cut.

††Redressed wheel to remove groove and reset.

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Appendix C

DATA FOR 6061-T6 ALUMINUM

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Table C-1. Height Measurements, 6061-T6 Aluminum,
0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.6508	0.6587	0.6553	0.0034
2	Entry	0.6568	0.6586	0.6553	0.0033
	Center	0.6566	0.6582	0.6553	0.0029
	Exit	0.6569	0.6585	0.6556	0.0029
1	Entry	0.6568	0.6586	0.6554	0.0032
	Center	0.6566	0.6582	0.6553	0.0029
	Exit	0.6571	0.6585	0.6559	0.0025
*1.000 inch = 25.400 mm.					

Table C-2. Parallelism Measurements, 6061-T6 Aluminum,
0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0011	0.00032	0.0020
2	Entry	0.0007	0.00030	0.0015
	Center	0.0006	0.00028	0.0014
	Exit	0.0009	0.00033	0.0018
1	Entry	0.0006	0.00026	0.0013
	Center	0.0005	0.00029	0.0013
	Exit	0.0006	0.00029	0.0014
*1.000 inch = 25.400 mm.				

Table C-3. Flatness Measurements, 6061-T6 Aluminum,
0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0005	0.00009	0.0008
2	Entry	0.0004	0.00011	0.0007
	Center	0.0003	0.00012	0.0006
	Exit	0.0004	0.00006	0.0006
1	Entry	0.0003	0.00009	0.0005
	Center	0.0003	0.00013	0.0006
	Exit	0.0003	0.00006	0.0004
*1.000 inch = 25.400 mm.				

Table C-4. Surface-Finish Measurements, 6061-T6 Aluminum,
0.001-Inch (0.025 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	41.4	3.8	31.3 to 51.4
Center	43.8	4.4	32.2 to 55.4
Exit	43.2	7.5	23.1 to 63.3
*1.000 inch = 25.400 mm.			

Table C-5. Height Measurements, 6061-T6 Aluminum, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.7097	0.7121	0.7071	0.0050
2	Entry	0.7100	0.7121	0.7074	0.0047
	Center	0.7094	0.7118	0.7071	0.0047
	Exit	0.7096	0.7116	0.7072	0.0044
1	Entry	0.7102	0.7121	0.7081	0.0040
	Center	0.7094	0.7117	0.7071	0.0046
	Exit	0.7098	0.7116	0.7078	0.0038
*1.000 inch = 25.400 mm.					

Table C-6. Parallelism Measurements, 6061-T6 Aluminum, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0017	0.00049	0.0030
2	Entry	0.0015	0.00046	0.0027
	Center	0.0007	0.00021	0.0012
	Exit	0.0009	0.00039	0.0020
1	Entry	0.0010	0.00031	0.0019
	Center	0.0006	0.00020	0.0011
	Exit	0.0006	0.00031	0.0015
*1.000 inch = 25.400 mm.				

Table C-7. Flatness Measurements, 6061-T6 Aluminum, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0013	0.00034	0.0022
2	Entry	0.0012	0.00043	0.0023
	Center	0.0006	0.00016	0.0010
	Exit	0.0010	0.00031	0.0019
1	Entry	0.0009	0.00030	0.0017
	Center	0.0005	0.00019	0.0009
	Exit	0.0007	0.00025	0.0013
*1.000 inch = 25.400 mm.				

Table C-8. Surface-Finish Measurements, 6061-T6 Aluminum, 0.005-Inch (0.127 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	69.6	15.8	28.2 to 111.1
Center	67.3	19.1	17.1 to 117.4
Exit	68.6	17.1	23.5 to 113.7
*1.000 inch = 25.400 mm.			

Table C-9. Height Measurements, 6061-T6 Aluminum, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.7238	0.7279	0.7211	0.0068
2	Entry	0.7242	0.7279	0.7202	0.0078
	Center	0.7231	0.7261	0.7201	0.0060
	Exit	0.7237	0.7266	0.7204	0.0061
1	Entry	0.7246	0.7279	0.7211	0.0068
	Center	0.7231	0.7260	0.7201	0.0059
	Exit	0.7240	0.7266	0.7210	0.0056
*1.000 inch = 25.400 mm.					

Table C-10. Parallelism Measurements, 6061-T6 Aluminum, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0033	0.00051	0.0046
2	Entry	0.0031	0.00050	0.0044
	Center	0.0013	0.00043	0.0024
	Exit	0.0019	0.00030	0.0027
1	Entry	0.0024	0.00045	0.0036
	Center	0.0012	0.00031	0.0020
	Exit	0.0015	0.00030	0.0023
*1.000 inch = 25.400 mm.				

Table C-11. Flatness Measurements, 6061-T6 Aluminum,
0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0031	0.00044	0.0042
2	Entry	0.0027	0.00037	0.0036
	Center	0.0016	0.00034	0.0025
	Exit	0.0026	0.00033	0.0035
1	Entry	0.0023	0.00036	0.0032
	Center	0.0012	0.00034	0.0021
	Exit	0.0020	0.00030	0.0028
*1.000 inch = 25.400 mm.				

Table C-12. Surface-Finish Measurements, 6061-T6 Aluminum,
0.010-Inch (0.254 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	40.2	4.3	29.0 to 51.4
Center	38.2	4.6	26.2 to 50.3
Exit	41.8	3.9	31.6 to 52.0
*1.000 inch = 25.400 mm.			

Table C-13. Height Measurements, 6061-T6 Aluminum,
0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}}$ $+k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}}$ $-k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit -Lower Limit (Inch)*
6	All	0.6322	0.6349	0.6307	0.0042
2	Entry	0.6326	0.6349	0.6308	0.0042
	Center	0.6318	0.6334	0.6308	0.0026
	Exit	0.6319	0.6335	0.6307	0.0028
1	Entry	0.6330	0.6349	0.6308	0.0042
	Center	0.6319	0.6333	0.6308	0.0025
	Exit	0.6319	0.6335	0.6307	0.0027
*1.000 inch = 25.400 mm.					

Table C-14. Parallelism Measurements, 6061-T6 Aluminum,
0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0027	0.00042	0.0038
2	Entry	0.0025	0.00036	0.0034
	Center	0.0012	0.00019	0.0017
	Exit	0.0013	0.00028	0.0020
1	Entry	0.0021	0.00030	0.0029
	Center	0.0011	0.00020	0.0017
	Exit	0.0011	0.00028	0.0019
*1.000 inch = 25.400 mm.				

Table C-15. Flatness Measurements, 6061-T6 Aluminum,
0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0024	0.00044	0.0036
2	Entry	0.0023	0.00038	0.0033
	Center	0.0015	0.00035	0.0024
	Exit	0.0018	0.00050	0.0031
1	Entry	0.0021	0.00039	0.0031
	Center	0.0013	0.00040	0.0023
	Exit	0.0013	0.00053	0.0028
*1.000 inch = 25.400 mm.				

Table C-16. Surface-Finish Measurements, 6061-T6 Aluminum,
0.020-Inch (0.508 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	50.9	10.0	24.7 to 77.1
Center	45.1	7.0	26.6 to 63.7
Exit	47.1	9.1	23.1 to 71.1
*1.000 inch = 25.400 mm.			

Table C-17. Height Measurements, 6061-T6 Aluminum, 0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.5706	0.5789	0.5660	0.0109
2	Entry	0.5711	0.5769	0.5662	0.0107
	Center	0.5699	0.5744	0.5660	0.0084
	Exit	0.5702	0.5743	0.5660	0.0083
1	Entry	0.5716	0.5769	0.5667	0.0101
	Center	0.5700	0.5743	0.5661	0.0082
	Exit	0.5704	0.5743	0.5658	0.0085
*1.000 inch = 25.400 mm.					

Table C-18. Parallelism Measurements, 6061-T6 Aluminum, 0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0049	0.00064	0.0066
2	Entry	0.0044	0.00063	0.0060
	Center	0.0022	0.00046	0.0034
	Exit	0.0030	0.00049	0.0043
1	Entry	0.0039	0.00054	0.0053
	Center	0.0020	0.00043	0.0031
	Exit	0.0030	0.00045	0.0042
*1.000 inch = 25.400 mm.				

Table C-19. Flatness Measurements, 6061-T6 Aluminum,
0.050-Inch (1.270 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0050	0.00037	0.0060
2	Entry	0.0047	0.00059	0.0062
	Center	0.0019	0.00081	0.0040
	Exit	0.0046	0.00048	0.0059
1	Entry	0.0047	0.00072	0.0066
	Center	0.0015	0.00084	0.0037
	Exit	0.0044	0.00054	0.0058
*1.000 inch = 25.400 mm.				

Table C-20. Surface-Finish Measurements, 6061-T6 Aluminum,
0.050-Inch (1.270 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	65.4	17.4	19.6 to 111.1
Center	68.9	31.0	0 to 150.4
Exit	66.3	20.0	13.6 to 119.0
*1.000 inch = 25.400 mm.			

Table C-21. Standard Deviations and Confidence Statements for Different Types of Cuts, 6061-T6 Aluminum

Depth-Of-Cut** (Inch)*	Minimum Part Tolerance**** 6-Inch Cut (Inch)*	Within-Part Standard Deviation (Confidence Statements***)		
		Total Bar, 6-Inch Cut† (Inch)*	Middle 4-Inch Cut†† (Inch)*	Middle 4-Inch Cut, Area B††† (Inch)*
0.050	0.0109	0.0014 (±0.0028)	0.0009 (±0.0019)	0.0004 (±0.0010)
0.020	0.0042	0.0008 (±0.0016)	0.0005 (±0.0011)	0.0003 (±0.0006)
0.010	0.0068	0.0009 (±0.0019)	0.0006 (±0.0012)	0.0004 (±0.0009)
0.005	0.0050	0.0005 (±0.0010)	0.0003 (±0.0007)	0.0003 (±0.0007)
0.001	0.0034	0.0003 (±0.0007)	0.0003 (±0.0006)	0.0002 (±0.0004)
<p>*1.000 inch = 25.400 mm.</p> <p>**The lengths and areas of cuts are shown in Figure 5.</p> <p>***The value listed in parentheses is the width of the tolerance interval within which 95 percent of the readings will fall 95 percent of the time.</p> <p>****Minimum Part Tolerance = The difference between the upper and lower 95-percent tolerance limits. This estimate contains both part-to-part and within-part variation.</p> <p>†Total Bar, 6-Inch Cut = The within-part variation using all 21 measurements shown in Figure 5.</p> <p>††Middle 4-Inch Cut = The within-part variation using the measurements in the middle 4-inch section shown in Figure 5. This has the entry and exit conditions removed.</p> <p>†††Middle 4-Inch Cut, Area B = The within-part variation using only those measurements in Area B of the middle 4 inches of each bar. This removes some variation across the bar perpendicular to the travel of the grinding wheel.</p>				

Table C-22. Minimum Part Tolerances, 6061-T6 Aluminum, 0.010- and 0.050-Inch (0.254 and 1.270 mm) Depths-Of-Cut

Bar Length Measured (Inch)*	0.010-Inch (0.254 mm) Depth-Of-Cut**			0.050-Inch (1.270 mm) Depth-Of-Cut**		
	Number of Bars	Total Process (Inch)*	Within-Part (Inch)*	Number of Bars	Total Process (Inch)*	Within-Part (Inch)*
6	25	0.0068	0.0038	25	0.0109	0.0056
	14	0.0056	0.0040	15	0.0096	0.0058
	11	0.0066	0.0036	10	0.0096	0.0056
2, Center	25	0.0060		25	0.0084	
	14	0.0039		15	0.0067	
	11	0.0041		10	0.0070	
1, Center	25	0.0059		25	0.0082	
	14	0.0038		15	0.0064	
	11	0.0040		10	0.0070	
4, Middle	25		0.0023	25		0.0038
	14		0.0024	15		0.0037
	11		0.0024	10		0.0041
4, Middle, Area B	25		0.0017	25		0.0019
	14		0.0019	15		0.0020
	11		0.0017	10		0.0021
<p>*1.000 inch = 25.400 mm.</p> <p>**Values given are estimates below which 95 percent of the readings will fall 95 percent of the time.</p>

Figure C-1. Height-Measurement Distribution for 6061-T6 Aluminum, 0.001-Inch (0.025 mm) Depth-Of-Cut

Figure C-2. Height-Measurement Distribution for 6061-T6 Aluminum, 0.005-Inch (0.127 mm) Depth-Of-Cut

Figure C-4. Height-Measurement Distribution for 6061-T6 Aluminum, 0.020-Inch (0.508 mm) Depth-Of-Cut

6061-T6 .050 IN. CUT

Figure C-5. Height-Measurement Distribution for 6061-T6 Aluminum, 0.050-Inch (1.270 mm) Depth-Of-Cut

Table C-23. Process Variables, 6061-T6 Aluminum, 0.001-Inch
(0.025 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 1800 rpm Set 0.657 inch (16.688 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	2.5	30	80-100	75	20
2	↑	↑	100	↑	18
3	↑	↑	80	↑	17
4	↑	↑	80	↑	18
5	↑	↑	70	↑	18
6	↑	↑	160	↑	18
7	↑	↑	70	↑	16
8	↑	↑	60	↑	18
9	↑	↑	100	↑	18
10	↑	↑	70	↑	18
11	↑	↑	80	↑	16
12	↑	↑	80	↑	16
13	↑	↑	70	↑	16
14	↑	↑	60	↑	16
15	↑	↑	60	↑	16
16	↑	↑	60	↑	16
17	↑	↑	80	↑	16
18	↑	↑	60	↑	18
19	↑	↑	120	↑	18
20	↑	↑	100	↑	18
21	↑	↑	100	↑	18
22	↑	↑	60	↑	16
23	↓	↓	80	↓	16
24	2.5	30	80	75	16
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

Table C-24. Process Variables, 6061-T6 Aluminum, 0.005-Inch
(0.127 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 1800 rpm Set 0.712 inch (18.085 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	5.5	16.0	300	75	20
2	5.5	20.0	400	↑	↑
3	5.5	16.0	260	↑	↑
4	4.0	↑	220	↑	↑
5	2.5	↑	200	↑	↑
6	↑	↑	200	↑	↑
7	↑	↑	200	↑	↑
8	↑	↑	200	↑	↑
9	↑	↑	200	↑	↑
10	↑	↑	180	↑	↑
11	↑	↑	180	↑	↑
12	↑	↑	160	↑	↑
13	↑	↑	↑	↑	↑
14	↑	↑	↑	↑	↑
15	↑	↑	↑	↑	↑
16	↑	↑	↑	↑	↑
17	↑	↑	↓	↑	↑
18	↑	↑	160	↑	↑
19	↑	↑	140	↑	↑
20	↑	↑	↑	↑	↑
21	↑	↑	↑	↑	↑
22	↑	↑	↑	↑	↑
23	↑	↑	↑	↑	↑
24	↑	↑	↑	↑	↑
25	2.5	16.0	140	75	20
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

Table C-25. Process Variables, 6061-T6 Aluminum 0.010-Inch
(0.254 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration					
Wheel Speed, 3600 rpm					
Set 0.725 inch (18.415 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	6.0	16.0	420	75	24
2	6.0	16.0	420		
3	6.0	16.0	400		
4	6.0	16.0	400		
5	6.0	14.0	380		
6	5.5	16.0	380		
7	6.0	↑	400		
8	↑		400		
9			400		
10			380		
11			380		
12			350		
13†			380		
14††			400		
15†††			300		
16			300		
17			300		
18			360		
19			380		
20			380		
21			360		
22††			360		
23			360		
24			320	75	24
25	6.0	16.0	340		

*1 ipm = 0.423 mm/s.

**1 gph = 1.052 cm³/s.

†Surging at end.

††Stopped in cycle.

†††Change in parts.

Table C-26. Process Variables, 6061-T6 Aluminum, 0.020-Inch
(0.508 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.636 inch (16.154 mm)					
Part Number†	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	6.0	8.0	420	75	26
2	↑	↑	420	↑	26
3	↑	↑	410	↑	24
4	↑	↑	410	↑	24
5	↑	↑	400	↑	24
6	↑	↑	400	↑	26
7	↑	↑	390	↑	24
8	↑	↑	390	↑	24
9	↑	↑	390	↑	24
10	↑	↑	390	↑	24
11	↑	↑	390	↑	24
12	↑	↑	390	↑	24
13	↑	↑	390	↑	24
14	↑	↑	380	↑	26
15	↑	↑	370	↑	26
16	↑	↑	360	↑	26
17	↑	↑	360	↑	24
18	↑	↑	360	↑	24
19	↑	↑	370	↑	24
20	↑	↑	360	↑	24
21	↑	↑	360	↑	24
22	↑	↑	360	↑	24
23	↑	↑	360	↑	24
24	↓	↓	360	↓	24
25	6.0	8.0	360	75	24
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s. †Spindle load at 4A on grinding, all parts.					

Table C-27. Process Variables, 6061-T6 Aluminum, 0.050-Inch
(1.270 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.578 inch (14.681 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	6	3.6	500	75	30
2	↑	↑	500	↑	30
3†	↑	↑	500	↑	40
4	↓	↑	500	↑	38
5	↓	↑	520	↑	40
6††	6	↑	500	↑	38
7	6.5	↑	500	↑	30
8	6	↑	500	↑	38
9	↑	↑	500	↑	38
10	↑	↑	500	↑	38
11	↑	↑	500	↑	38
12	↑	↑	500	↑	38
13	↑	↑	480	↑	38
14	↑	↑	480	↑	38
15	↑	↑	480	↑	40
16	↑	↑	480	↑	40
17	↑	↑	480	↑	40
18	↑	↑	480	↑	40
19	↑	↑	480	↑	40
20	↑	↑	480	↑	40
21	↑	↑	480	↑	40
22	↑	↑	460	↑	40
23	↑	↑	460	↑	40
24	↓	↓	460	↓	40
25	6	3.6	460	75	40
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s. †Loosened nozzle fluttering. ††Sludge buildup.					

Appendix D

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Table D-1. Height Measurements, Beryllium Copper, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.7027	0.7046	0.7007	0.0039
2	Entry	0.7027	0.7046	0.7008	0.0038
	Center	0.7026	0.7043	0.7008	0.0034
	Exit	0.7027	0.7042	0.7008	0.0034
1	Entry	0.7028	0.7046	0.7010	0.0036
	Center	0.7026	0.7043	0.7009	0.0034
	Exit	0.7028	0.7042	0.7011	0.0032
*1.000 inch = 25.400 mm.					

Table D-2. Parallelism Measurements, Beryllium Copper, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0010	0.00059	0.0026
2	Entry	0.0006	0.00034	0.0018
	Center	0.0006	0.00034	0.0015
	Exit	0.0007	0.00033	0.0016
1	Entry	0.0005	0.00040	0.0015
	Center	0.0005	0.00031	0.0013
	Exit	0.0006	0.00029	0.0014
*1.00 inch = 25.400 mm.				

Table D-3. Flatness Measurements, Beryllium Copper, 0.001-Inch (0.025 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0005	0.00023	0.0011
2	Entry	0.0004	0.00016	0.0008
	Center	0.0003	0.00022	0.0009
	Exit	0.0005	0.00022	0.0011
1	Entry	0.0003	0.00009	0.0005
	Center	0.0003	0.00019	0.0008
	Exit	0.0004	0.00019	0.0009
*1.000 inch = 25.400 mm.				

Table D-4. Surface-Finish Measurements, Beryllium Copper, 0.001-Inch (0.025 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	58.96	18.39	9.8 to 108.1
Center	57.96	14.30	19.7 to 96.2
Exit	54.57	9.27	29.8 to 79.3
*1.000 inch = 25.400 mm.			

Table D-5. Height Measurements, Beryllium Copper, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.7126	0.7145	0.7095	0.0049
2	Entry	0.7127	0.7148	0.7098	0.0050
	Center	0.7123	0.7139	0.7098	0.0039
	Exit	0.7125	0.7139	0.7102	0.0029
1	Entry	0.7129	0.7148	0.7100	0.0047
	Center	0.7123	0.7139	0.7099	0.0040
	Exit	0.7126	0.7139	0.7106	0.0033
*1.000 inch = 25.400 mm.					

Table D-6. Parallelism Measurements, Beryllium Copper, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0015	0.00079	0.0033
2	Entry	0.0012	0.00060	0.0028
	Center	0.0008	0.00065	0.0025
	Exit	0.0009	0.00068	0.0027
1	Entry	0.0009	0.00054	0.0023
	Center	0.0006	0.00052	0.0020
	Exit	0.0007	0.00052	0.0020
*1.000 inch = 25.400 mm.				

Table D-7. Flatness Measurements, Beryllium Copper, 0.005-Inch (0.127 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0012	0.00090	0.0035
2	Entry	0.0010	0.00082	0.0032
	Center	0.0006	0.00083	0.0028
	Exit	0.0010	0.00086	0.0033
1	Entry	0.0008	0.00083	0.0030
	Center	0.0005	0.00080	0.0026
	Exit	0.0008	0.00087	0.0031
*1.000 inch = 25.400 mm.				

Table D-8. Surface-Finish Measurements, Beryllium Copper, 0.005-Inch (0.127 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	63.0	11.9	35.8 to 90.3
Center	61.8	8.7	42.0 to 81.7
Exit	62.4	11.8	35.4 to 89.4
*1.000 inch = 25.400 mm.			

Table D-9. Height Measurements, Beryllium Copper, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.7253	0.7275	0.7231	0.0044
2	Entry	0.7255	0.7276	0.7232	0.0043
	Center	0.7248	0.7265	0.7230	0.0035
	Exit	0.7253	0.7274	0.7233	0.0041
1	Entry	0.7257	0.7264	0.7250	0.0038
	Center	0.7248	0.7251	0.7244	0.0035
	Exit	0.7256	0.7264	0.7247	0.0029
*1.000 inch = 25.400 mm.					

Table D-10. Parallelism Measurements, Beryllium Copper, 0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0021	0.00031	0.0028
2	Entry	0.0018	0.00033	0.0025
	Center	0.0008	0.00020	0.0012
	Exit	0.0019	0.00027	0.0025
1	Entry	0.0014	0.00032	0.0021
	Center	0.0007	0.00020	0.0011
	Exit	0.0017	0.00027	0.0023
*1.000 inch = 25.400 mm.				

Table D-11. Flatness Measurements, Beryllium Copper,
0.010-Inch (0.254 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit -0 (Inch)*
6	All	0.0022	0.00027	0.0029
2	Entry	0.0019	0.00029	0.0026
	Center	0.0008	0.00018	0.0012
	Exit	0.0020	0.00030	0.0027
1	Entry	0.0016	0.00026	0.0022
	Center	0.0007	0.00013	0.0010
	Exit	0.0018	0.00024	0.0024
*1.000 inch = 25.400 mm.				

Table D-12. Surface-Finish Measurements, Beryllium Copper,
0.010-Inch (0.254 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	81.6	10.6	57.4 to 105.8
Center	83.5	12.8	54.2 to 112.8
Exit	81.6	11.3	55.7 to 107.4
*1.000 inch = 25.400 mm.			

Table D-13. Height Measurements, Beryllium Copper, 0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average Part Size (Inch)*	Upper Limit $\bar{X}_{\text{High}} + k s_{\text{High}}$ (Inch)*	Lower Limit $\bar{X}_{\text{Low}} - k s_{\text{Low}}$ (Inch)*	Minimum Tolerance Upper Limit - Lower Limit (Inch)*
6	All	0.6790	0.6810	0.6772	0.0038
2	Entry	0.6793	0.6810	0.6776	0.0034
	Center	0.6791	0.6807	0.6776	0.0031
	Exit	0.6787	0.6804	0.6771	0.0033
1	Entry	0.6794	0.6811	0.6777	0.0034
	Center	0.6791	0.6806	0.6776	0.0030
	Exit	0.6786	0.6803	0.6771	0.0032
*1.000 inch = 25.400 mm.					

Table D-14. Parallelism Measurements, Beryllium Copper, 0.020-Inch (0.508 mm) Depth-Of-Cut

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit - 0 (Inch)*
6	All	0.0018	0.00041	0.0029
2	Entry	0.0012	0.00027	0.0019
	Center	0.0011	0.00024	0.0017
	Exit	0.0011	0.00027	0.0019
1	Entry	0.0010	0.00025	0.0016
	Center	0.0009	0.00021	0.0015
	Exit	0.0008	0.00022	0.0014
*1.000 inch = 25.400 mm.				

Table D-15. Flatness Measurements, Beryllium Copper,
0.020-Inch (0.508 mm) Depth-Of-Out

Bar Length Measured (Inch)*	Area of Block	Average (Inch)*	Standard Deviation	Minimum Tolerance Upper Limit (Inch)*
6	All	0.0012	0.00038	0.0022
2	Entry	0.0010	0.00014	0.0013
	Center	0.0009	0.00019	0.0014
	Exit	0.0009	0.00030	0.0017
1	Entry	0.0009	0.00014	0.0013
	Center	0.0008	0.00014	0.0012
	Exit	0.0008	0.00031	0.0016
*1.000 inch = 25.400 mm.				

Table D-16. Surface-Finish Measurements, Beryllium Copper,
0.020-Inch (0.508 mm) Depth-Of-Cut

Position on 6-Inch* Bar	Average (Microinches, AA)*	Standard Deviation	95-95 Confidence Interval (Microinches, AA)*
Entry	112.3	19.9	59.6 to 165.0
Center	111.1	21.3	54.8 to 167.5
Exit	108.9	24.0	45.4 to 172.4
*1.000 inch = 25.400 mm.			

Table D-17. Standard Deviations and Confidence Statements for Different Types of Cuts, Beryllium Copper

Depth-Of-Cut** (Inch)*	Minimum Part Tolerance**** 6-Inch Cut (Inch)*	Within-Part Standard Deviation (Confidence Statements***)		
		Total Bar, 6-Inch Cut† (Inch)*	Middle 4-Inch Cut†† (Inch)*	Middle 4-Inch Cut, Area B††† (Inch)*
0.020	0.0038	0.0005 (±0.0011)	0.0005 (±0.0009)	0.0003 (±0.0006)
0.010	0.0044	0.0007 (±0.0014)	0.0004 (±0.0008)	0.0003 (±0.0007)
0.005	0.0049	0.0005 (±0.0010)	0.0004 (±0.0008)	0.0003 (±0.0006)
0.001	0.0039	0.0003 (±0.0006)	0.0003 (±0.0006)	0.0002 (±0.0005)
<p>*1.000 inch = 25.400 mm.</p> <p>**The lengths and areas of cuts are shown in Figure 5.</p> <p>***The value listed in parentheses is the width of the tolerance interval within which 95 percent of the readings will fall 95 percent of the time.</p> <p>****Minimum Part Tolerance = The difference between the upper and lower 95-percent tolerance limits. This estimate contains both part-to-part and within-part variation.</p> <p>†Total Bar, 6-Inch Cut = The within-part variation using all 21 measurements shown in Figure 5.</p> <p>††Middle 4-Inch Cut = The within-part variation using the measurements in the middle 4-inch section shown in Figure 5. This has the entry and exit conditions removed.</p> <p>†††Middle 4-Inch Cut, Area B = The within-part variation using only those measurements in Area B of the middle 4 inches of each bar. This removes some variation across the bar perpendicular to the travel of the grinding wheel.</p>

Figure D-1. Height-Measurement Distribution for Beryllium Copper, 0.001-Inch (0.025 mm) Depth-Of-Cut

Figure D-3. Height-Measurement Distribution for Beryllium Copper, 0.010-Inch (0.254 mm) Depth-Of-Cut

Table D-18. Process Variables, Beryllium Copper, 0.001-Inch
(0.025 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.702 inch (17.831 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	4.0	40.0	220	75	10
2	↑	35.0	200	↑	10
3	↑	30.0	120	↑	10
4	↑	↑	160	↑	10
5	↑	↑	200	↑	12
6	↑	↑	120	↑	14
7	↑	↑	120	↑	12
8	↑	↑	120	↑	↑
9	↑	↑	100	↑	↑
10	↑	↑	100	↑	↑
11	↑	↑	100	↑	↑
12	↑	↑	100	↑	↑
13	↑	↑	100	↑	↑
14	↑	↑	60	↑	↑
15	↑	↑	60	↑	↑
16	↑	↑	80	↑	↑
17	↑	↑	60	↑	↑
18	↑	↑	60	↑	↑
19	↑	↑	60	↑	↑
20	↑	↑	60	↑	↑
21	↑	↑	60	↑	↑
22	↑	↑	60	↑	↑
23	4.0	30.0	60	75	12

*1 ipm = 0.423 mm/s.
 **1 gph = 1.052 cm³/s.

Table D-19. Process Variables, Beryllium Copper, 0.005-Inch
(0.127 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.714 inch (18.136 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
1	5.0	13.0	450	75	22
2	6.0	13.0	340	75	↑
3	5.0	10.0	300	0	↑
4	↑	↑	280	75	↑
5	↑	↑	200	75	↑
6	↑	↑	200	50	↑
7	↑	↑	240	↑	↑
8	↑	↑	200	↑	↑
9	↑	↑	200	↑	↑
10	↑	↑	150	↑	↑
11	↑	↑	200	↑	↑
12	↑	↑	220	↑	↑
13	↑	↑	200	↑	↑
14	↑	↑	200	↑	↑
15	↑	↑	200	↑	↑
16	↑	↑	180	↑	↑
17	↑	↑	180	↑	↑
18	↑	↑	180	↑	↑
19	↑	↑	180	↑	↑
20	↑	↑	180	↑	↑
21	↑	↑	180	↑	↑
22	↑	↑	200	↑	↑
23	↑	↑	180	↑	↑
24	↓	↓	160	↓	↓
25	5.0	10.0	200	50	22
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

Table D-20. Process Variables, Beryllium Copper, 0.010-Inch
(0.254 mm) Depth-Of-Cut.

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.725 inch (18.415 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)†	Percent Spark Suppression	Flow Rate (gph)**
1	6.0	7.5		75	28
2	↑	↑		↑	↑
3					
4					
5					
6					
7					
8					
9	↓				
10	6.0				
11††	5.5				
12	↑				
13					
14††					
15††					
16††					
17					
18					
19					
20					
21		↓			
22		7.5			
23††		7.0			
24		7.0		↓	
25	5.5	7.0		75	28
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s. †Current values not recorded by operator. ††Excessive arcing.					

Table D-21. Process Variables, Beryllium Copper, 0.020-Inch
(0.508 mm) Depth-Of-Cut

Conditions: Electrolyte, Anocut Solution 90, 2:1 Concentration Wheel Speed, 3600 rpm Set 0.681 inch (17.297 mm)					
Part Number	Voltage (V)	Feed Rate (ipm)*	Current (A)	Percent Spark Suppression	Flow Rate (gph)**
Setup	6	4.0	200	75	18
1	↑	4.0	200	↑	18
2		4.0	220		18
3		4.0	220		20
4		3.8	220		20
5		4.0	260		18
6		↑	↑		↑
7			↑		
8			↓		
9					
10			260		
11			240		
12			240		
13			250		
14			240		18
15			240		20
16			260		↑
17			280		
18			280		
19			280		
20			260		↓
21			260		
22			260		
23	↓	↓	260	↓	↓
24	6	4.0	260	75	20
*1 ipm = 0.423 mm/s. **1 gph = 1.052 cm ³ /s.					

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