United States
Department of
Agriculture

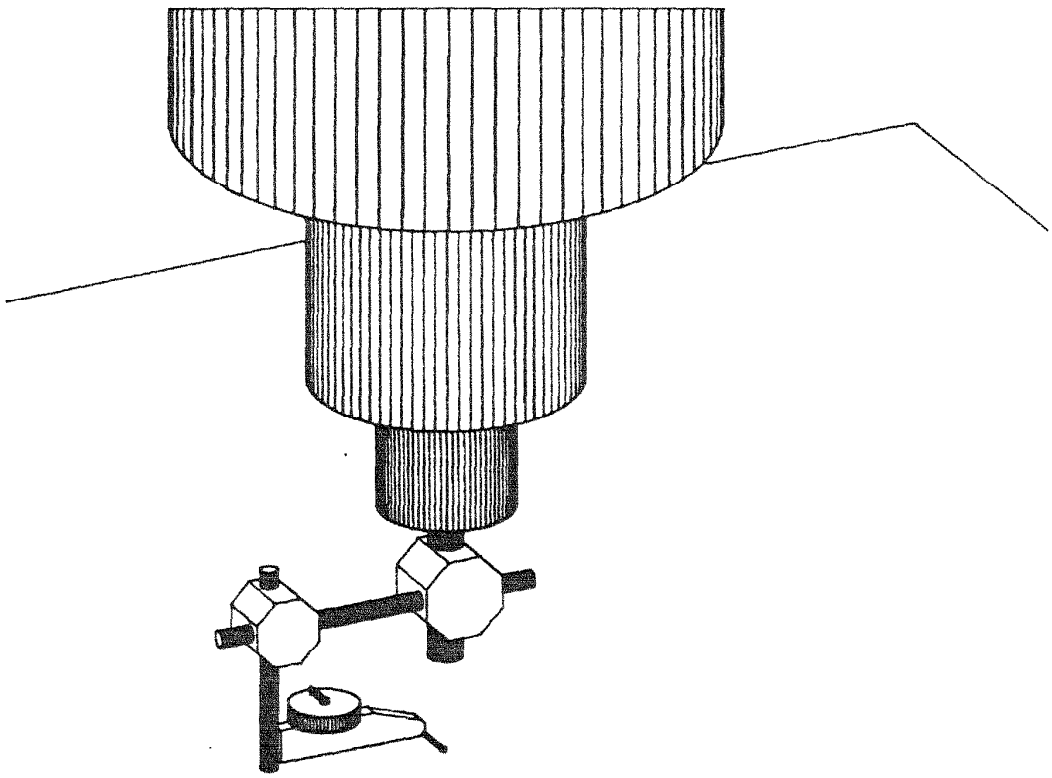
Forest Service

**Northeastern Forest
Experiment Station**

General Technical
Report NE-201

CNC Router Evaluation Procedures

Edward L. Adams
Everette D. Rast
Neal D. Bennett



Abstract

The lack of procedures for evaluating computer numerically controlled (CNC) routers makes it difficult for the buyers and sellers of these machines to communicate when trying to determine the best machine for a given production situation. This report provides procedures to evaluate specific machine capabilities as related to production situations. By using the procedures, both the buyers and the sellers will know how the evaluations were made and what the results mean.

The Authors

EDWARD L. ADAMS is a forest products technologist with the Northeastern Forest Experiment Station's Forestry Sciences Laboratory at Princeton, West Virginia. He received a B.S. degree in forest management and an M.S. degree in forest mensuration at West Virginia University. He worked for the USDA Forest Service in Oregon from 1960 to 1963 and joined the Northeastern Station in 1968. He retired in January 1995.

EVERETTE D. RAST is a forest products technologist with the Northeastern Forest Experiment Station's Forestry Sciences Laboratory at Princeton, West Virginia. He received a B.S. degree in forestry from the University of Missouri in 1960 and an M.S. degree in agricultural economics from The Ohio State University in 1970. He joined the USDA Forest Service in 1960 as a forester on the Mendocino National Forest and transferred to the Northeastern Forest Experiment Station, Delaware, Ohio, in 1966. From 1966 to 1987, he was with the log and tree grade project and then the management and utilization alternatives for nonindustrial private forests. In 1987 he was transferred to the Advanced Hardwood Processing and Technical Resource Center.

NEAL D. BENNETT is a general engineer with the Northeastern Forest Experiment Station's Forestry Sciences Laboratory at Princeton, West Virginia. He received a B.S. degree in biology from Concord College, Athens, West Virginia, in 1983 and an A.S. degree in mechanical engineering from Bluefield State College, Bluefield, West Virginia, in 1992. He joined the USDA Forest Service in 1988.

Manuscript received for publication 30 June 1994

USDA FOREST SERVICE
5 RADNOR CORP CTR STE 200
PO BOX 6775
RADNOR PA 19087-8775

June 1995

Contents

Appendix

Introduction

Managers of furniture and cabinet manufacturing plants have the difficult task of purchasing the best computer numerical controlled (CNC) machines for particular situations. They need machines that will not only perform present tasks but also possible future tasks. Much of the information needed to compare machines is not available in the sales literature. And, because procedures are not available for evaluating the machines, managers find it difficult to communicate with machine dealers in their search for the best machine for the job.

Machine dealers also are concerned about this problem. If a dealer sells a brand "A" CNC router and it does not meet a plant manager's needs, that manager is going to be upset. And, he will probably tell others about his dissatisfaction with the machine. The negative advertising produced by this situation may cause potential buyers to avoid brand "A" when that machine may be exactly what their production situation requires. Thus, both the seller and potential buyers of the brand "A" machine lose.

This paper provides procedures for evaluating CNC routers that can be used to help solve the communication problem between buyers and sellers. By using the procedures, these individuals can, in effect, speak the same language as they try to match machines to production situations. It is not necessary to use all of the procedures when evaluating a router. Only those needed to provide information that is critical to the production situation need to be used. For example, if tool positioning accuracy is only critical in the Z-axis, the only procedures needed are those that measure the ability of the router to position the tool in this axis. The procedures for the X-axis and the Y-axis are not necessary. Also, the procedures do not include recommended tolerances. These values will depend on the individual production situations and must be determined by the machine user.

It should be emphasized that we are not attempting to set evaluation standards for the industry. The purpose of this paper is to provide an objective means for the buyers and sellers of CNC routers to discuss needs in terms of accuracy, repeatability, and suitability for particular production situations. However, if the secondary processing industry decides to develop standards in the future, the procedures presented in this paper could provide a good base to start from.

Following are discussions of the possible uses, the evaluation methods, and the sample results for each evaluation procedure. The procedures are divided into three categories: (1) basic evaluations, (2) spindle/table travel evaluations, and (3) machining evaluations.

List of Abbreviations

CNC	-	computer numerically controlled
CPM	-	cycles per minute
deg	-	degrees of angular measurement
E	-	volts
F	-	Fahrenheit
FLP	-	full load power (kilowatts) requirement of an electric motor
G&M code	-	more or less standard computer code for controlling computer numerically controlled equipment
hp	-	horsepower
Hz	-	hertz (one cycle per second)
I	-	electric current in amperes
IPM	-	inches per minute
kW	-	1000 watts
MDF	-	medium density fiberboard
min	-	minutes of angular measurement
mm	-	millimeters
PC	-	microcomputer
pf	-	power factor (electric motors)
RPM	-	revolutions per minute
sec	-	seconds of angular measurement
TGP	-	turned-ground-polished
thou	-	thousandths of an inch

APPENDIX A.1

Figure A.1.1. is an example of positioning programs (G&M code) that are required by many of the laser measurement procedures for evaluating router spindle/table movements.

LINEAR POSITIONING IN X-AXIS

STANDARD UNITS

```
O0001;
M98 P50002;
M30;
O0002;
G20;
G91 G1 F100;
M98 P350003;
X1;
X-1;
G4 X5;
M98 P350004;
X-1;
X1;
G4 X5;
M99;
O0003;
X2;
G4 X5;
M99;
O0004;
X-2;
G4 X5;
M99;
```

METRIC UNITS

```
O0005;
M98 P50006;
M30;
O0006;
G21;
G91 G1 F2540;
M98 P350007;
X25;
X-25;
G4 X5;
M98 P350008;
M99;
O0007
X50;
G4 X5;
M99;
O0008;
X-50;
G4 X5;
M99;
```

LINEAR POSITIONING IN Y-AXIS

STANDARD UNITS

```
O0009;
M98 P50010
M30;
O0010;
G20;
G91 G1 F100;
M98 P160011;
Y1;
Y-1;
G4 X5;
M98 P160012
Y-1;
Y1;
G4 X5;
M99;
O0011;
Y2;
G4 X5;
M99;
O00012;
Y-2;
G4 X5;
M99;
```

METRIC UNITS

```
O0013;
M98 P50014;
M30;
O0014;
G21;
G91 G1 F2540;
M98 P160015;
Y25;
Y-25;
G4 X5;
M98 P160016;
M99;
O0015;
Y50;
G4 X5;
M99;
O0016
Y-50;
G4 X5;
M99;
```

LINEAR POSITIONING IN Z-AXIS

STANDARD UNITS

```
O0017;
M98 P50018;
M30;
O0018;
G20;
G91 G1 F25;
M98 P210019;
Z.25;
Z-.25;
G4 X5;
M98 P210020;
Z-.25;
Z.25
G4 X5;
M99;
O0019;
Z.25;
G4 X5;
M99;
O0020
Z-.25;
G4 X5;
M99;
```

METRIC UNITS

```
O0021;
M98 P50022;
M30;
O0022;
G21;
G91 G1 F762;
M98 P210023;
Z6;
Z-6;
G4 X5;
M98 P210024;
M99;
O0023;
Z6;
G4 X5;
M99;
O0024;
Z-6;
G4 X5;
M99;
```

Figure A.1.1—Programs (G&M codes) for linear positioning evaluation in the X-axis, Y-axis, and Z-axis.

APPENDIX A.2

Figure A.2.1. is an example of programs (G&M code) that are required when measuring the router spindle/table feed rates with the laser measurement system.

SAMPLE FEED RATE PROGRAMS

(X-AXIS)

```
O0040;
G90G1F50X0;
M98 P0041;
F100;
M98 P0041;
F150;
M98 P0041;
F200;
M98 P0041;
F250;
M98 P0041;
F300;
M98 P0041;
F350;
M98 P0041;
F400;
M98 P0041;
F450;
M98 P0041;
F500;
M98 P0041;
F550;
M98 P0041;
F600;
M98 P0041;
M30;

O0041;
X72;
G4X2;
F200;
X0;
G4X2;
M99;
```

(Y-AXIS)

```
O0042;
G90G1F50Y0;
M98 P0043;
F100;
M98 P0043;
F150;
M98 P0043;
F200;
M98 P0043;
F250;
M98 P0043;
F300;
M98 P0043;
F350;
M98 P0043;
F400;
M98 P0043;
F450;
M98 P0043;
F500;
M98 P0043;
F550;
M98 P0043;
F600;
M98 P0043;
M30;

O0043;
Y31;
G4X2;
F200;
Y0;
G4X2;
M99;
```

(Z-AXIS)

```
O0044;
G90G1F50Z0;
M98 P0045;
F100;
M98 P0045;
F150;
M98 P0045;
F200;
M98 P0045;
F250;
M98 P0045;
F300;
M98 P0045;
F350;
M98 P0045;
F400;
M30;

O0045;
Z6;
G4X2;
F100;
Z0;
G4X2;
M99;
```

Figure A.2.1—Programs (G&M codes) for feed rate evaluations in the X-axis, Y-axis, and Z-axis.

APPENDIX A.3

Program for Circles Cut in Acrylic Sheets
(Accuracy)

Following are procedures for developing a G&M program for determining the accuracy of cutting circles in acrylic sheets. Figure A.3.1 provides information to assist in this development. Figure A.3.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.3.3 shows only the actual cuts made in the material. Use the following steps to develop the required program in an absolute mode. Although feed rates are not discussed in these steps, they must be included in the program so they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

Make a positioning move to Point A (X0.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the left slot. Move 0.5 inch to the right at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move for 1 inch. Then raise the tool to 0.25 inch above the material and move 0.5 inch to the right at 0° to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X11.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the right slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 1.

Step 4

Make a positioning move to Point C (X7.0,Y13.5) in line with and 0.5 inch from the upper end of the vertical line that represents the upper slot. Move down 0.5 inch at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move down for 1 inch. Then raise the tool to 0.25 inch above the material and move down 0.5 inch at 0° to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X7.0,Y2.5) in line with and 0.5 inch above the upper end of the vertical line representing the lower slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 4.

Step 6

Make a positioning move to Point E (X11.1875,Y7.0) at the right edge of the circle with a diameter of 8.375 inches. Lower the tool to a depth of -0.1875 inch and make a 360° move (roughing cut) in a counter clockwise direction without cutter compensation.

Step 7

Raise the tool to 0.25 inch above the material and make a positioning move to Point F (X3.6599,Y4.6108) to start the finish cut of the 8-inch circle. From this point, make a right cutter compensation move to point (X4.0429,Y2.2894). Next, lower the tool to -0.1562 inch and make a lead-in cut in a clockwise arc with a radius of 2 inches to point (X4.1716,Y4.1716). Then make the 360° counter clockwise finish cut to the 8-inch circle. From the finish point of the circle, make a lead-out cut in a clockwise arc with a radius of 2 inches to point (X4.2894,Y4.0429). Raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to point (X4.6108,Y3.6599).

Step 8

Make a positioning move to Point G (X8.1875,Y7.0) at the right edge of the circle with a diameter of 2.375 inches. Lower the tool to a depth of -0.1875 inch and make a 360° move (roughing cut) in a counter clockwise direction without cutter compensation.

Step 9

Raise the tool to 0.25 inch above the material and make a positioning move to Point H (X5.7812,Y6.7322) to start the finish cut of the 2-inch circle. From this point, make a right cutter compensation move to point (X6.1643,Y6.4108). Next, lower the tool to -0.1562 inch and make a lead-in cut in a clockwise arc with a radius of 2 inches to point (X6.2929,Y6.2929). Then make the 360° counter clockwise finish cut to the 2-inch circle. From the finish point of the circle, make a lead-out cut in a clockwise arc with a radius of 2 inches to point (X6.4108,Y6.1643). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to point (X6.7322,Y5.7812). End with a move to machine reference zero.

Figure A.3.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

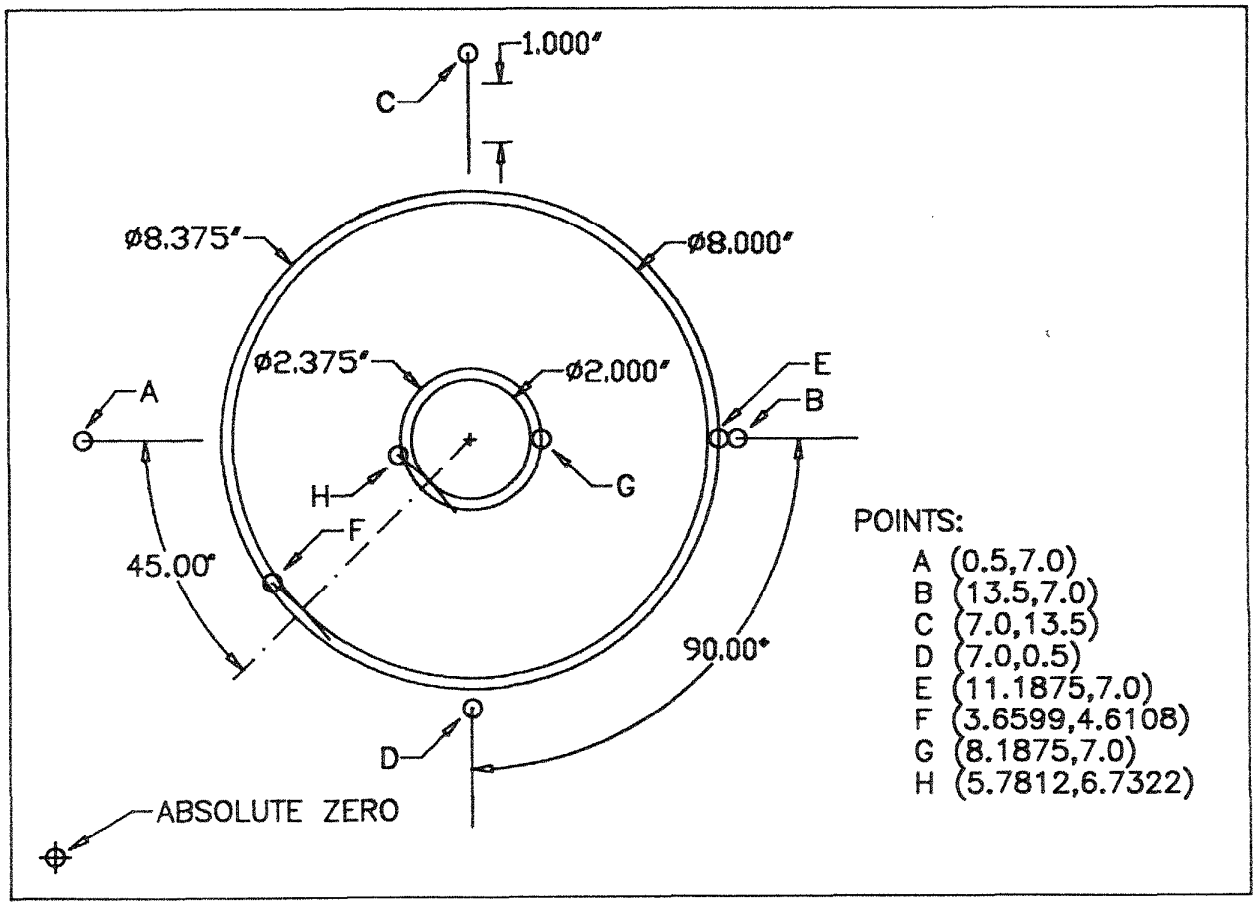


Figure A.3.1—Drawing showing information for developing a program (G&M code) needed to make circle accuracy cuts in acrylic sheets.

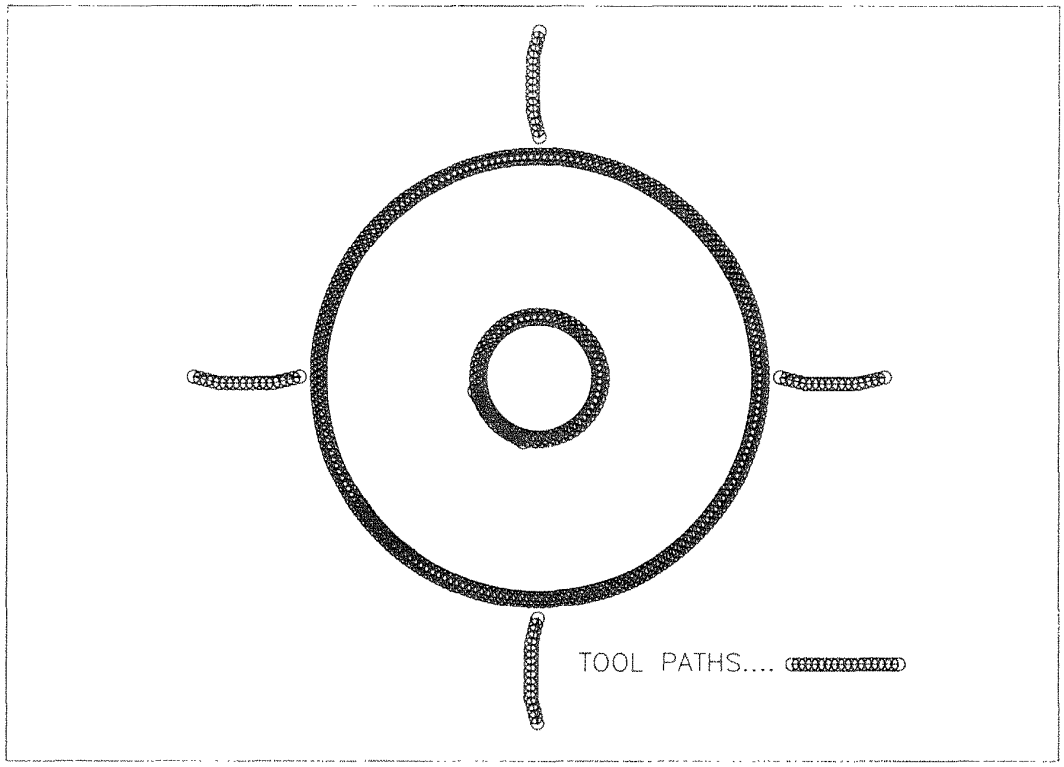


Figure A.3.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch circles in an acrylic sheet for accuracy evaluation.

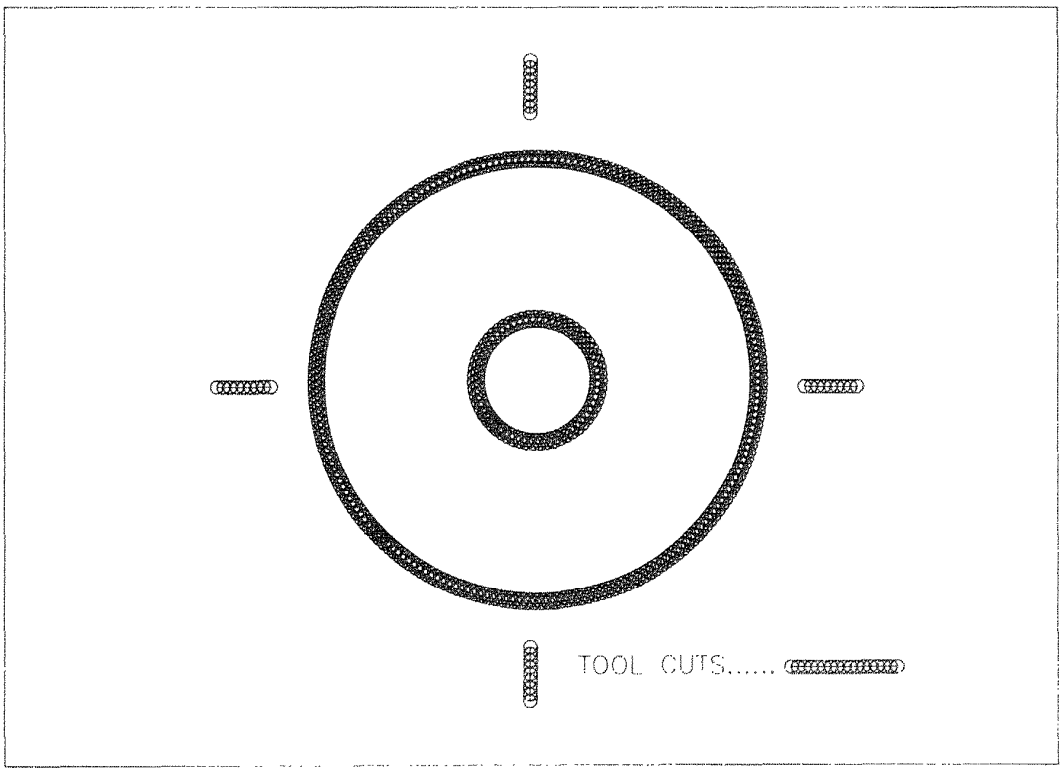


Figure A.3.3—Drawing showing only the actual cuts made in an acrylic sheet for the 2-inch and 8-inch circles used in accuracy evaluation.

PROGRAM FOR CIRCLES CUT IN ACRYLIC SHEETS
(ACCURACY)

```
O0050;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X0.5Y7.0;
N27Z0.25;
N30G42H1G01X1.0F100;
N35Z-0.1875;
N40X2.0;
N42Z0.25;
N45G40H1X2.5;
N50G00X11.5Y7.0;
N55G42H1G01X12.0F100;
N60Z-0.1875;
N65X13.0;
N70Z0.25;
N75G40H1X13.5;
N80G00X7.0Y13.5;
N85G42H1G01Y13.0F100;
N90Z-0.1875;
N95Y12.0;
N100Z0.25;
N105G40H1Y11.5;
N115G00X7.0Y2.5;
N120G42H1G01Y2.0F100;
N125Z-0.1875;
N130Y1.0;
N132Z0.25;
N135G40H1Y0.5;
N145G00X11.1875Y7.0;
N147Z-0.1875;
N150G03I-4.1875F100;
N155G00Z0.25;
N160G00X3.6599Y4.6108;
N165G42H1G01X4.0429Y4.2894F100;
N170Z-0.1562;
N175G02X4.1716Y4.1716R2.0;
N180G03X9.8284Y9.8284R4;
N182G03X4.1716Y4.1716R4;
N185G02X4.2894Y4.0429R2.0;
N187G1Z0.25;
N190G40H1G01X4.6108Y3.6599;
N200G00X8.1875Y7.0;
N202Z-0.1875;
N205G03I-1.1875F100;
N210G00Z0.25;
N215G00X5.7812Y6.7322;
N220G42H1G01X6.1643Y6.4108F100;
N225Z-0.1562;
N230G02X6.2929Y6.2929R2.0;
N235G03X7.7071Y7.7071R1;
N237X6.2929Y6.2929R1;
N240G02X6.4108Y6.1643R2.0;
N242G1Z0.25;
N245G40H1G01X6.7322Y5.7812;
N250G28X0Y0Z0;
N255M30;
```

NOTE:
The feed speeds in Statements N165 and N220 are changed to match the desired feed speed.

Figure A.3.4—Sample program (G&M code) for accuracy cutting of circles in acrylic sheets.

APPENDIX A.4

Program for Squares Cut in Acrylic Sheets (Accuracy)

Following are procedures for developing a G&M program for determining the accuracy of cutting squares in acrylic sheets. Figure A.4.1 provides information to assist in this development. Figure A.4.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.4.3 shows only the actual cuts made in the material. Use the following procedures to develop the required program in an absolute mode. Although feed rates are not discussed in these procedures, they must be included in the program so they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

Make a positioning move to Point A (X0.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the left slot. Move 0.5 inch to the right at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move for 1 inch. Then raise the tool to 0.25 inch above the material move 0.5 inch to the right at 0° to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X11.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the right slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 1.

Step 4

Make a positioning move to Point C (X7.0,Y13.5) in line with and 0.5 inch from the upper end of the vertical line that represents the upper slot. Move down 0.5 inch at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move down for 1 inch. Then, raise the tool to 0.25 inch above the material and move down 0.5 inch at 0° to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X7.0,Y2.5) in line with and 0.5 inch above the upper end of the vertical line representing the lower slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 4.

Step 6

Make a positioning move to Point E (X2.8125,Y2.8125) at lower left corner of the 8.375-inch square. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves horizontally to point (X11.1875), vertically to point (Y11.1875), horizontally to point (X2.8125), and vertically back to point (Y2.8125).

Step 7

Raise the tool to 0.25 inch above the material and make a positioning move to Point F (X2.25,Y3.0) to start the finish cut of the 8-inch square. From this point, make a horizontal cutter compensation move to point (X2.75). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves horizontally to point (X11.0), vertically to point (Y11.0), horizontally to point (X3.0), and vertically to point (Y2.75). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a vertical move to point (Y2.25).

Step 8

Make a positioning move to Point G (X5.8125,Y5.8125) at lower left corner of the 2.375-inch square. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves horizontally to point (X8.1875), vertically to point (Y8.1875), horizontally to point (X5.8125), and vertically back to point (Y5.8125).

Step 9

Raise the tool to 0.25 inch above the material and make a positioning move to Point H (X5.25,Y6.0) to start the finish cut of the 2-inch square. From this point, make a horizontal cutter compensation move to point (X5.75). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves horizontally to point (X8.0), vertically to point (Y8.0), horizontally to point (X6.0), and vertically to point (Y5.75). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a vertical move to point (Y5.25). End with a move to machine reference zero.

Figure A.4.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

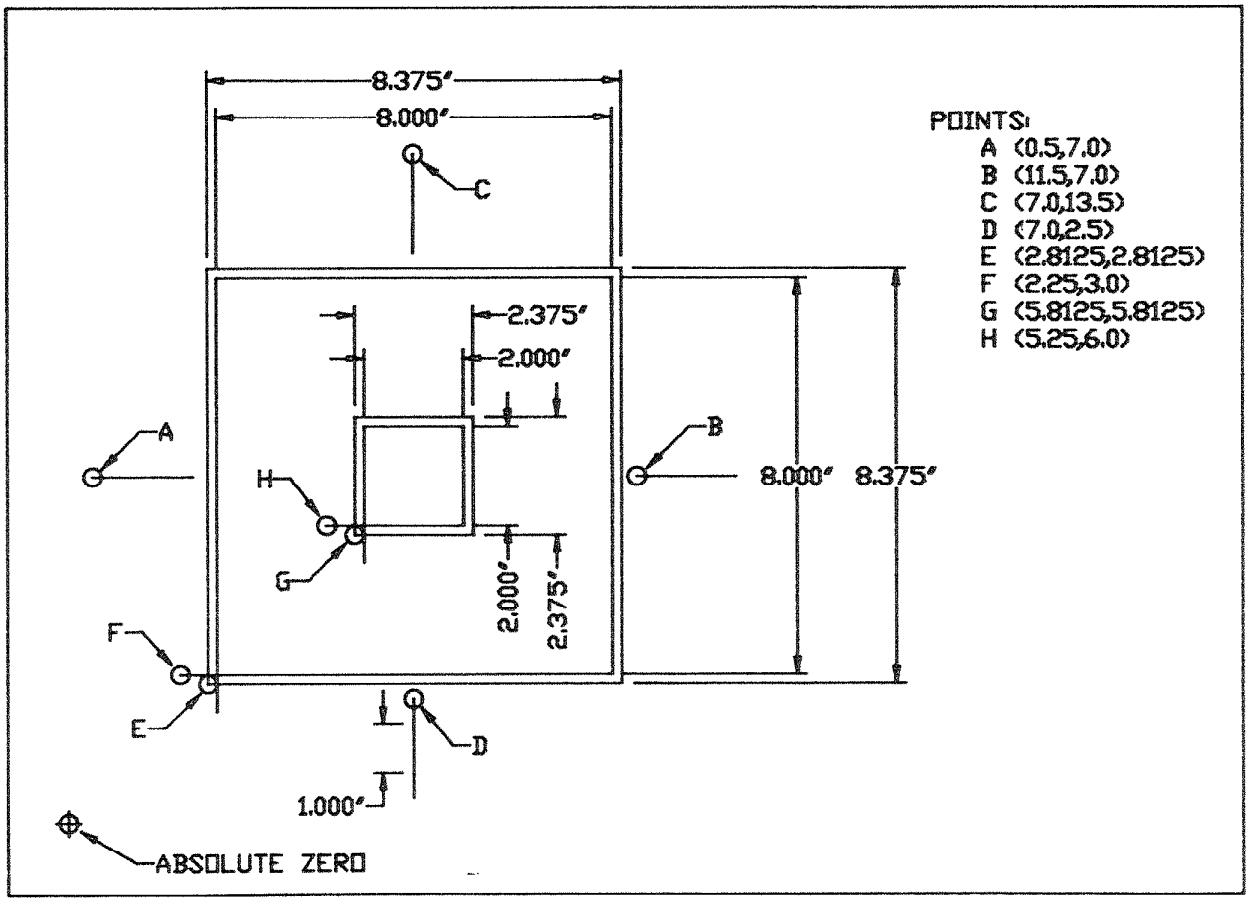


Figure A.4.1—Drawing showing information for developing a program (G&M code) needed to make square accuracy cuts in acrylic sheets.

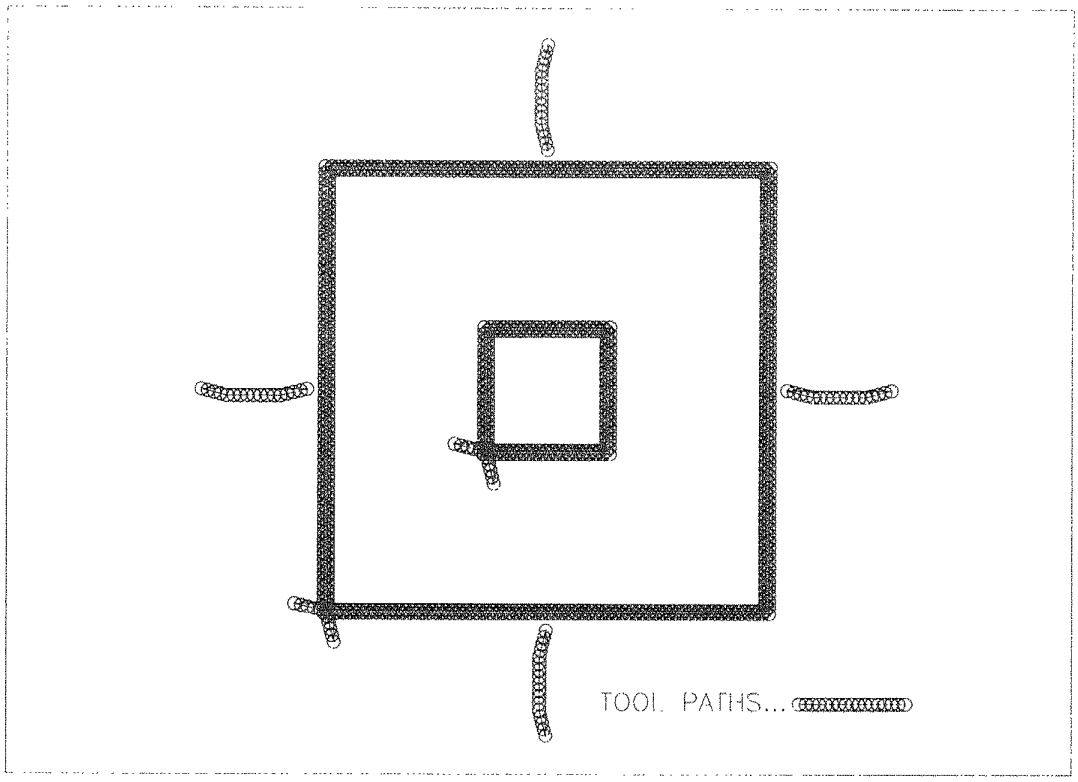


Figure A.4.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch squares in an acrylic sheet for accuracy evaluation.

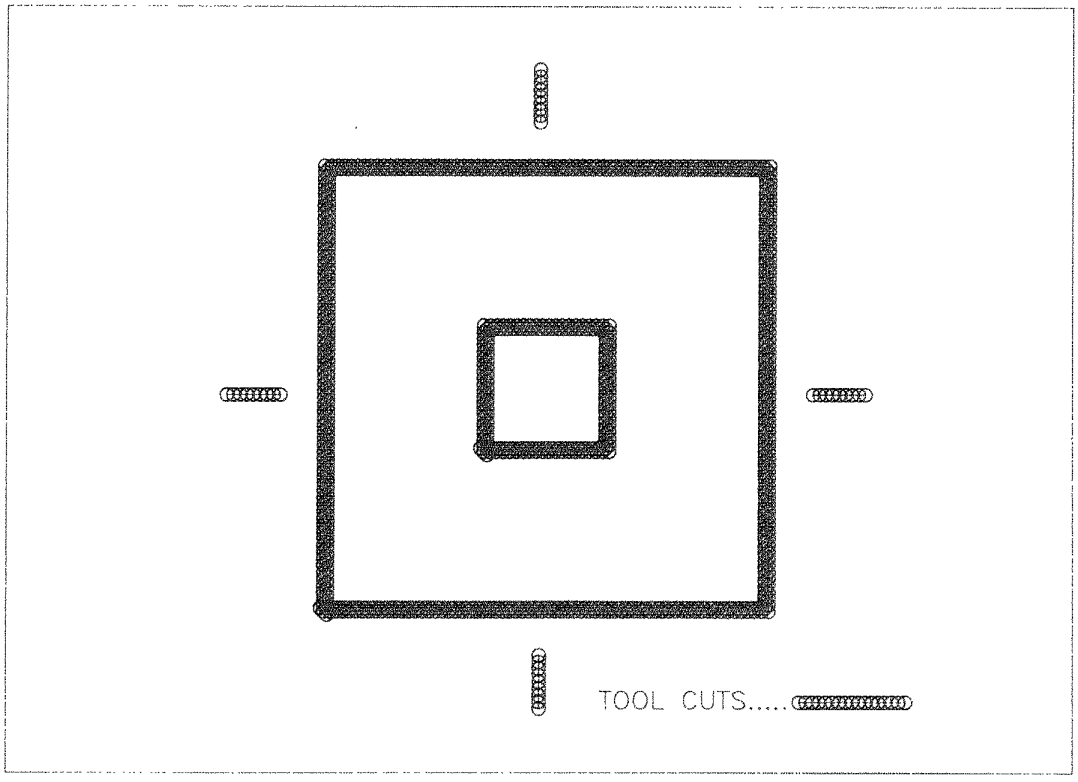


Figure A.4.3—Drawing showing only the actual cuts made in an acrylic sheet for the 2-inch and 8-inch squares used in accuracy evaluation.

PROGRAM FOR SQUARES CUT IN ACRYLIC SHEETS
(ACCURACY)

```
O0051;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X0.5Y7.0;
N27Z0.25;
N30G42H1G01X1.0F100;
N35Z-0.1875;
N40X2.0;
N42Z0.25;
N45G40H1X2.5;
N50G00X11.5Y7.0;
N55G42H1G01X12.0F100;
N60Z-0.1875;
N65X13.0;
N70Z0.25;
N75G40H1X13.5;
N80G00X7.0Y13.5;
N85G42H1G01Y13.0F100;
N90Z-0.1875;
N95Y12.0;
N100Z0.25;
N105G40H1Y11.5;
N115G00X7.0Y2.5;
N120G42H1G01Y2.0F100;
N125Z-0.1875;
N130Y1.0;
N132Z0.25;
N135G40H1Y0.5;
N140G00Z0.25;
N145G00X2.8125Y2.8125;
N147Z-0.1875;
N150G01X11.1875F100;
N160Y11.1875;
N165X2.8125;
N170Y2.8125;
N175G00Z0.25;
N180G00X2.25Y3.0;
N185G42H1G01X2.75F100;
N190Z-0.1562;
N195X11.0;
N197G4;
N200Y11.0;
N202G4;
N205X3.0;
N207G4;
N210Y2.75;
N211G4;
N212Z0.25;
N215G40H1Y2.25;
N225G00X5.8125Y5.8125;
N227Z-0.1875;
N230G01X8.1875F100;
N240Y8.1875;
N245X5.8125;
N250Y5.8125;
N255G00Z0.25;
N260G00X5.25Y6.0;
N265G42H1G01X5.75F100;
N270Z-0.1562;
N275X8.0;
N277G4;
NN280Y8.0;
N282G4;
N285X6.0;
N287G4;
N290Y5.75;
N291G4;
N292Z0.25;
N295G40H1Y5.25;
N300G28X0Y0Z0;
N305M30;
```

NOTE:
The feed speeds in Statements N185 and N265 are changed to match the desired feed speed.

Figure A.4.4—Sample program (G&M code) for accuracy cutting of squares in acrylic sheets.

APPENDIX A.5

Program for Diamonds Cut in Acrylic Sheets
(Accuracy)

Following are procedures for developing a G&M program for determining the accuracy of cutting diamonds in acrylic sheets. Figure A.5.1 provides information to assist in this development. Figure A.5.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.5.3 shows only the actual cuts made in the material. Use the following procedures to develop the required program in an absolute mode. Although feed rates are not discussed in these procedures, they must be included in the program so they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

Make a positioning move to Point A (X2.4038,Y2.4038) in line with and 0.5 inch from the lower left end of the line that represents the lower left slot. Move 0.5 inch to point (X2.7574,Y2.7574) with a left cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X3.4645,Y3.4645). Then raise the tool to 0.25 inch above the material and move to point (X3.818,Y3.818) to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X10.182,Y10.182) in line with and a 0.5 inch from the lower left end of the line that represents the upper right slot. Move 0.5 inch move to point (X10.5355,Y10.5355) with a left cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X11.2426,Y11.2426). Then raise the tool to 0.25 inch above the material and move to point (X11.5962,Y11.5962) to remove the cutter compensation.

Step 4

Make a positioning move to Point C (X2.4038,Y11.5962) in line with and 0.5 inch from the upper left end of the line that represents the upper left slot. Move 0.5 inch to point (X2.7574,Y11.2426) with a right cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X3.4645,Y10.5355). Then raise the tool to 0.25 inch above the material and move to point (X3.818,Y10.182) to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X10.182,Y3.818) in line with and 0.5 inch from the upper left end of the line that represents the lower right slot. Move 0.5 inch to point (X10.5355,Y3.4645) with a right cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X11.2426,Y2.7574). Then raise the tool to 0.25 inch above the material and move to point (X11.5962,Y2.4038) to remove the cutter compensation.

Step 6

Make a positioning move to Point E (X1.078,Y7.0) at left corner of the 8.375-inch diamond. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves to point (X7.0,Y1.078), to point (X12.922,Y7.0), to point (X7.0,Y12.922), and back to point (X1.078,Y7.0).

Step 7

Raise the tool to 0.25 inch above the material and make a positioning move to Point F (X0.8128,Y7.5303) to start the finish cut of the 8-inch diamond. From this point, make a right cutter compensation move to point (X1.1664,Y7.1768). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves to point (X7.0,Y1.3431), to point (X12.6569,Y7.0), to point (X3.0), and to point (X1.1664,Y6.8232). Then, raise the

tool to 0.25 inch above the material and remove the cutter compensation with a move to point (X0.8128,Y6.4697).

Step 8

Make a positioning move to Point G (X5.3206,Y7.0) at left corner of the 2.375-inch diamond. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves to point (X7.0,Y5.3206), to point (X8.6794,Y7.0), to point (X7.0,Y8.6794), and back to point (X5.3206,Y7.0).

Step 9

Raise the tool to 0.25 inch above the material and make a positioning move to Point H (X5.0555,Y7.5303) to start the finish cut of the 2-inch diamond. From this point, make a cutter compensation move to point (X5.409,Y7.1768). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves to point (X7.0,Y5.5858), to point (X8.4142,Y7.0), to point (X7.0,Y8.4142), and to point (X5.409,Y6.8232). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to point (X5.0555,Y6.4697). End with a move to machine reference zero.

Figure A.5.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

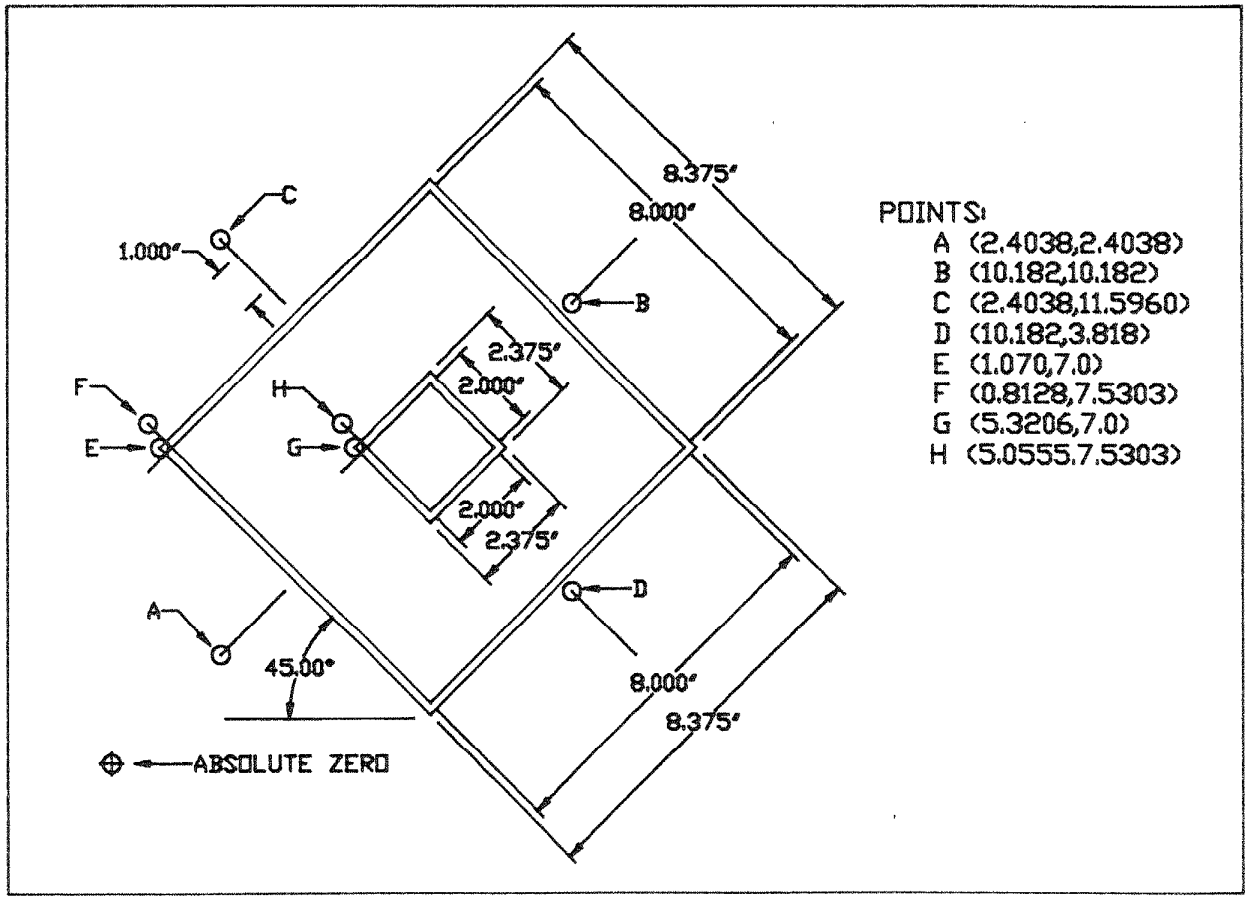


Figure A.5.1—Drawing showing information for developing a program (G&M code) needed to make diamond accuracy cuts in acrylic sheets.

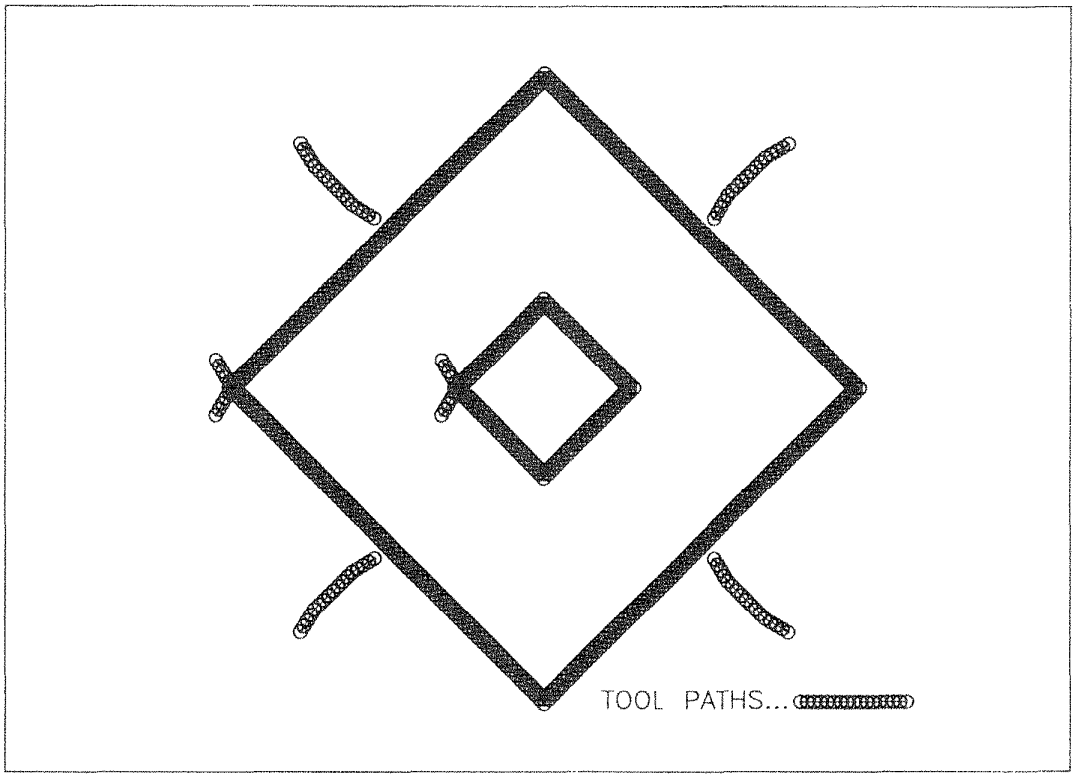


Figure A.5.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch diamonds in an acrylic sheet for accuracy evaluation.

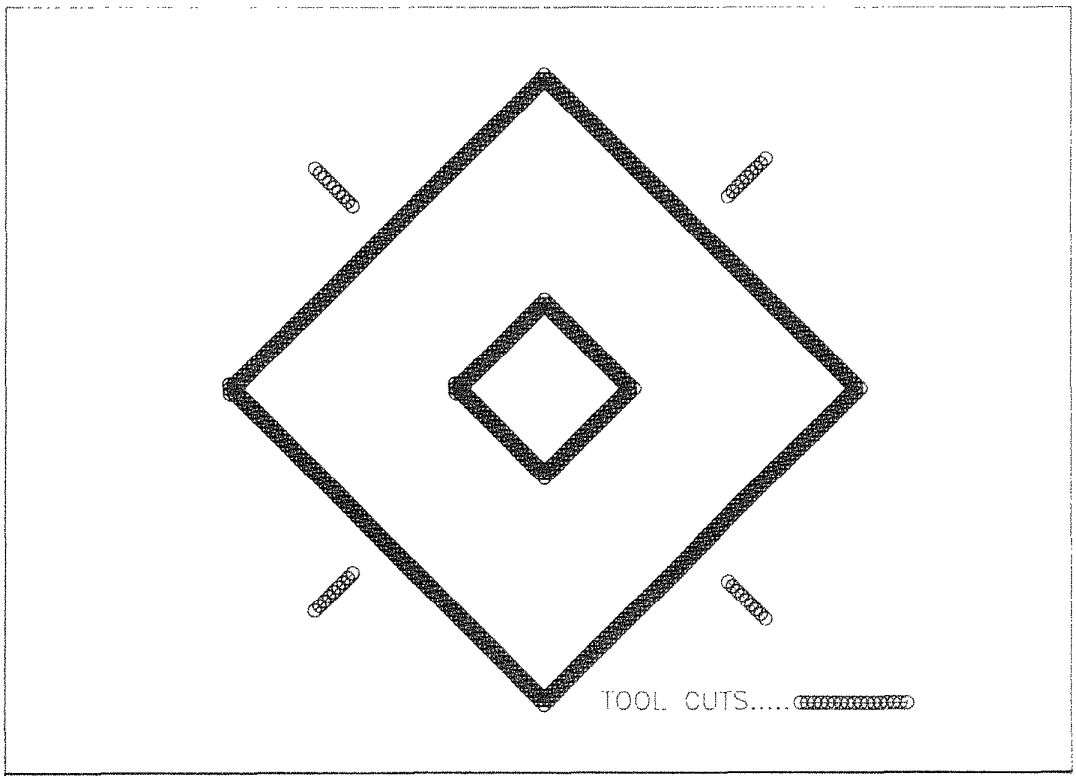


Figure A.5.3—Drawing showing only the actual cuts made in an acrylic sheet for the 2-inch and 8-inch diamonds used in accuracy evaluation.

PROGRAM FOR DIAMONDS CUT IN ACRYLIC SHEETS
(ACCURACY)

```
O0052;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X2.4038Y2.4038;
N27Z0.25;
N30G41H1G01X2.7574Y2.7574F100;
N35Z-0.1875;
N40X3.4645Y3.4645;
N42Z0.25;
N45G40H1X3.818Y3.818;
N50G00X10.182Y10.182;
N55G41H1G01X10.5355Y10.5355F100;
N60Z-0.1875;
N65X11.2426Y11.2426;
N70Z0.25;
N75G40H1X11.5962Y11.5962;
N80G00X2.4038Y11.5962;
N85G42H1G01X2.7574Y11.2426F100;
N90Z-0.1875;
N95X3.4645Y10.5355;
N100Z0.25;
N105G40H1X3.818Y10.182;
N115G00X10.182Y3.818;
N120G42H1G01X10.5355Y3.4645F100;
N125Z-0.1875;
N130X11.2426Y2.7574;
N132Z0.25;
N135G40H1X11.5962Y2.4038;
N145G00X1.078Y7.0;
N147Z-0.1875;
N150G01X7.0Y1.078F100;
N160X12.922Y7.0;
N165X7.0Y12.922;
N170X1.078Y7.0;
N175G00Z0.25;
N180G00X0.8128Y7.5303;
N185G42H1G01X1.1664Y7.1768F100;
N190Z-0.1562;
N195X7.0Y1.3431;
N197G4;
N200X12.6569Y7.0;
N202G4;
N205X7.0Y12.6569;
N207G4;
N210X1.1664Y6.8232;
N211G4;
N212Z0.25;
N215G40H1X0.8128Y6.4697;
N225G00X5.3206Y7.0;
N227Z-0.1875;
N230G01X7.0Y5.3206F100;
N240X8.6794Y7.0;
N245X7.0Y8.6794;
N250X5.3206Y7.0;
N255G00Z0.25;
N260G005.0555Y7.5303;
N265G42H1G01X5.409
                    Y7.1768F100;
N270Z-0.1562;
N275X7.0Y5.5858;
N277G4;
N280X8.4142Y7.0;
N282G4;
N285X7.0Y8.4142;
N287G4;
N290X5.409Y6.8232;
N291G4;
N292Z0.25;
N295G40H1X5.0555Y6.4697;
N297G28X0Y0Z0;
N305M30;
```

NOTE:
The feed speeds in Statements N185 and N265 are changed to match the desired feed speed.

Figure A.5.4—Sample program (G&M code) for accuracy cutting of diamonds in acrylic sheets.

APPENDIX A.6

Program for Circles Cut in Specified Raw Material
(Accuracy)

Following are procedures for developing a G&M program for determining the accuracy of cutting circles in the specified raw material. Figure A.6.1 provides information to assist in this development. Figure A.6.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.6.3 shows only the actual cuts made in the material. Use the following procedures to develop the required program in an absolute mode. Although feed rates are not discussed in these procedures, they must be included in the program so that they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

Make a positioning move to Point A (X0.25,Y7.0) in line with and 0.75 inch from the left end of the horizontal line that represents the left slot. Move 0.75 inch to the right at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.625 inch and make a cutting move for 1 inch. Then raise the tool to 0.5 inch above the material and move 0.75 inch to the right at 0° to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X11.25,Y7.0) in line with and 0.75 inch from the left end of the horizontal line that represents the right slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 1.

Step 4

Make a positioning move to Point C (X7.0,Y13.75) in line with and 0.75 inch from the upper end of the vertical line that represents the upper slot. Move down 0.75 inch at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.625 inch and make a cutting move down for 1 inch. Then raise the tool to 0.5 inch above the material and move down 0.75 inch at 0° to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X7.0,Y2.75) in line with and 0.75 inch above the upper end of the vertical line representing the lower slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 4.

Step 6

Make a positioning move to Point E (X11.5,Y7.0) at the right edge of the circle with a diameter of 9.0 inches. Lower the tool to a depth of -0.625 inch and make a 360° move (roughing cut) in a counter clockwise direction without cutter compensation.

Step 7

Raise the tool to 0.5 inch above the material and make a positioning move to Point F (X4.9692,Y3.0854) to start the finish cut of the 8-inch circle. From this point, make a right cutter compensation move to point (X4.3957,Y3.9045). Next, lower the tool to -0.625 inch and make a lead-in cut in a clockwise arc with a radius of 2 inches to the point (X4.1716,Y4.1716). Then make the 360° counter clockwise finish cut to the 8-inch circle. From the finish point of the circle, make a lead-out cut in a clockwise arc with a radius of 2 inches to the point (X3.9045,Y4.3957). Raise the tool to 0.5 inch above the material and remove the cutter compensation with a move to the point (X3.0854,Y4.9692).

Step 8

Make a positioning move to Point G (X8.5,Y7.0) at the right side of the circle with a diameter of 3.0 inches. Lower the tool to a depth of -0.625 inch and make a 360° move (roughing cut) in a counter clockwise direction without cutter compensation.

Step 9

Raise the tool to 0.5 inch above the material and make a positioning move to Point H (X7.0906,Y5.2067) to start the finish cut of the 2-inch circle. From this point, make a right cutter compensation move to point (X6.517,Y6.0258). Next, lower the tool to -0.625 inch and make a lead-in cut in a clockwise arc with a radius of 2 inches to the point (X6.2929,Y6.2929). Then make the 360° counter clockwise finish cut to the 2-inch circle. From the finish point of the circle, make a lead-out cut in a clockwise arc with a radius of 2 inches to the point (X6.0258,Y6.517). Raise the tool to 0.5 inch above the material and remove the cutter compensation with a move to the point (X5.2067,Y7.0906). End with a move to machine reference zero.

Figure A.6.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

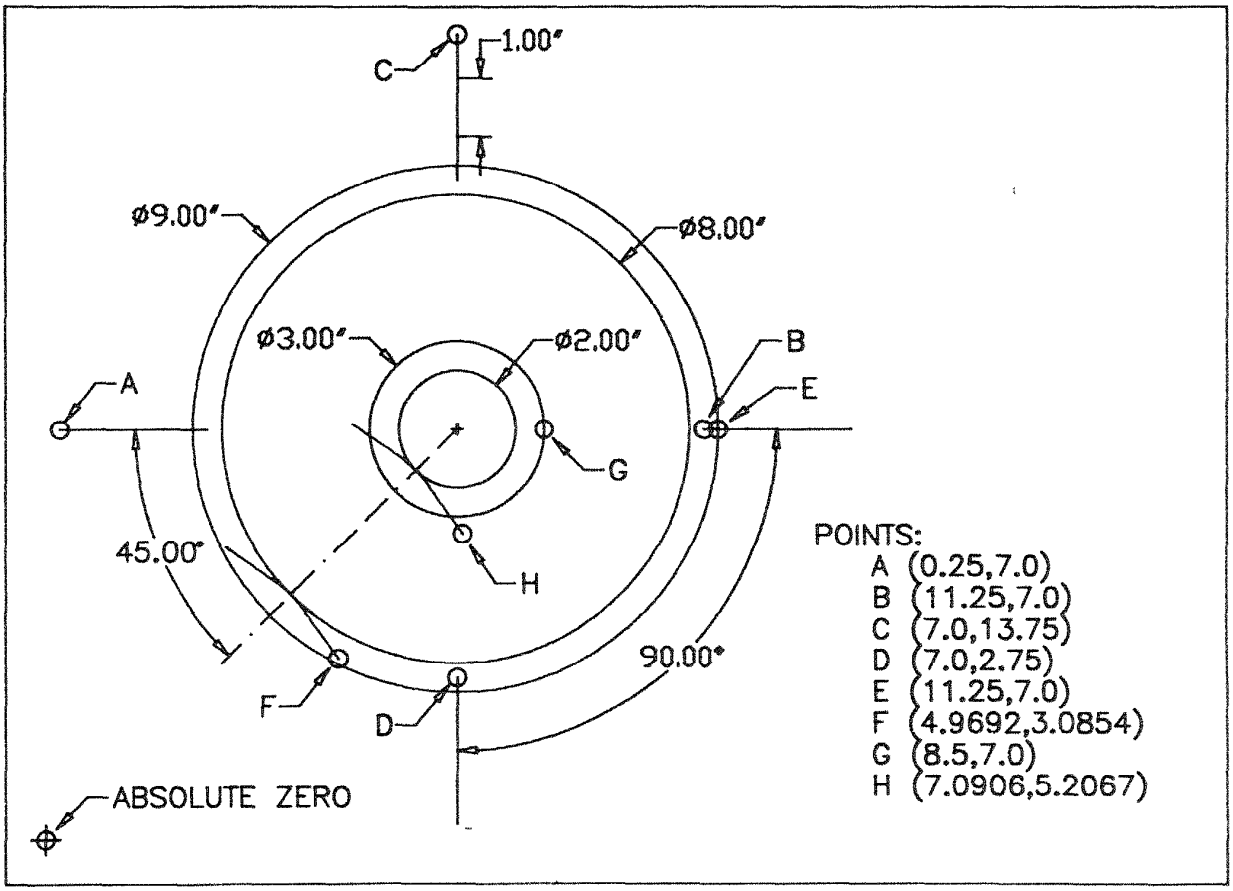


Figure A.6.1—Drawing showing information for developing a program (G&M code) needed to make circle accuracy cuts in specified raw material.

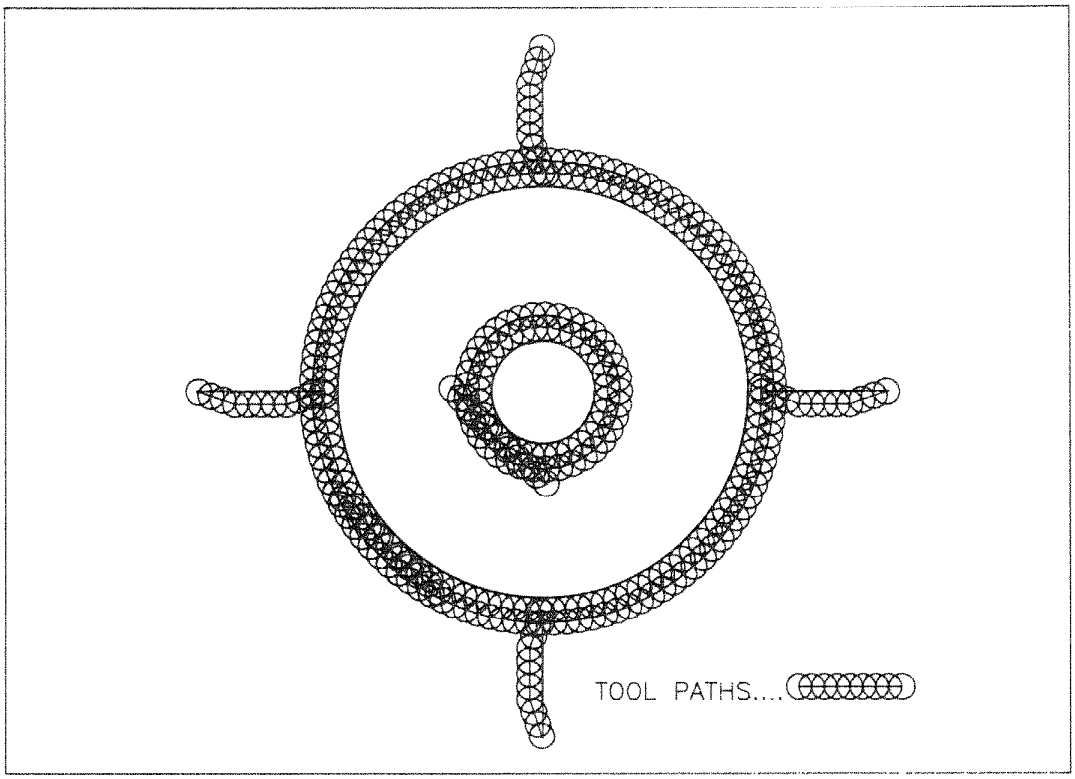


Figure A.6.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch circles in the specified raw material for accuracy evaluation.

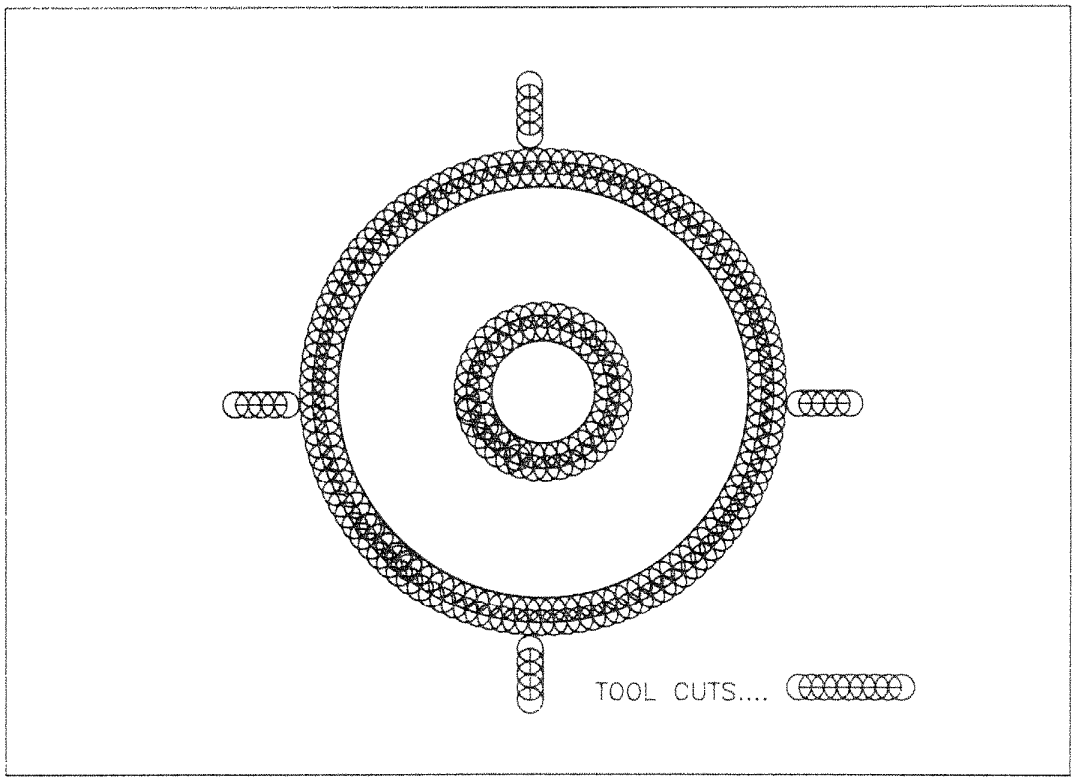


Figure A.6.3—Drawing showing only the actual cuts made in the specified raw material for the 2-inch and 8-inch circles used in accuracy evaluation.

PROGRAM FOR CIRCLES CUT IN SPECIFIED RAW MATERIAL
(ACCURACY)

```
O0053;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X0.25Y7.0;
N27F50Z0.5;
N30G42H2G01X1.0F315;
N35Z-0.625;
N40X2.0;
N42Z0.5;
N45G40H2X2.75;
N50G00X11.25Y7.0;
N55G42H2G01X12.0F315;
N60Z-0.625;
N65X13.0;
N70Z0.5;
N72G40H2X13.75;
N75G00X7.0Y13.75;
N80G42H2G01Y13.0F315;
N85Z-0.625;
N90Y12.0;
N95Z0.5;
N100G40H2Y11.25;
N105G00X7.0Y2.75;
N120G42H2G01Y2.0F315;
N125Z-0.625;
N130Y1.0;
N132Z0.5;
N135G40H2Y0.25;
N145G00X11.5Y7.0;
N147Z-0.625G1F100;
N150G02I-4.5F315;
N155G00Z0.5;
N160G00X4.9692Y3.0854;
N165G41H2G01X4.3957Y3.9045F315;
N170Z-0.625;
N175G03X4.1716Y4.1716R2.0;
N180G02X9.8284Y9.8284R4;
N182X4.1716Y4.1716R4;
N185G03X3.9045Y4.3957R2.0;
N190G40H2G01X3.0854Y4.9692;
N195G00Z0.5;
N200G00X8.5Y7.0;
N202Z-0.625G1F100;
N205G02I-1.5F315;
N210G00Z0.5;
N215G00X7.0906Y5.2067;
N220G41H2G01X6.517Y6.0258F315;
N225Z-0.625;
N230G03X6.2929Y6.2929R2.0;
N235G02X7.7071Y7.7071R1;
N237X6.2929Y6.2929R1;
N240G03X6.0258Y6.517R2.0;
N247G1Z0.5;
N245G40H2G01X5.2067Y7.0906;
N247G28X0Y0Z0;
N255M30;
```

NOTE:
All feed speeds in the program are changed to match the desired feed speed.

Figure A.6.4—Sample program (G&M code) for accuracy cutting of circles in specified raw material.

APPENDIX A.7

Program for Squares Cut in Specified Raw Material (Accuracy)

Following are procedures for developing a G&M program for determining the accuracy of cutting squares in the specified raw material. Figure A.7.1 provides information to assist in this development. Figure A.7.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.7.3 shows only the actual cuts made in the material. Use the following steps to develop the required program in an absolute mode. Although feed rates are not discussed in these steps, they must be included in the program so that they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

Make a positioning move to Point A (X0.25,Y7.0) in line with and 0.75 inch from the left end of the horizontal line that represents the left slot. Move 0.75 inch to the right at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.625 inch and make a cutting move for 1 inch. Then raise the tool to 0.5 inch above the material and move 0.75 inch to the right at 0° to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X11.75,Y7.0) in line with and 0.75 inch from the left end of the horizontal line that represents the right slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 1.

Step 4

Make a positioning move to Point C (X7.0,Y13.75) in line with and 0.75 inch from the upper end of the vertical line that represents the upper slot. Move down 0.75 inch at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.625 inch and make a cutting move down for 1 inch. Then raise the tool to 0.5 inch above the material and move down 0.75 inch at 0° to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X7.0,Y2.75) in line with and 0.75 inch above the upper end of the vertical line representing the lower slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 4.

Step 6

Make a positioning move to Point E (X2.5,Y2.5) at lower left corner of the 9-inch square. Lower the tool to a depth of -0.625 inch and without cutter compensation make counter clockwise cutting moves horizontally to point (X11.5), vertically to point (Y11.5), horizontally to point (X2.5), and vertically back to point (Y2.5).

Step 7

Raise the tool to 0.5 of an inch above the material and make a positioning move to Point F (X3.0,Y1.5) to start the finish cut of the 8-inch square. From this point, make a horizontal cutter compensation move to point (X2.5). Next, lower the tool to -0.625 inch and make counter clockwise cutting moves horizontally to point (X11.0), vertically to point (Y11.0), horizontally to point (X3.0), and vertically to point (Y2.5). Then, raise the tool to 0.5 inch above the material and remove the cutter compensation with a vertical move to point (Y1.5).

Step 8

Make a positioning move to Point G (X5.5,Y5.5) at lower left corner of the 3-inch square. Lower the tool to a depth of -0.625 inch and without cutter compensation make counter clockwise cutting moves horizontally to point (Y8.5), vertically to point (X8.5), horizontally to point (Y5.5), and vertically back to point (X5.5).

Step 9

Raise the tool to 0.5 of an inch above the material and make a positioning move to Point H (X6.0,Y4.5) to start the finish cut of the 2-inch square. From this point, make a horizontal cutter compensation move to point (Y5.5). Next, lower the tool to -0.625 inch and make counter clockwise cutting moves horizontally to point (Y8.0), vertically to point (X8.0), horizontally to point (Y6.0), and vertically to point (X5.5). Then, raise the tool to 0.5 inch above the material and remove the cutter compensation with a vertical move to point (X4.5). End with a move to machine reference zero.

Figure A.7.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

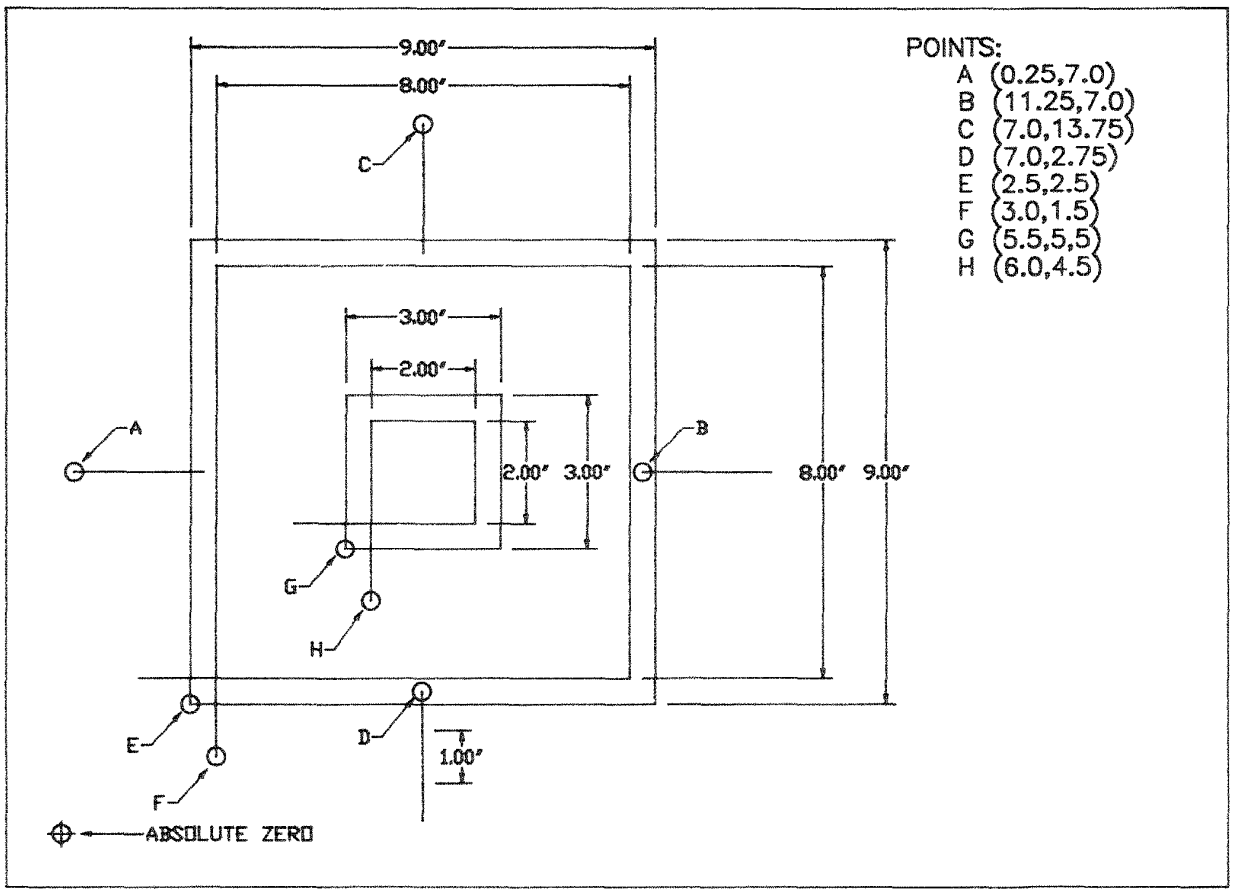


Figure A.7.1—Drawing showing information for developing a program (G&M code) needed to make square accuracy cuts in specified raw material.

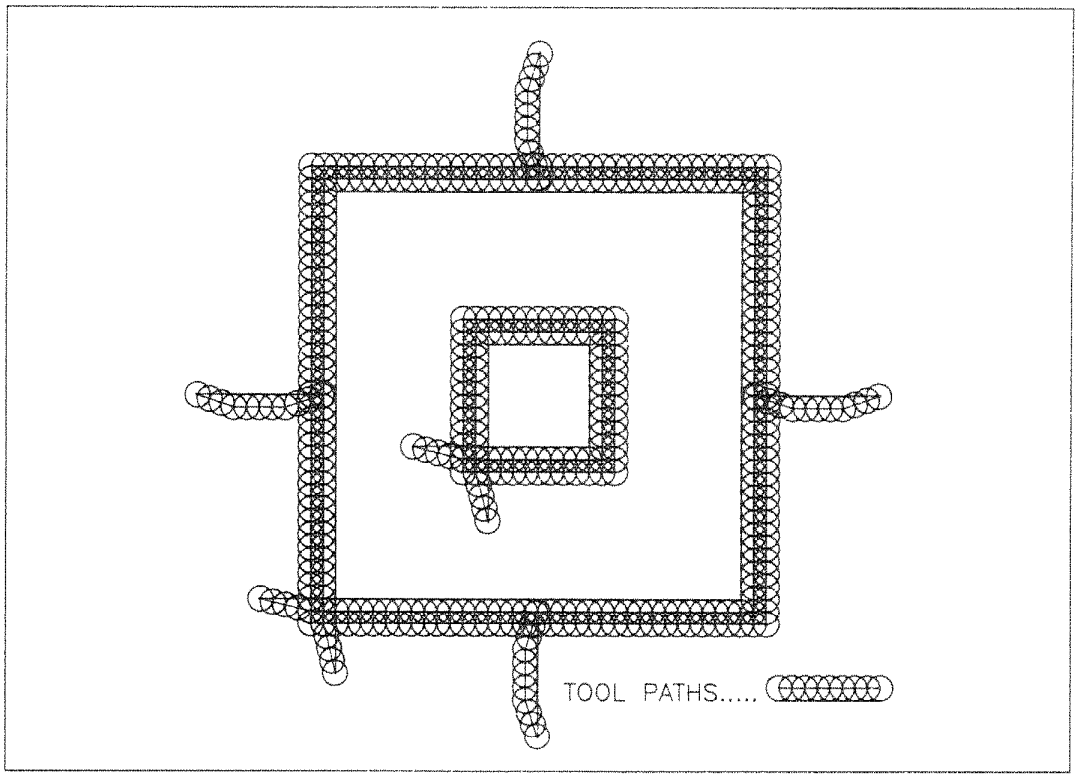


Figure A.7.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch squares in the specified raw material for accuracy evaluation.

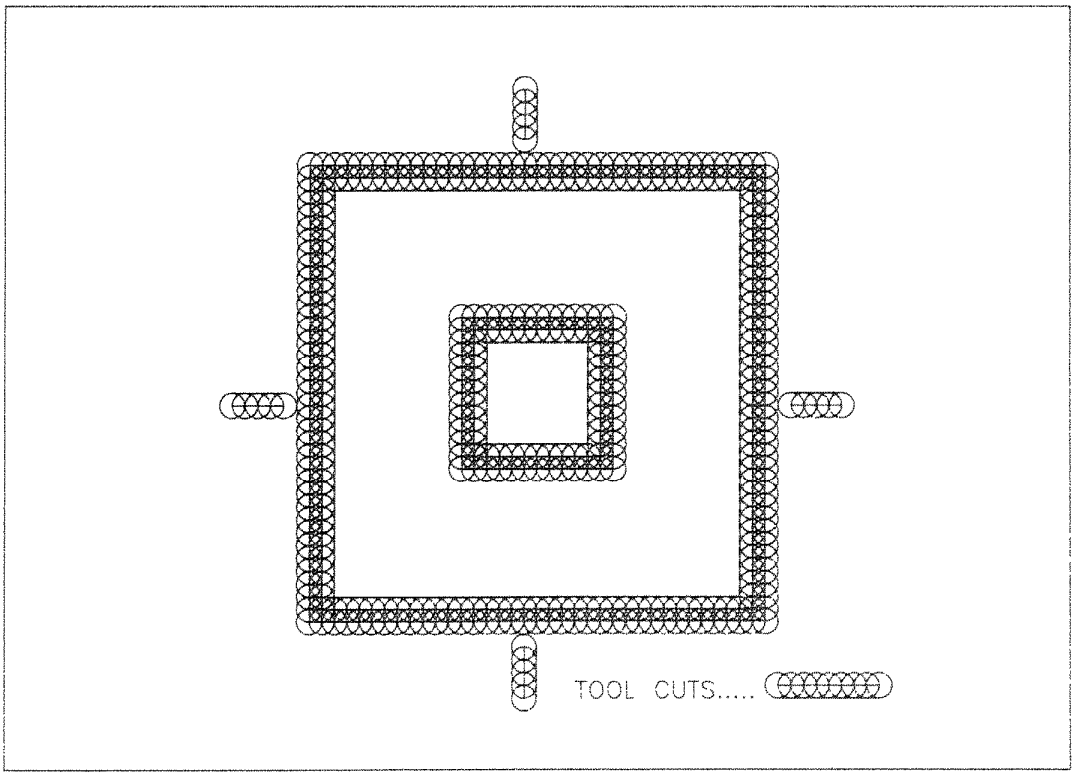


Figure A.7.3—Drawing showing only the actual cuts made in the specified raw material for the 2-inch and 8-inch squares used in accuracy evaluation.

PROGRAM FOR SQUARES CUT IN SPECIFIED RAW MATERIAL
(ACCURACY)

```
O0054;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X0.25Y7.0;
N27Z0.5;
N30G42H2G01X1.0F315;
N35Z-0.625;
N40X2.0;
N47Z0.5;
N45G40H2X2.75;
N50G00X11.25Y7.0;
N55G42H2G01X12.0F315;
N60Z-0.625;
N65X13.0;
N70Z0.5;
N75G40H2X13.75;
N80G00X7.0Y13.75;
N85G42H2G01Y13.0F315;
N90Z-0.625;
N95Y12.0;
N100Z0.5;
N105G40H2Y11.25;
N115G00X7.0Y2.75;
N120G42H2G01Y2.0F315;
N125Z-0.625;
N130Y1.0;
N132Z0.5;
N135G40H2Y0.25;
N145G00X2.5Y2.5;
N147Z-0.625;
N150G01Y11.5F315;
N160X11.5;
N165Y2.5;
N170X2.5;
N175G00Z0.5;
N180G00X3.0Y1.5;
N185G41H2G01Y2.5F315;
N190Z-0.625;
N195Y11.0;
N197G4;
N200X11.0;
N202G4;
N205Y3.0;
N207G4;
N210X2.5;
N211G4;
N212Z0.5;
N215G40H2X1.5;
N225G00X5.5Y5.5;
N227Z-0.625;
N230G01Y8.5F315;
N240X8.5;
N245Y5.5;
N250X5.5;
N255G00Z0.5;
N260G00X6.0Y4.5;
N265G41H2G01Y5.5F315;
N270Z-0.625
275Y8.0;
N277G4;
N280X8.0;
N282G4;
N285Y6.0;
N287G4;
N290X5.5;
N291G4;
N292Z0.5;
N295G40H2X4.5;
N297G28X0Y0Z0;
N305M30;
```

Note: All feed speeds in the program are changed to match the desired feed speed.

Figure A.7.4—Sample program (G&M code) for accuracy cutting of squares in specified raw material.

APPENDIX A.8

Program for Diamonds Cut in Specified Raw Material
(Accuracy)

Following are procedures for developing a G&M program for determining the accuracy of cutting diamonds in the specified raw material. Figure A.8.1 provides information to assist in this development. Figure A.8.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.8.3 shows only the actual cuts made in the material. Use the following steps to develop the required program in an absolute mode. Although feed rates are not discussed in these steps, they must be included in the program so that they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

Make a positioning move to Point A (X2.227,Y2.227) in line with and 0.75 inch from the lower left end of the line that represents the lower left slot. Move 0.75 inch to point (X2.7574,Y2.7574) with a left cutter compensation. Next, lower the tool to a depth of -0.625 inch and make a cutting move to point (X3.4645,Y3.4645). Then raise the tool to 0.5 inch above the material and move to point (X3.9948,Y3.9948) to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X10.0052,Y10.0052) in line with and 0.75 inch from the lower left end of the line that represents the upper right slot. Move 0.75 inch to point (X10.5355,Y10.5355) with a left cutter compensation. Next, lower the tool to a depth of -0.625 inch and make a cutting move to point (X11.2426,Y11.2426). Then raise the tool to 0.5 inch above the material and move to point (X11.773,Y11.773) to remove the cutter compensation.

Step 4

Make a positioning move to Point C (X2.227,Y11.773) in line with and a 0.75 inch from the upper left end of the line that represents the upper left slot. Move 0.5 inch to point (X2.7574,Y11.2426) with a right cutter compensation. Next, lower the tool to a depth of -0.625 inch and make a cutting move to point (X3.4645,Y10.5355). Then raise the tool to 0.5 inch above the material and move to point (X3.9948,Y10.0052) to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X10.0052,Y3.9948) in line with and a 0.75 inch from the upper left end of the line that represents the lower right slot. Move 0.75 inch to point (X10.5355,Y3.4645) with a right cutter compensation. Next, lower the tool to a depth of -0.625 inch and make a cutting move to point (X11.2426,Y2.7574). Then, raise the tool to 0.5 inch above the material and move to point (X11.773,Y2.227) to remove the cutter compensation.

Step 6

Make a positioning move to Point E (X0.636,Y7.0) at left corner of the 9-inch diamond. Lower the tool to a depth of -0.625 inch and without cutter compensation make counter clockwise cutting moves to point (X7.0,Y13.364), to point (X13.364,Y7.0), to point (X7.0,Y0.636), and back to point (X0.636,Y7.0).

Step 7

Raise the tool to 0.5 inch above the material and make a positioning move to Point F (X0.2825,Y5.9393) to start the finish cut of the 8-inch diamond. From this point, make a right cutter compensation move to point (X0.9896,Y6.6464). Next, lower the tool to -0.625 inch and make counter clockwise cutting moves to point (X7.0,Y12.6569), to point (X12.6569,Y7.0), to point (X7.0,Y1.3431), and to point (X0.9896,Y7.3536). Then,

raise the tool to 0.5 inch above the material and remove the cutter compensation with a move to point (X0.2825,Y8.0607).

Step 8

Make a positioning move to Point G (X4.8787,Y7.0) at left corner of the 3-inch diamond. Lower the tool to a depth of -0.625 inch and without cutter compensation make counter clockwise cutting moves to point (X7.0,Y9.1213), to point (X9.1213,Y7.0), to point (X7.0,Y4.8787), and back to point (X4.8787,Y7.0).

Step 9

Raise the tool to 0.5 inch above the material and make a positioning move to Point H (X4.5251,Y5.9393) to start the finish cut of the 2-inch diamond. From this point, make a cutter compensation move to point (X5.2322,Y6.6464). Next, lower the tool to -0.625 inch and make counter clockwise cutting moves to point (X7.0,Y8.4142), to point (X8.4142,Y7.0), to point (X7.0,Y5.5858), and to point (X5.2322,Y7.3536). Then, raise the tool to 0.5 inch above the material and remove the cutter compensation with a move to point (X4.5251,Y8.0607). End with a move to machine reference zero.

Figure A.5.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

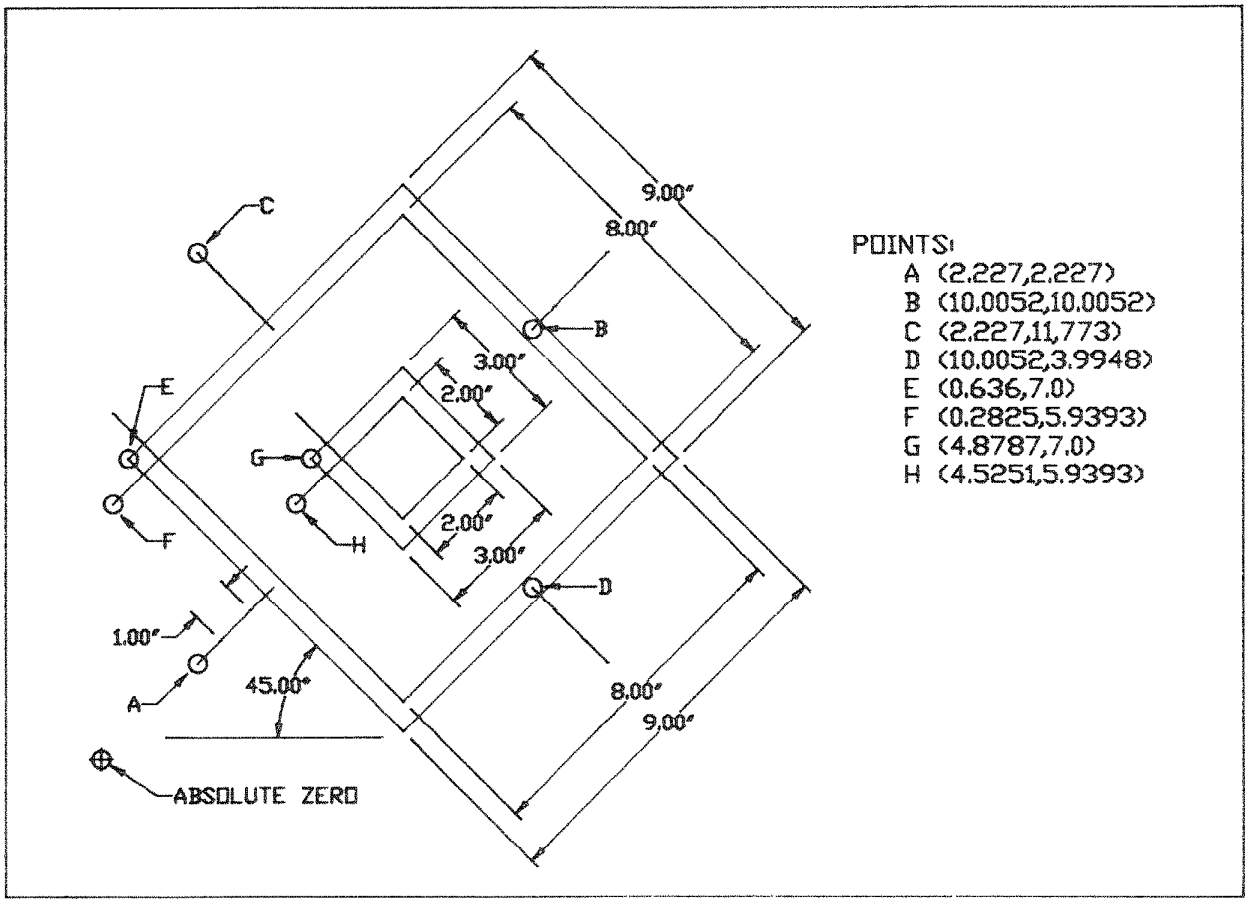


Figure A.8.1—Drawing showing information for developing a program (G&M code) needed to make diamond accuracy cuts in specified raw material.

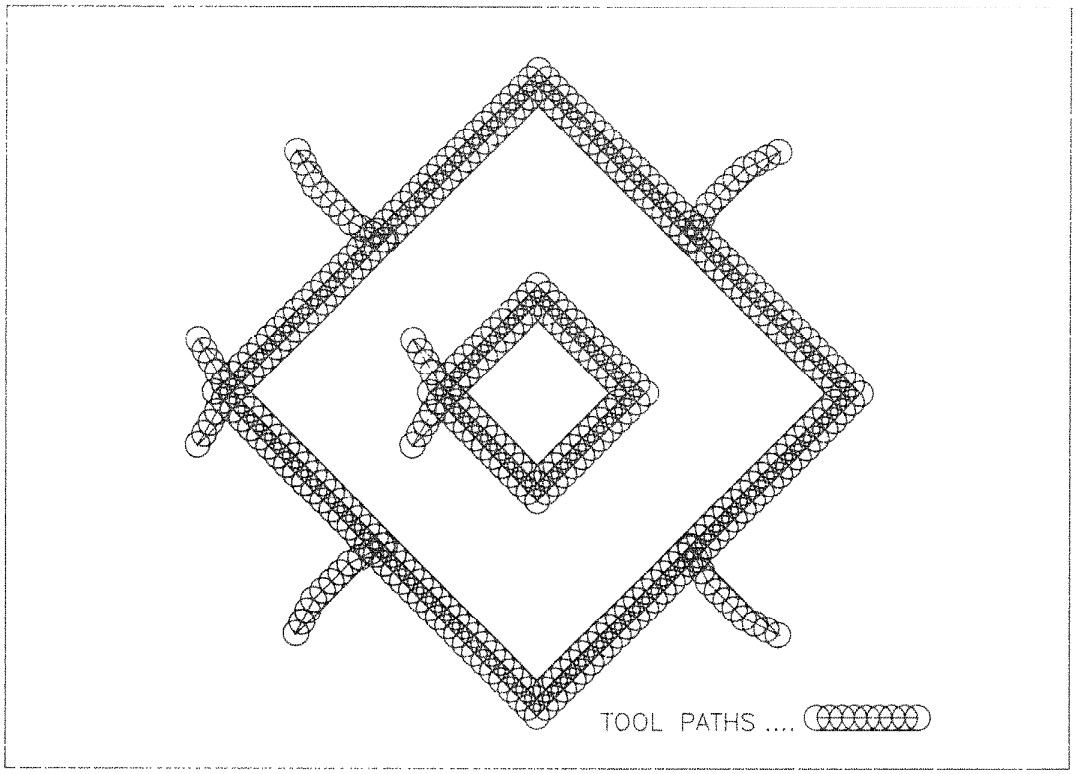


Figure A.8.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch diamonds in the specified raw material for accuracy evaluation.

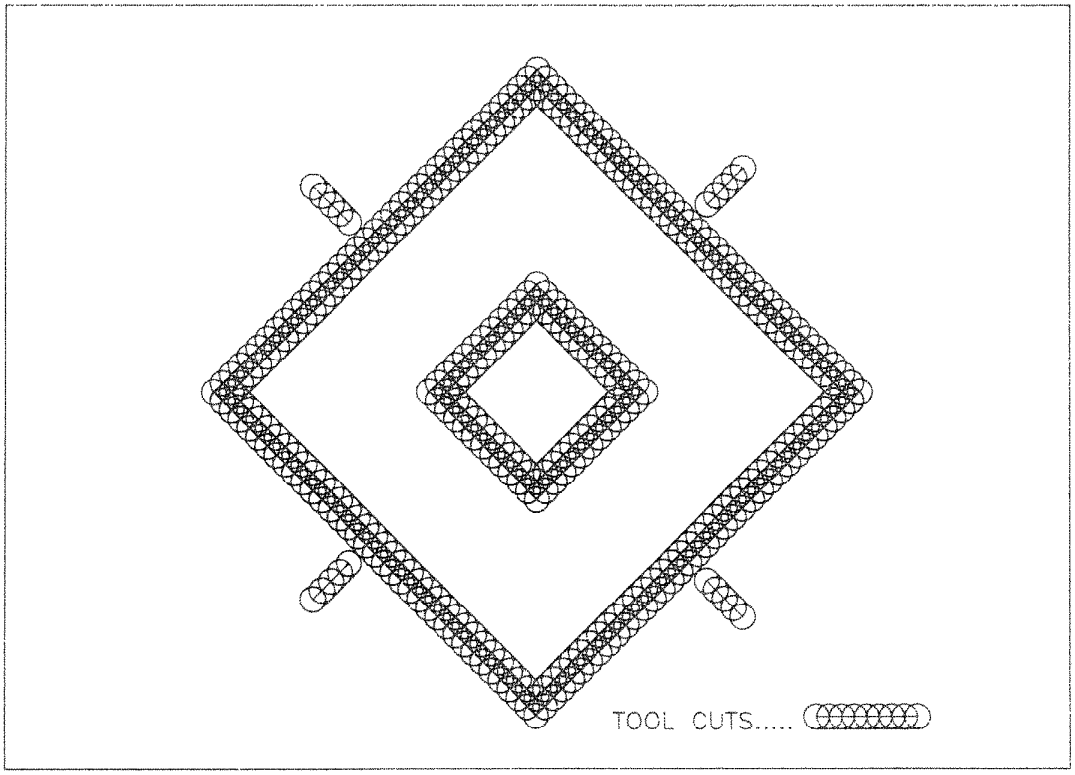


Figure A.8.3—Drawing showing only the actual cuts made in the specified raw material for the 2-inch and 8-inch diamonds used in accuracy evaluation.

PROGRAM FOR DIAMONDS CUT IN SPECIFIED RAW MATERIAL
(ACCURACY)

```
O0055;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X2.227Y2.227;
N27Z0.5;
N30G41H2G01X2.7574Y2.7574F315;
N35Z-0.625;
N40X3.4645Y3.4645;
N42Z0.5;
N45G40H2X3.9948Y3.9948;
N50G00X10.0052Y10.0052;
N55G41H2G01X10.5355Y10.5355F315;
N60Z-0.625;
N65X11.2426Y11.2426;
N70Z0.5;
N75G40H2X11.773Y11.773;
N80G00X2.227Y11.773;
N85G42H2G01X2.7574Y11.2426F315;
N90Z-0.625;
N95X3.4645Y10.5355;
N100Z0.5;
N105G40H2X3.9948Y10.0052;
N115G00X10.0052Y3.9948;
N120G42H2G01X10.5355Y3.4645F315;
N125Z-0.625;
N130X11.2426Y2.7574;
N132Z0.5;
N135G40H2X11.773Y2.227;
N145G00X0.636Y7.0;
N147Z-0.625;
N150G01X7.0Y13.364F315;
N160X13.364Y7.0;
N165X7.0Y0.636;
N170X0.636Y7.0;
N175G00Z0.5;
N180G00X0.2825Y5.9393;
N185G41H2G01X0.9896Y6.6464F315;
N190Z-0.625;
N195X7.0Y12.6569;
N197G4;
N200X12.6569Y7.0;
N202G4;
N205X7.0Y1.3431;
N207G4;
N210X0.9896Y7.3536;
N211G4;
N212Z0.5;
N215G40H2X0.2825Y8.0607;
N225G00X4.8787Y7.0;
N227Z-0.625;
N230G01X7.0Y9.1213F315;
N240X9.1213Y7.0;
N245X7.0Y4.8787;
N250X4.8787Y7.0;
N255G00Z0.5;
N260G00X4.5251Y5.9393;
N265G41H2G01X5.2322
                    Y6.6464F315;
N270Z-0.625;
N275X7.0Y8.4142;
N277G4;
N280X8.4142Y7.0;
N282G4;
N285X7.0Y5.5858;
N287G4;
N290X5.2322Y7.3536;
N291G4;
N292Z0.5;
N295G40H2X4.5251Y8.0607;
N297G28X0Y0Z0;
N305M30;
```

Note: All feed speeds in the program are changed to match the desired feed speed.

Figure A.8.4—Sample program (G&M code) for accuracy cutting of diamonds in specified raw material.

APPENDIX A.9

Program for Circles Cut in Acrylic Sheets (Repeatability)

Following are procedures for developing a G&M program for determining the repeatability of cutting circles in acrylic sheets. Figure A.9.1 provides information to assist in this development. Figure A.9.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.9.3 shows only the actual cuts made in the material. Use the following steps to develop the required main program and its subroutine in an absolute mode. Although feed rates are not discussed in these steps, they must be included in the program so that they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

To start the main program, make a positioning move to Point A (X0.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the left slot. Move 0.5 inch to the right at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move for 1 inch. Then, raise the tool to 0.25 inch above the material and move 0.5 inch to the right at 0° to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X11.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the right slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 1.

Step 4

Make a positioning move to Point C (X7.0,Y13.5) in line with and 0.5 inch from the upper end of the vertical line that represents the upper slot. Move down 0.5 inch at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move down for 1 inch. Then, raise the tool to a 0.25 inch above the material and move down 0.5 inch at 0° to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X7.0,Y2.5) in line with and 0.5 inch above the upper end of the vertical line representing the lower slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 4.

Step 6

Make a positioning move to Point E (X11.1875,Y7.0) at the right edge of the circle with a diameter of 8.375 inches. Lower the tool to a depth of -0.1875 inch and make a 360° move (roughing cut) in a counter clockwise direction without cutter compensation. Then, raise the cutter to 0.5 inch.

Step 7

Make a positioning move to Point G (X8.1875,Y7.0) at the right edge of the circle with a diameter of 2.375 inches. Lower the tool to a depth of -0.1875 inch and make a 360° move (roughing cut) in a counter clockwise direction without cutter compensation. Then, raise the cutter to 0.5 inch.

Step 8

At the end of the main program, include a subroutine call statement to run the subroutine 25 times. After the subroutine is called 25 times, move to machine reference zero.

Step 9

Start the subroutine by making a positioning move to Point F (X3.6599Y4.6108) to start the finish cut of the 8-inch circle. From this point, make a right cutter compensation move to point (X4.0429,Y4.2894). Next, lower the tool to -0.1562 inch and make a lead-in cut in a clockwise arc with a radius of 2 inches to the point (X4.1716,Y4.1716). Then, make the 360° counter clockwise finish cut to the 8-inch circle. From the finish point of the circle, make a lead-out cut in a clockwise arc with a radius of 2 inches to the point (X4.2894,Y4.0429). Raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to the point (X4.6108,Y3.6599).

Step 10

Raise the tool to 0.25 inch above the material and make a positioning move to Point H (X5.7812,Y6.7322) to start the finish cut of the 2-inch circle. From this point, make a right cutter compensation move to point (X6.1643,Y6.4108). Next, lower the tool to -0.1562 inch and make a lead-in cut in a clockwise arc with a radius of 2 inches to the point (X6.2929,Y6.2929). Then make the 360° counter clockwise finish cut to the 2-inch circle. From the finish point of the circle, make a lead-out cut in a clockwise arc with a radius of 2 inches to the point (X6.4108,Y6.1643). Raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to the point (X6.7322,Y5.7812).

Figure A.9.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

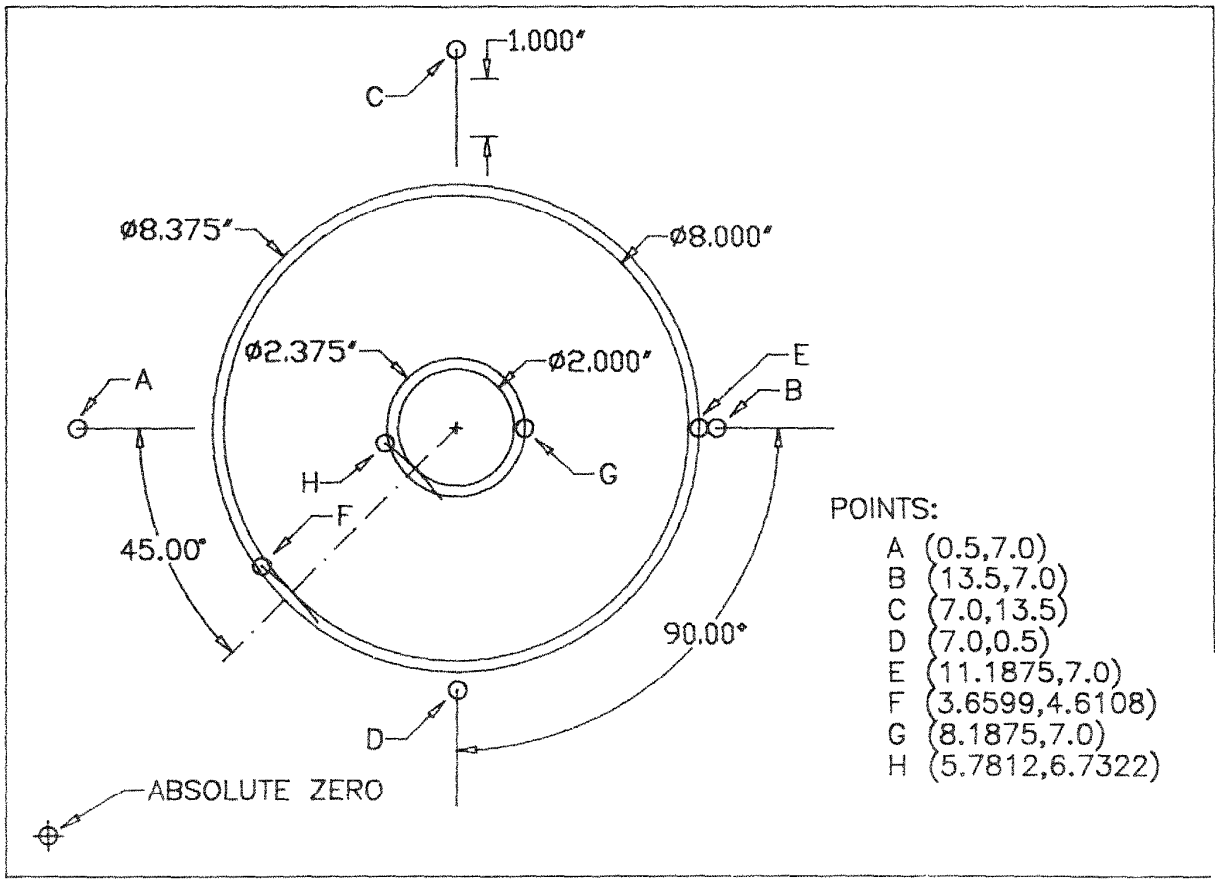


Figure A.9.1—Drawing showing information for developing a program (G&M code) needed to make circle repeatability cuts in acrylic sheets.

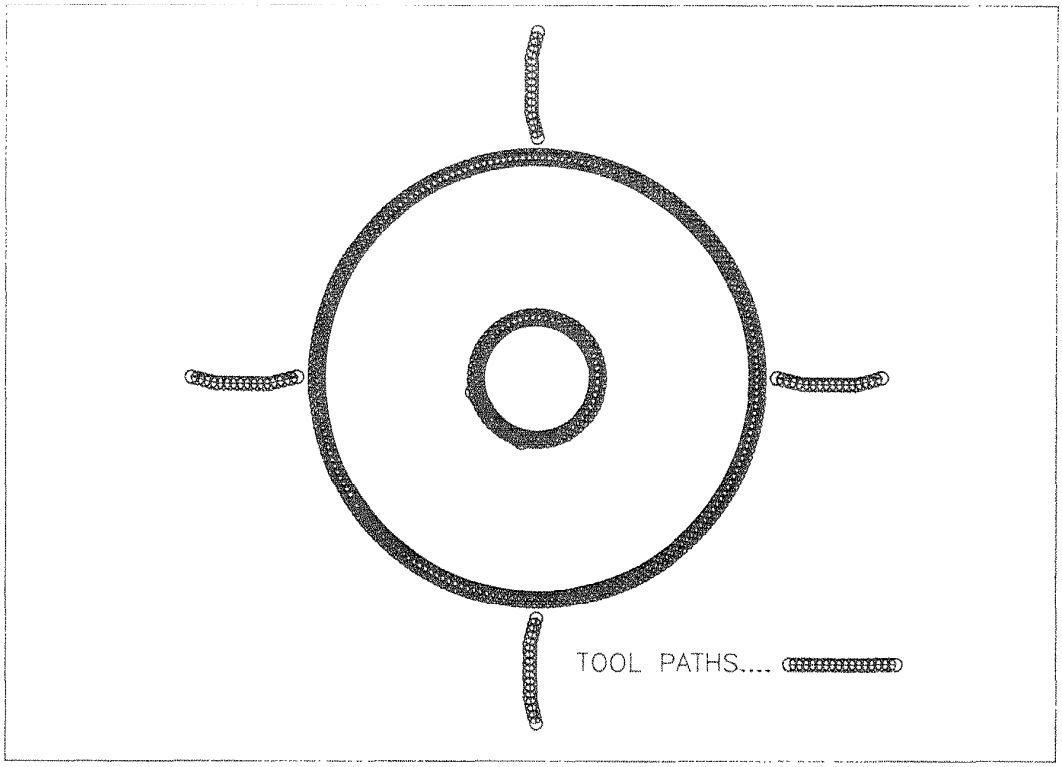


Figure A.9.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch circles in an acrylic sheet for repeatability evaluation.

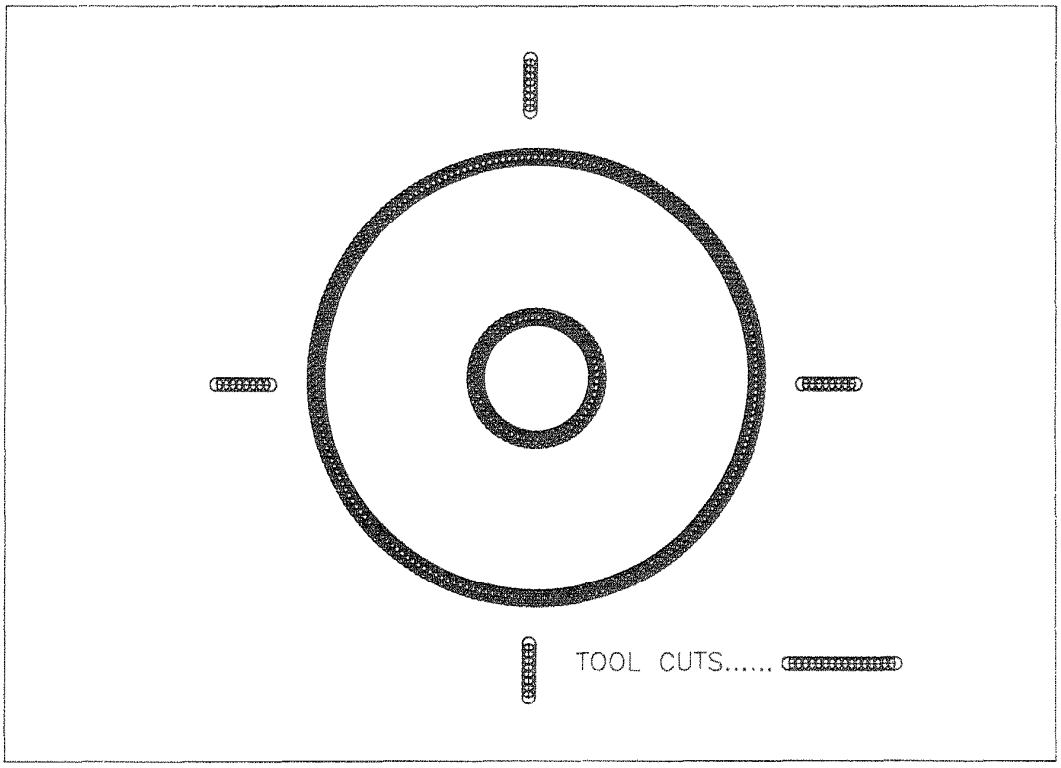


Figure A.9.3—Drawing showing only the actual cuts made in an acrylic sheet for the 2-inch and 8-inch circles used in repeatability evaluation.

PROGRAM FOR CIRCLES CUT IN ACRYLIC SHEETS
(REPEATABILITY)

```
O0056;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X0.5Y7.0;
N27Z0.25;
N30G42H1G01X1.0F100;
N35Z-0.1875;
N40X2.0;
N42Z0.25;
N45G40H1X2.5;
N55G00X11.5Y7.0;
N60G42H1G01X12.0F100;
N65Z-0.1875;
N70X13.0;
N72Z0.25;
N75G40H1X13.5;
N85G00X7.0Y13.5;
N90G42H1G01Y13.0F100;
N95Z-0.1875;
N100Y12.0;
N102Z0.25;
N105G40H1Y11.5;
N115G00X7.0Y2.5;
N120G42H1G01Y2.0F100;
N125Z-0.1875;
N130Y1.0;
N132Z0.25;
N135G40H1Y0.5
N145G00X11.1875Y7.0;
N147Z-0.1875;
N150G03I-4.1875F100;
N155G00Z0.25;
N160G00X8.1875Y7.0;
N165Z-0.1875;
N170G03I-1.1875F100;
N175G1F100Z0.25;
N180M98P250057;
N185M30;
```

```
O0057;
N5X0Y0;
N10G1F100X3.6599Y4.6108;
N15G42H1G1X4.0429Y4.2894F90;
N20Z-0.1562;
N25G2X4.1716Y4.1716R2;
N30G3X9.8284Y9.8284R4;
N35G3X4.1716Y4.1716R4;
N40G2X4.2894Y4.0429R2;
N45G1F100Z0.25;
N50G40H1G1X4.6108Y3.6599;
N55Y3.25;
N60G1F100X5.7812Y6.7322;
N65G42H1G1X6.1643Y6.4108F100;
N70Z-0.1562;
N75G2X6.2929Y6.2929R2;
N80G3X7.7071Y7.7071R1;
N85X6.2929Y6.2929R1;
N90G2X6.4108Y6.1643R2;
N95G1F100Z0.25;
N100G40H1G1X6.7322Y5.7812;
N105M99;
```

NOTE:
The feed speeds in Statements N15 and N65 of Subroutine O0057 are changed to match the deired feed speed.

Figure A.9.4—Sample program (G&M code) for repeatability cutting of circles in acrylic sheets.

APPENDIX A.10

Program for Squares Cut in Acrylic Sheets (Repeatability)

Following are procedures for developing a G&M program for determining the repeatability of cutting squares in acrylic sheets. Figure A.10.1 provides information to assist in this development. Figure A.10.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.10.3 shows only the actual cuts made in the material. Use the following steps to develop the required main program and its subroutine in an absolute mode. Although feed rates are not discussed in these steps, they must be included in the program so they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

To start the main program, make a positioning move to Point A (X0.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the left slot. Move 0.5 inch to the right at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move for 1 inch. Then, raise the tool 0.25 inch above the material and move 0.5 inch to the right at 0° to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X11.5,Y7.0) in line with and 0.5 inch from the left end of the horizontal line that represents the right slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 1.

Step 4

Make a positioning move to Point C (X7.0,Y13.5) in line with and 0.5 inch from the upper end of the vertical line that represents the upper slot. Move down 0.5 inch at 0° to provide a cutter compensation to the right side of the horizontal line. Next, lower the tool to a depth of -0.1875 inch and make a cutting move down for 1 inch. Then, raise the tool 0.25 inch above the material and move down 0.5 inch at 0° to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X7.0,Y2.5) in line with and 0.5 inch above the upper end of the vertical line representing the lower slot. Then, repeat the cutter compensation and cutting moves as discussed in Step 4.

Step 6

Make a positioning move to Point E (X2.8125,Y2.8125) at lower left corner of the 8.375-inch square. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves horizontally to point (X11.1875), vertically to point (Y11.1875), horizontally to point (X2.8125), and vertically back to point (Y2.8125). Then, raise the cutter to 0.25 inch.

Step 7

Make a positioning move to Point G (X5.8125,Y5.8125) at lower left corner of the 2.375-inch square. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves horizontally to point (X8.1875), vertically to point (Y8.1875), horizontally to point (X5.8125), and vertically back to point (Y5.8125). Then, raise the cutter to 0.25 inch.

Step 8

At the end of the main program, include a subroutine call statement to run the subroutine 25 times. After the subroutine is called 25 times, move to machine reference zero.

Step 9

Start the subroutine by making a positioning move to Point F (X2.25,Y3.0) to start the finish cut of the 8-inch square. From this point, make a horizontal cutter compensation move to point (X2.75). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves horizontally to point (X11.0), vertically to point (Y11.0), horizontally to point (X3.0), and vertically to point (Y2.75). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a vertical move to point (Y2.25).

Step 10

Raise the tool to 0.25 inch above the material and make a positioning move to Point H (X5.25,Y6.0) to start the finish cut of the 2-inch square. From this point, make a horizontal cutter compensation move to point (X5.75). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves horizontally to point (X8.0), vertically to point (Y8.0), horizontally to point (X6.0), and vertically to point (Y5.75). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a vertical move to point (Y5.25).

Figure A.10.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

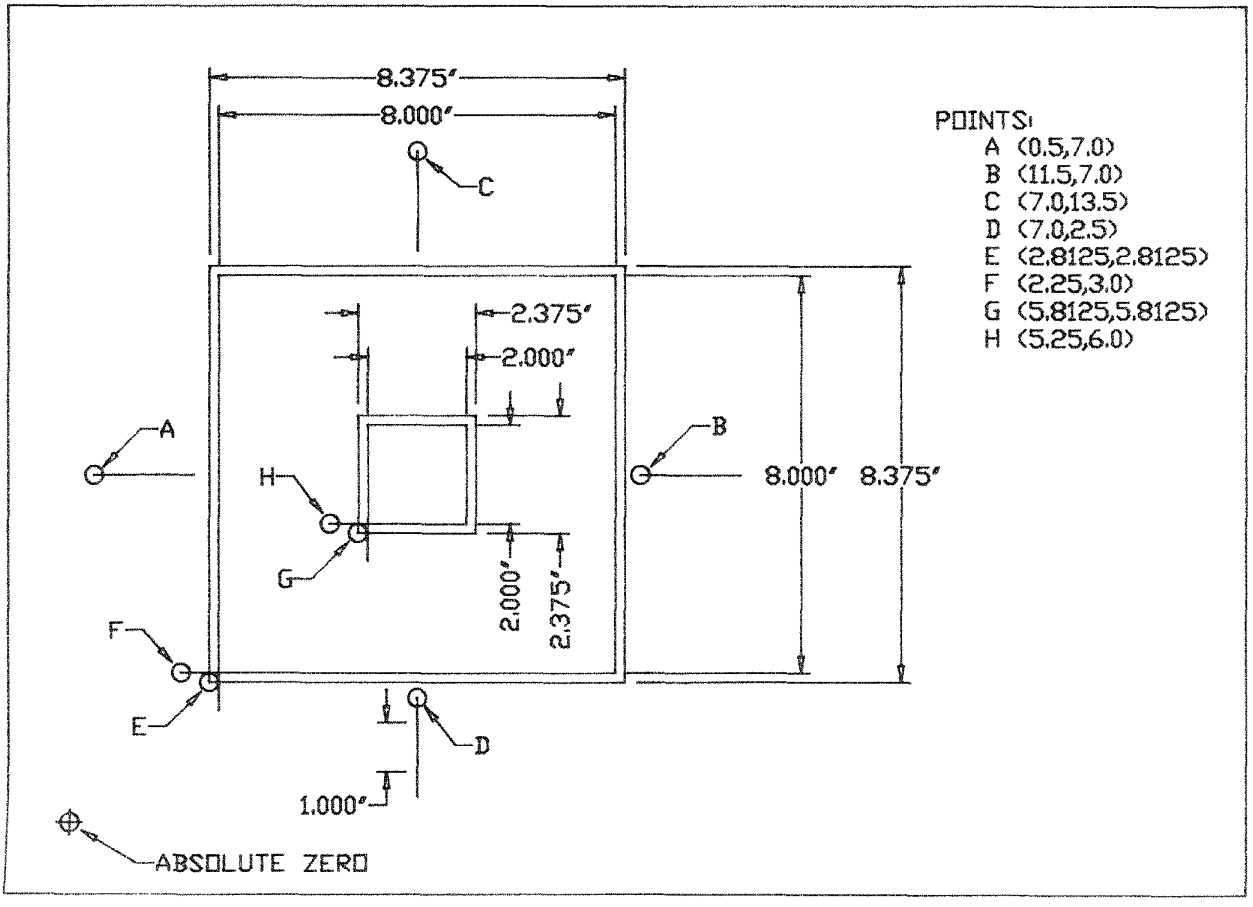


Figure A.10.1—Drawing showing information for developing a program (G&M code) needed to make square repeatability cuts in acrylic sheets.

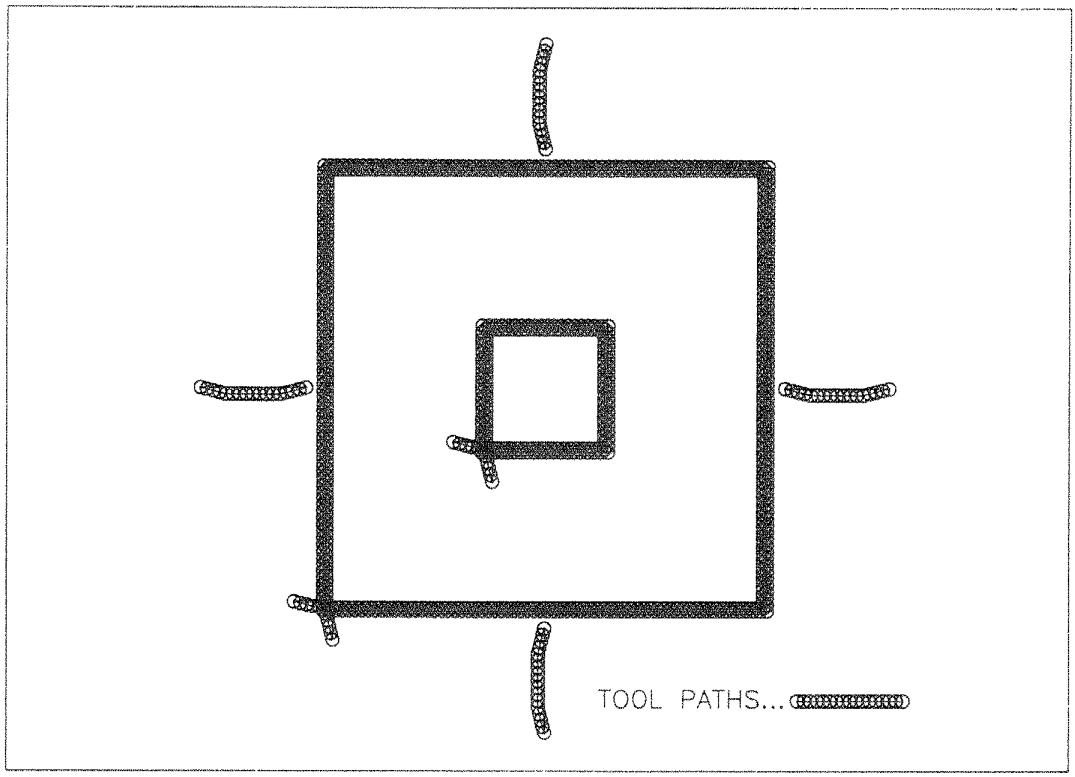


Figure A.10.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch squares in an acrylic sheet for repeatability evaluation.

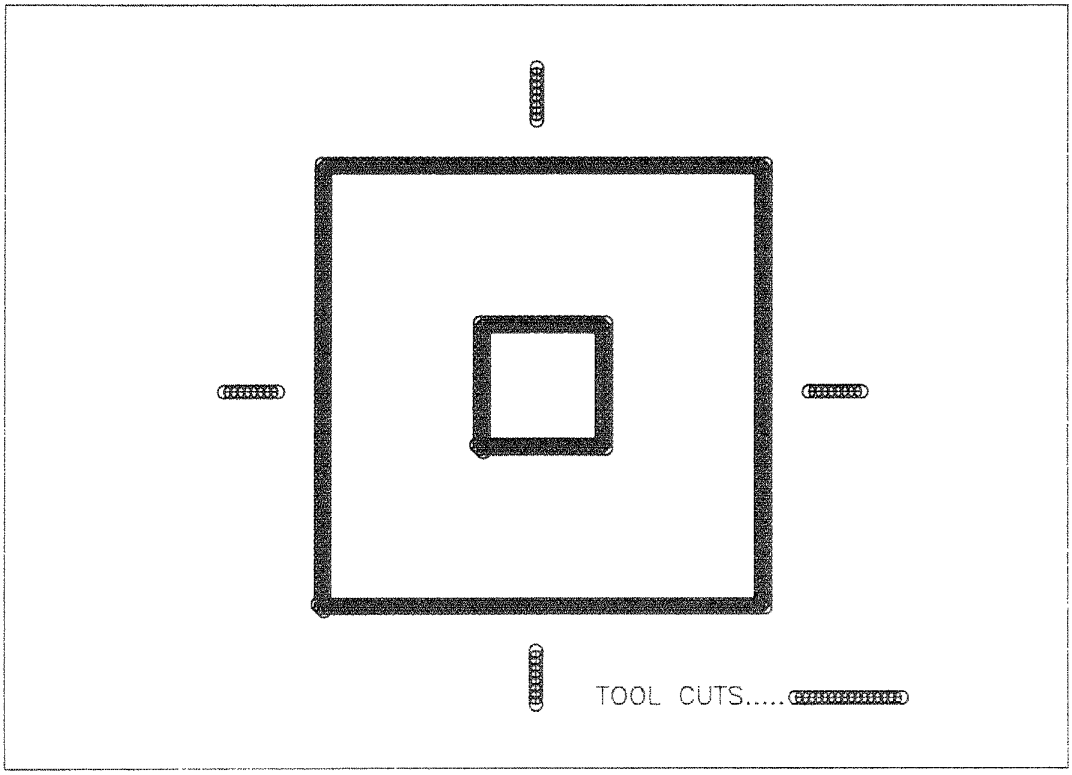


Figure A.10.3—Drawing showing only the actual cuts made in an acrylic sheet for the 2-inch and 8-inch squares used in repeatability evaluation.

PROGRAM FOR SQUARES CUT IN ACRYLIC SHEETS
(REPEATABILITY)

```
O0058;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X0.5Y7.0;
N30Z0.25;
N35G42H1G01X1.0F100;
N40Z-0.1875;
N45X2.0;
N50Z0.25;
N55G40H1X2.5;
N60G00G1X11.5Y7.0;
N62G42H1G01X12.0F100;
N65Z-0.1875;
N70X13.0;
N72Z0.25;
N75G40H1X13.5;
N85G00X7.0Y13.5;
N90G42H1G01Y13.0F100;
N95Z-0.1875;
N100Y12.0;
N102Z0.25;
N105G40H1Y11.5;
N115G00X7.0Y2.5;
N120G42H1G01Y2.0F100;
N125Z-0.1875;
N130Y1.0;
N132Z0.25;
N135G40H1Y0.5;
N140G00Z0.25;
N145G00X2.8125Y2.8125;
N150Z-0.1875;
N155G01X11.1875F100;
N160Y11.1875;
N165X2.8125;
N170Y2.8125;
N175G00Z0.25;
N180G00X5.8125Y5.8125;
N185Z-0.1875;
N190G01X8.1875F100;
N195Y8.1875;
N200X5.8125;
N205Y5.8125;
N210G00Z0.25;
N215M98P250059;
N220M30;
```

```
O0059;
N2X0Y0;
N5G1F100X2.25Y3;
N10G42H1G1X2.75F100;
N15Z-0.1562;
N20X11;
N22G4;
N25Y11;
N27G4:
N30X3;
N32G4;
N35Y2.75;
N37G4;
N40Z0.25;
N45G40H1Y2.25;
N50Y2;
N55G1F100X5.25Y6.0;
N60G42H1G01X5.75F100;
N65Z-0.1562;
N70X8;
N72G4;
N75Y8;
N77G4;
N80X6;
N82G4;
N85Y5.75;
N87G4;
N90Z0.25;
N95G40H1Y5.25;
N100M99;
```

NOTE:
The feed speeds in Statements N10 and N60 of Subroutine O0059 are changed to match the desired feed speed.

Figure A.10.4—Sample program (G&M code) for repeatability cutting of squares in acrylic sheets.

APPENDIX A.11

Program for Diamonds Cut in Acrylic Sheets
(Repeatability)

Following are procedures for developing a G&M program for determining the repeatability of cutting diamonds in acrylic sheets. Figure A.11.1 provides information to assist in this development. Figure A.11.2 shows the tool path for all moves including cutter compensations, lead-in/lead-out cuts, roughing cuts, and final cuts. Figure A.11.3 shows only the actual cuts made in the material. Use the following steps to develop the required main program and its subroutine in an absolute mode. Although feed rates are not discussed in these steps, they must be included in the program so that they can be changed as necessary.

Step 1

Set the absolute zero position at a point -7 inches in the X-axis and -7 inches in the Y-axis from the exact center of the table.

Step 2

To start the main program make a positioning move to Point A (X2.4038,Y2.4038) in line with and 0.5 inch from the lower left end of the line that represents the lower left slot. Move 0.5 inch to point (X2.7574,Y2.7574) with a left cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X3.4645,Y3.4645). Then, raise the tool to 0.25 inch above the material and move to point (X3.818,Y3.818) to remove the cutter compensation.

Step 3

Make a positioning move to Point B (X10.182,Y10.182) in line with and 0.5 inch from the lower left end of the line that represents the upper right slot. Move 0.5 inch to point (X10.5355,Y10.5355) with a left cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X11.2426,Y11.2426). Then, raise the tool to 0.25 inch above the material and move to point (X11.5962,Y11.5962) to remove the cutter compensation.

Step 4

Make a positioning move to Point C (X2.4038,Y11.5962) in line with and 0.5 inch from the upper left end of the line that represents the upper left slot. Move 0.5 inch to point (X2.7574,Y11.2426) with a right cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X3.4645,Y10.5355). Then, raise the tool to 0.25 inch above the material and move to point (X3.818,Y10.182) to remove the cutter compensation.

Step 5

Make a positioning move to Point D (X10.182,Y3.818) in line with and 0.5 inch from the upper left end of the line that represents the lower right slot. Move 0.5 inch to point (X10.5355,Y3.4645) with a right cutter compensation. Next, lower the tool to a depth of -0.1875 inch and make a cutting move to point (X11.2426,Y2.7574). Then, raise the tool to 0.25 inch above the material and move to point (X11.5962,Y2.4038) to remove the cutter compensation.

Step 6

Make a positioning move to Point E (X1.078,Y7.0) at left corner of the 8.375-inch diamond. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves to point (X7.0,Y1.078), to point (X12.922,Y7.0), to point (X7.0,Y12.922), and back to point (X1.078,Y7.0). Then, raise the cutter to 0.25 inch.

Step 7

Make a positioning move to Point G (X5.3206,Y7.0) at left corner of the 2.375-inch diamond. Lower the tool to a depth of -0.1875 inch and without cutter compensation make counter clockwise cutting moves to point (X7.0,Y5.3206), to point (X8.6794,Y7.0), to point (X7.0,Y8.6794), and back to point (X5.3206,Y7.0). Then, raise the cutter to 0.25 inch.

Step 8

At the end of the main program, include a subroutine call statement to run the subroutine 25 times. After the subroutine is called 25 times, move to machine reference zero.

Step 9

Start the subroutine by making a positioning move to Point F (X0.8128,Y7.5303) to start the finish cut of the 8-inch diamond. From this point, make a right cutter compensation move to point (X1.1664,Y7.1768). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves to point (X7.0,Y1.3431), to point (X12.6569,Y7.0), to point (X3.0), and to point (X1.1664,Y6.8232). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to point (X0.8128,Y6.4697).

Step 10

Raise the tool to 0.25 inch above the material and make a positioning move to Point H (X5.0555,Y7.5303) to start the finish cut of the 2-inch diamond. From this point, make a cutter compensation move to point (X5.409,Y7.1768). Next, lower the tool to -0.1562 inch and make counter clockwise cutting moves to point (X7.0,Y5.5858), to point (X8.4142,Y7.0), to point (X7.0,Y8.4142), and to point (X5.409,Y6.8232). Then, raise the tool to 0.25 inch above the material and remove the cutter compensation with a move to point (X5.0555,Y6.4697).

Figure A.11.4 shows a sample program for this procedure. Due to differences in controllers, it may be necessary to make minor changes in this program.

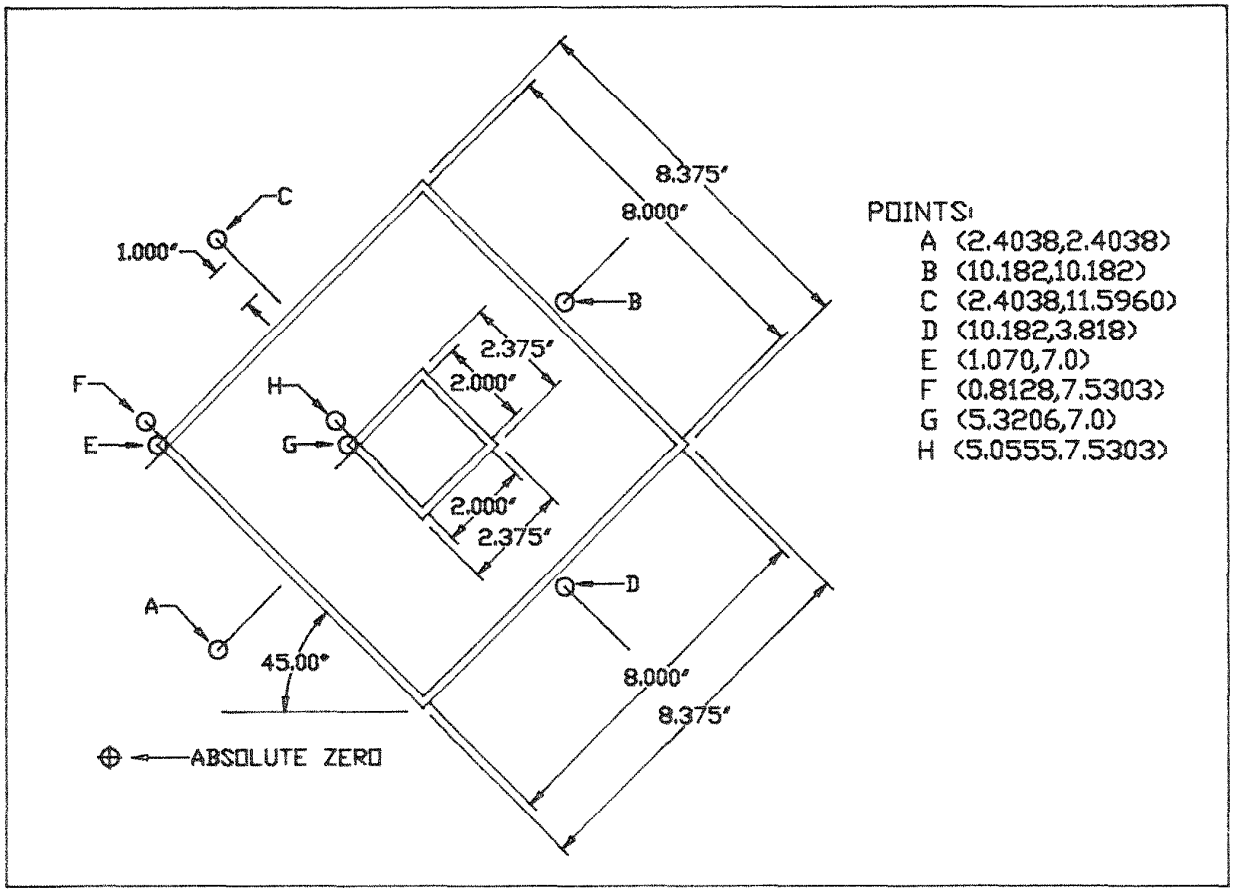


Figure A.11.1—Drawing showing information for developing a program (G&M code) needed to make diamond repeatability cuts in acrylic sheets.

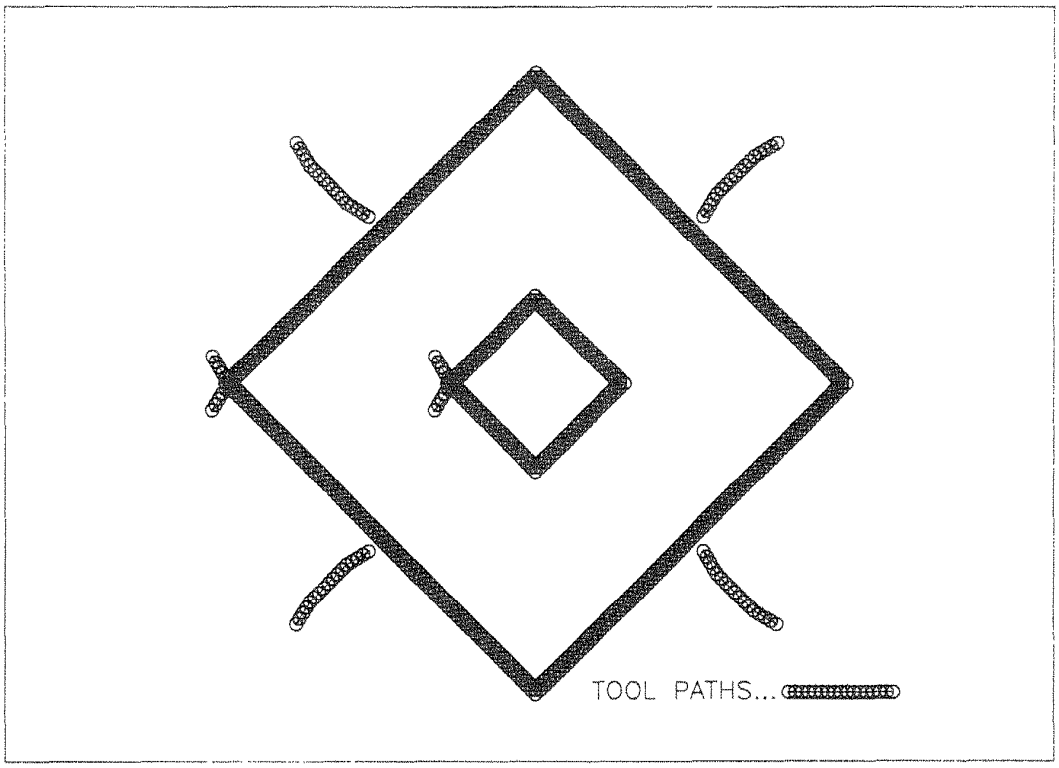


Figure A.11.2—Drawing showing tool paths (roughing cuts, offset moves, lead-in cuts, and finish cuts) used to cut both the 2-inch and 8-inch diamonds in an acrylic sheet for repeatability evaluation.

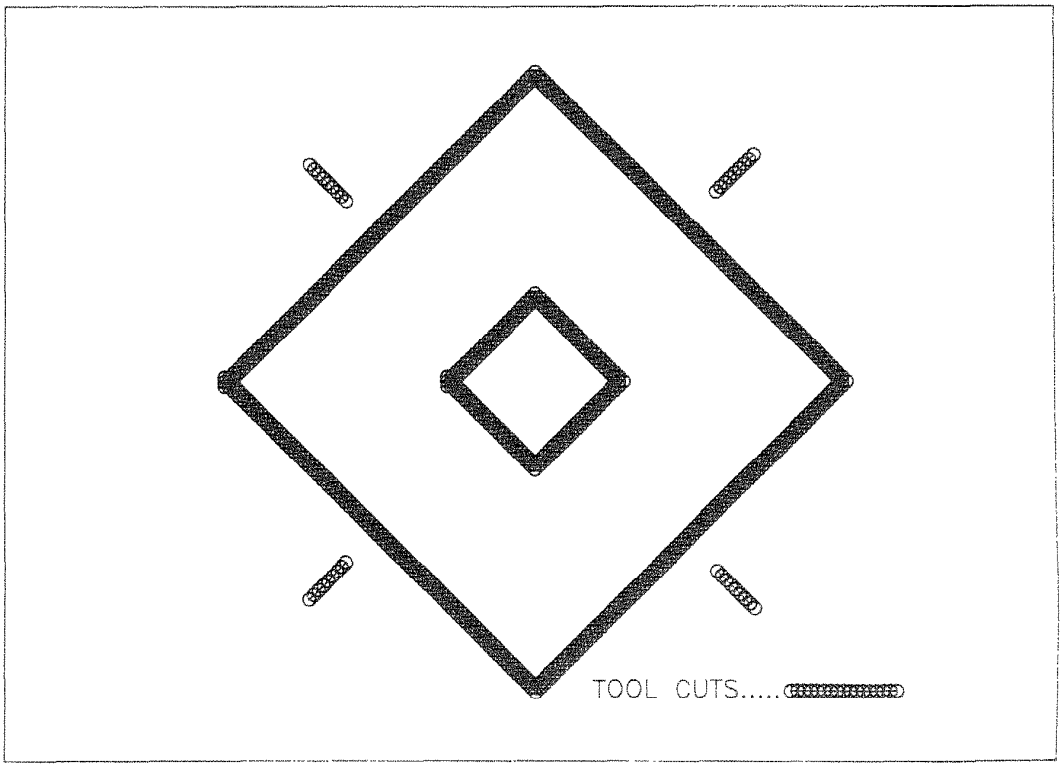


Figure A.11.3—Drawing showing only the actual cuts made in an acrylic sheet for the 2-inch and 8-inch diamonds used in repeatability evaluation.

PROGRAM FOR DIAMONDS CUT IN ACRYLIC SHEETS
(REPEATABILITY)

```
O0060;
N5G91;
N10G28X0Y0Z0;
N15G92X-31.5Y22.5;
N20G90;
N25G00X2.4038Y2.4038;
N27Z0.25;
N30G41H1G01X2.7574Y2.7574F100;
N35Z-0.1875;
N40X3.4645Y3.4645;
N42Z0.25;
N45G40H1X3.818Y3.818;
N55G00X10.182Y10.182;
N60G41H1G01X10.5355Y10.5355F100;
N65Z-0.1875;
N70X11.2426Y11.2426;
N72Z0.25;
N75G40H1X11.5962Y11.5962;
N85G00X2.4038Y11.5962;
N90G42H1G01X2.7574Y11.2426F100;
N95Z-0.1875;
N100X3.4645Y10.5355;
N102Z0.25;
N105G40H1X3.818Y10.182;
N115G00X10.182Y3.818;
N120G42H1G01X10.5355Y3.4645F100;
N125Z-0.1875;
N130X11.2426Y2.7574;
N132Z0.25;
N135G40H1X11.5962Y2.4038;
N145G00X1.078Y7.0;
N147Z-0.1875;
N150G01X7.0Y1.078F100;
N160X12.922Y7.0;
N165X7.0Y12.922;
N170X1.078Y7.0;
N175G00Z0.25;
N180G00X5.3206Y7.0;
N185Z-0.1875;
N190G01X7.0Y5.3206F100;
N195X8.6794Y7.0;
N200X7.0Y8.6794;
N205X5.3206Y7.0;
N210G00Z0.25;
N215M98P250061;
N220M30;
```

```
O0061;
N5X0Y0;
N10G1F100X0.8128Y7.5303;
N15G42H1G1X1.1664
                Y7.1768F100;
N20Z-0.1562;
N25X7Y1.3431;
N27G4;
N30X12.6569Y7;
N32G4;
N35X7Y12.6569;
N37G4;
N40X1.1664Y6.8232;
N42G4;
N45Z0.25;
N50G40H1X0.8128Y6.4697;
N55G1F100X5.0555Y7.5303;
N60G42H1G1X5.409
              Y7.1768F100;
N65Z-0.1562;
N70X7Y5.5858;
N72G4;
N75X8.4142Y7;
N77G4;
N80X7Y8.142;
N82G4;
N85X5.409Y6.8232;
N87G4;
N90X0.25;
N95G40H1X5.0555Y6.4697;
N100M99;
```

NOTE:
The feed speeds in Statements N15 and N60 of Subroutine O0061 are changed to match the desired feed speed.

Figure A.11.4—Sample program (G&M code) for repeatability cutting of diamonds in acrylic sheets.