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CNC Router Evaluation Procedures

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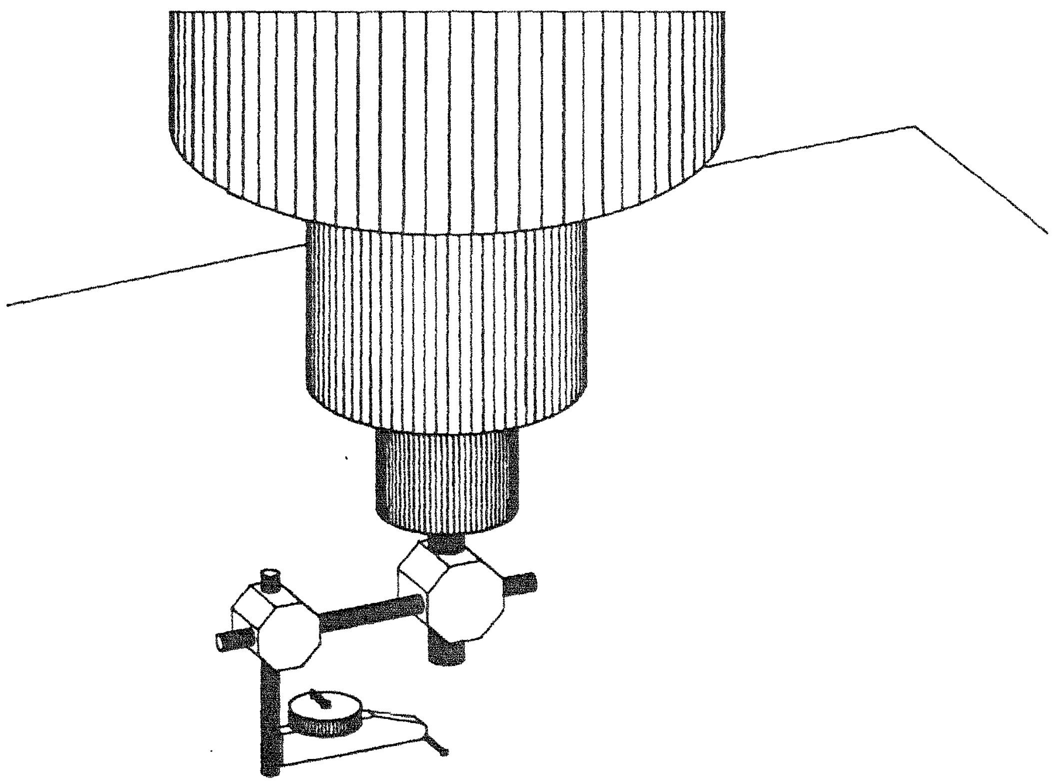

Abstract

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.

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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

3.0 Machining Evaluation

3.1 Accuracy (Cuts In Acrylic Sheets)

3.1.1 Circles Cut In Acrylic Sheets

Purpose—This procedure determines the ability of the router to accurately cut circles at different feed rates with minimal effects of cutting pressures.

Recommended equipment:

- A 1/4-inch-thick, 12-inch-square sheet of cast acrylic (Lucite'L or equivalent) is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the circles used in the procedure. This is discussed later.
- A 0.25-inch collet and 0.25-inch upcut spiral tool for cutting the acrylic.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) used in the procedure will be specified by the potential user of the machine. For each feed rate, the circles are cut in 1/4-inch-thick cast acrylic sheets. Because the final cuts only remove 0.0625 inch of material, there is minimal cutting pressure. The following steps describe the procedure in detail.

Step 1
Develop and load a program into the CNC controller for cutting two circles with finish diameters of 2 and 8 inches. First, roughing cuts are made with an offset of 0.0625 inch from the finish circles' diameters to a depth of 0.1875 of an inch. Then, the final cuts are made to the target dimensions to a depth of 0.1562 of an inch. The program also must provide for cutting 1.25-inch slots with the center of the tool starting 1 inch from the outer circle and radiating out at 0°, 90°, 180°, and 270°. The center of the tool should be offset to the right for the 0° and 270° slots and offset to the left for the 90° and 180° slots. These slots are used as guides for a straightedge to mark the circles for measurements. Figure 3.1 shows the cuts made in the material. Appendix A.3 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification.

Step 2
Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3
Mount the 0.25-inch tool for cutting the acrylic into the spindle collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4
Using a proper fixture, attach a 12-inch-square, 1/4-inch-thick acrylic sheet to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the circle program and cut the first group of circles. Be sure to mark the feet rate used on the acrylic sheet.

Step 5
Repeat Step 4 with a new acrylic sheet for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.25-inch slots as guides, mark or scratch lines through the center of the circles in both the X-axis and Y-axis on the acrylic squares as shown in Figure 3.1. Identify the points where the lines intersect the circles with letters of the alphabet as shown in the figure. Measure and record diameters A-B and C-D of the large circle and diameters E-F and G-H of the small circle. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each acrylic square representing the different feed speeds. Here is an example of the study router's circle cutting accuracy at three different feed rates:

	Circle Cutting Accuracy					
	Feed Speed					
Measurement	100 IPM		200 IPM		300 IPM	
Location	Target	Actual	Target	Actual	Target	Actual
	- - - - - - - - - - Diameter (*Inches*) - - - - - - - - -					
A-B	8.000	7.977	8.000	7.975	8.000	7.973
C-D	8.000	7.982	8.000	7.980	8.000	7.978
E-F	2.000	1.992	2.000	1.985	2.000	1.974
G-H	2.000	1.992	2.000	1.986	2.000	1.975

Note: The above procedure evaluates the cutting accuracy only at the center of the router table. However, if accuracy is a critical factor, the same procedure can be done at other locations on the table.

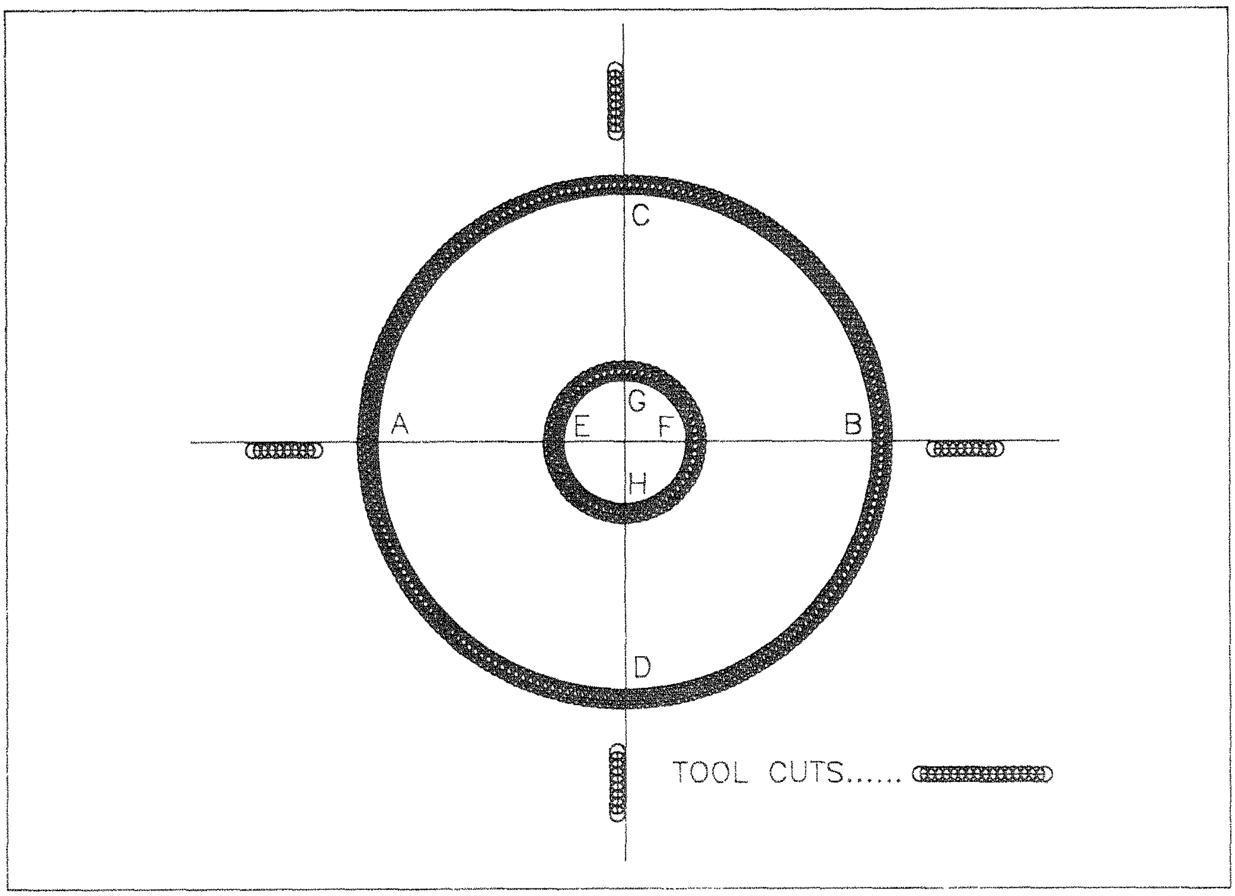


Figure 3.1—Drawing showing accuracy cuts in acrylic sheet and measurement points for both the 2-inch and 8-inch circles.

3.1.2 Squares Cut In Acrylic Sheets

Purpose—This procedure determines the ability of the router to accurately cut squares at different feed rates with minimal effects of cutting pressures.

Recommended equipment:

- A 1/4-inch-thick, 12-inch-square sheet of cast acrylic (Lucite'L or equivalent) is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Programs for the CNC controller to cut the squares used in the procedure. This is discussed later.
- A 0.25-inch collet and 0.25-inch upcut spiral tool for cutting the acrylic.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) used in the procedure will be specified by the potential user of the machine. For each feed rate, the squares are cut in 1/4-inch-thick cast acrylic sheets. Because the final cuts only remove 0.0625 inch of material, there is minimal cutting pressure. The following steps describe the procedure in detail.

Step 1
Develop and load a program into the CNC controller for cutting two squares with finish dimensions of 2 and 8 inches. First, roughing cuts are made with an offset of 0.0625 inch from the finish squares' dimensions to a depth of 0.1875 of an inch. Then, the final cuts are made to the target dimensions to a depth of 0.1562 of an inch. The program also must provide for cutting 1.25-inch slots with the center of the tool starting 1 inch from the outer square and radiating out at 0°, 90°, 180°, and 270°. The center of the tool should be offset to the right for the 0° and 270° slots and offset to the left for the 90° and 180° slots. These slots are used as guides for a straightedge to mark the squares for measurements. Figure 3.2 shows the cuts made in the material. Appendix A.4 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification. Notice in the program that there is a G4 exact stop code at each corner of the square when making the finish cuts. These stop codes must be used to assure that the corners of the square are not rounded off.

Step 2
Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3
Mount the 0.25-inch tool for cutting the acrylic into the spindle collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

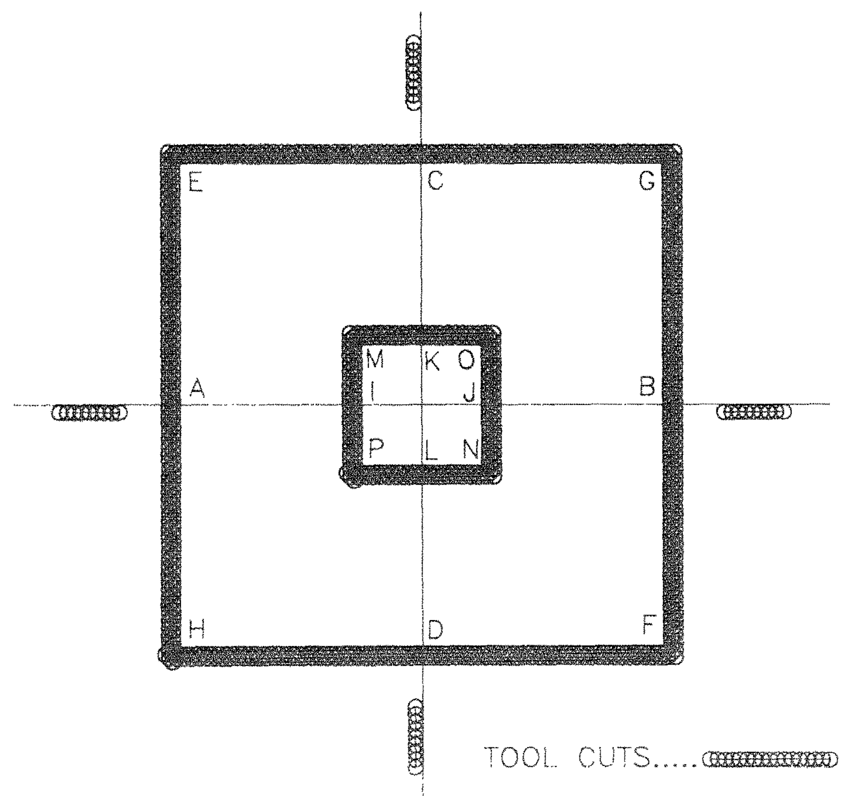
Step 4
Using a proper fixture, attach a 12-inch-square, 1/4-inch-thick acrylic sheet to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the square program and cut the first group of squares. Be sure to mark the feed rate used on the acrylic sheet.

Step 5
Repeat Step 4 with a new acrylic sheet for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.25-inch slots as guides, mark or scratch lines through the center of the squares in both the X-axis and Y-axis on the acrylic squares as shown in Figure 3.2. Identify the points where the lines intersect the squares and the corners of the squares with letters of the alphabet as shown in the figure. Measure and record dimensions A-B, C-D, E-F, and G-H of the large square and dimensions I-J, K-L, M-N, and O-P of the small square. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each acrylic square representing the different feed speeds. Here is an example of the study router's square cutting accuracy at three different feed rates:

Square Cutting Accuracy						
	Feed Speed					
Measurement	100 IPM		200 IPM		300 IPM	
Location	Target	Actual	Target	Actual	Target	Actual
	- - - - - - - - - Dimension (*Inches*) - - - - - - - - -					
A-B	8.000	8.003	8.000	8.003	8.000	8.003
C-D	8.000	8.007	8.000	8.008	8.000	8.008
E-F	11.314	11.317	11.314	11.316	11.314	11.315
G-H	11.314	11.318	11.314	11.319	11.314	11.318
I-J	2.000	2.001	2.000	2.002	2.000	2.003
K-L	2.000	2.004	2.000	2.005	2.000	2.003
M-N	2.828	2.829	2.828	2.827	2.828	2.828
O-P	2.828	2.828	2.828	2.827	2.828	2.828

Note: The above procedure evaluates the cutting accuracy only at the center of the router table. However, if accuracy is a critical factor, the same procedure can be done at other locations on the table.



ıre 3.2—Drawing showing accuracy cuts in acrylic sheet and measurement points for both 2-inch and 8-inch squares.

3.1.3 Diamonds Cut in Acrylic Sheets

Purpose—This procedure determines the ability of the router to accurately cut diamonds at different feed rates with minimal effects of cutting pressures.

Recommended equipment:

- A 1/4-inch-thick, 12-inch-square sheet of cast acrylic (Lucite'L or equivalent) is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Programs for the CNC controller to cut the diamonds used in the procedure. This is discussed later.
- A 0.25-inch collet and 0.25-inch upcut spiral tool for cutting the acrylic.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) used in the procedure will be specified by the potential user of the machine. For each feed rate, the diamonds are cut in 1/4-inch-thick cast acrylic sheets. Because the final cuts only remove 0.0625 inch of material, there is minimal cutting pressure. The following steps describe the procedure in detail.

Step 1

Develop and load a program into the CNC controller for cutting two diamonds with finish dimensions of 2 and 8 inches. First, roughing cuts are made with an offset of 0.0625 inch from the finish diamonds' dimensions to a depth of 0.1875 of an inch. Then, the final cuts are made to the target dimensions to a depth of 0.1562 = of an inch. The program also must provide for cutting 1.25-inch slots with the center of the tool starting 1 inch from the outer diamond and radiating out at 45°,135°, 225°, and 315°. The center of the tool should be offset to the right for the 225° and 315° slots and offset to the left for the 45° and 135° slots. These slots are used as guides for a straightedge to mark the diamonds for measurements. Figure 3.3 shows the cuts made in the material. Appendix A.5 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification. Notice in the program that there is a G4 exact stop code at each corner of the diamond when making the finish cuts. These stop codes must be used to assure that the corners of the diamonds are not rounded off.

Step 2

Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3

Mount the 0.25-inch tool for cutting the acrylic into the spindle collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4

Using a proper fixture, attach a 12-inch square, 1/4-inch-thick acrylic sheet to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the diamond program and cut the first group of diamonds. Be sure to mark the feed rate used on the acrylic sheet.

Step 5

Repeat Step 4 with a new acrylic sheet for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.25-inch slots as guides, mark or scratch lines through the center of the diamonds on the acrylic squares as shown in Figure 3.3. Identify the points where the lines intersect the diamonds and the corners of the diamonds with letters of the alphabet as shown in the figure. Measure and record dimensions A-B, C-D, E-F, and G-H of the large diamond and dimensions I-J, K-L, M-N, and O-P of the small diamond. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each acrylic square representing the different feed speeds. Here is an example of the study router's diamond cutting accuracy at three different feed rates:

	Diamond Cutting Accuracy					
	Feed Speed					
Measurement	100 IPM		200 IPM		300 IPM	
Location	Target	Actual	Target	Actual	Target	Actual
	--------- Dimension (Inches) ---------					
A-B	8.000	8.005	8.000	8.009	8.000	8.009
C-D	8.000	8.004	8.000	8.009	8.000	8.007
E-F	11.314	11.313	11.314	11.311	11.314	11.316
G-H	11.314	11.323	11.314	11.328	11.314	11.323
I-J	2.000	2.002	2.000	2.006	2.000	2.006
K-L	2.000	2.002	2.000	2.004	2.000	2.006
M-N	2.828	2.827	2.828	2.823	2.828	2.828
O-P	2.828	2.829	2.828	2.832	2.828	2.828

Note: The above procedure evaluates the cutting accuracy only at the center of the router table. However, if accuracy is a critical factor, the same procedure can be done at other locations on the table.

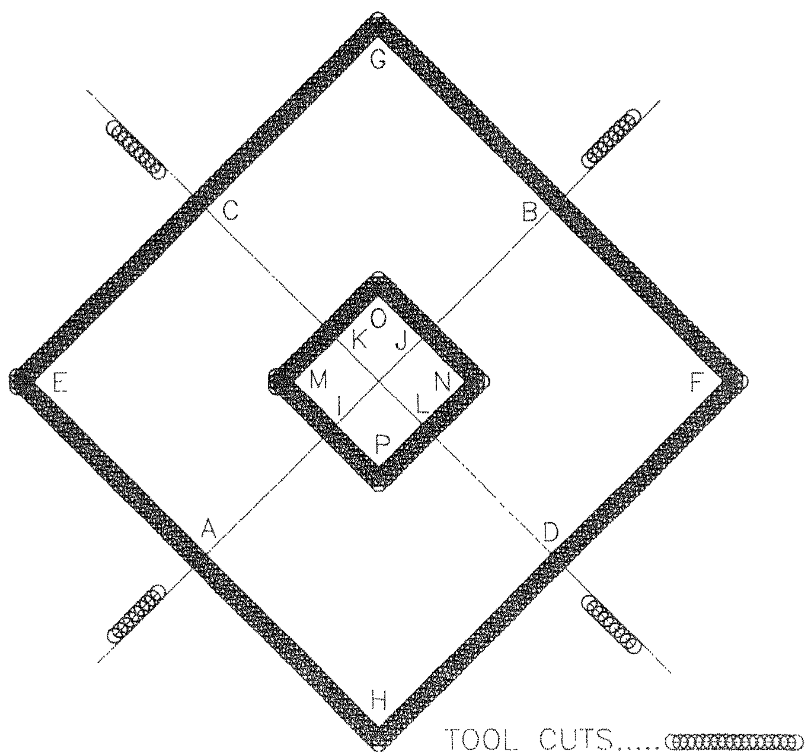


Figure 3.3—Drawing showing accuracy cuts in acrylic sheet and measurement points for both the 2-inch and 8-inch diamonds.

3.2 Accuracy (Cuts in Specified Raw Material)

3.2.1 Circles Cut in Specified Raw Material

Purpose—This procedure determines the ability of the router to accurately cut circles in specified raw material at specified feed rates.

Recommended equipment:

- A 3/4-inch-thick, 12-inch-square piece of the specified raw material is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the circles used in the procedure. This is discussed later.
- A tool/bit with a 0.5-inch diameter cutting head.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) and raw material used in the procedure will be specified by the potential user of the machine. For each feed rate, the circles are cut in the 3/4-inch-thick raw material. The final cuts remove material from only one side of the tool. The resulting side pressure is transferred to the spindle. This procedure measured how the side pressure affects cutting accuracy. The following steps describe the procedure in detail.

Step 1

Develop and load a program into the CNC controller for cutting two circles with diameters of 2 and 8 inches with 0.5-inch lead-in and lead-out cuts of "0°" at the start and end of the cut for each circle. First, roughing cuts are made with an offset from the finish circles' diameters to a depth of 0.625 of an inch. Then, the final cuts are made to the target dimensions to a depth of 0.625 of an inch. The program also must provide for cutting 1.5-inch slots, with the center of the tool starting 1 inch from the outer circle and radiating out at 0°, 90°, 180°, and 270°. The center of the tool should be offset to the right for the 0° and 270° slots and offset to the left for the 90° and 180° slots. These slots are used as guides for a straightedge to mark the circles for measurements. Figure 3.4 shows the cuts made in the material. Appendix A.6 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification.

Step 2

Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3

Mount the 0.5-inch tool into the collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4

Using a proper fixture, attach the 12-inch-square panel to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the circle program and cut the first group of circles. Be sure to mark the feed rate used on the panel.

Step 5

Repeat Step 4 with a new raw material panel for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.5-inch slots as guides, mark or scratch lines through the center of the circles in both the X-axis and Y-axis on the raw material panels as shown in Figure 3.4. Identify the points where the lines intersect the circles with letters of the alphabet as shown in the figure. Measure and record diameters A-B and C-D of the large circle and diameters E-F and G-H of the small circle. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each raw material panel representing the different feed speeds. Here is an example of the study router's circle cutting accuracy in the specified raw material at a feed rate of 315 IPM.

Circle Cutting Accuracy		
Measurement Location	Target	Actual
	- Diameter (*Inches*) -	
A-B	8.000	7.984
C-D	8.000	7.994
E-F	2.000	1.987
G-H	2.000	1.995

Note: The above procedure evaluates the cutting accuracy only at the center of the router table. However, if accuracy is a critical factor, the same procedure can be done at other locations on the table.

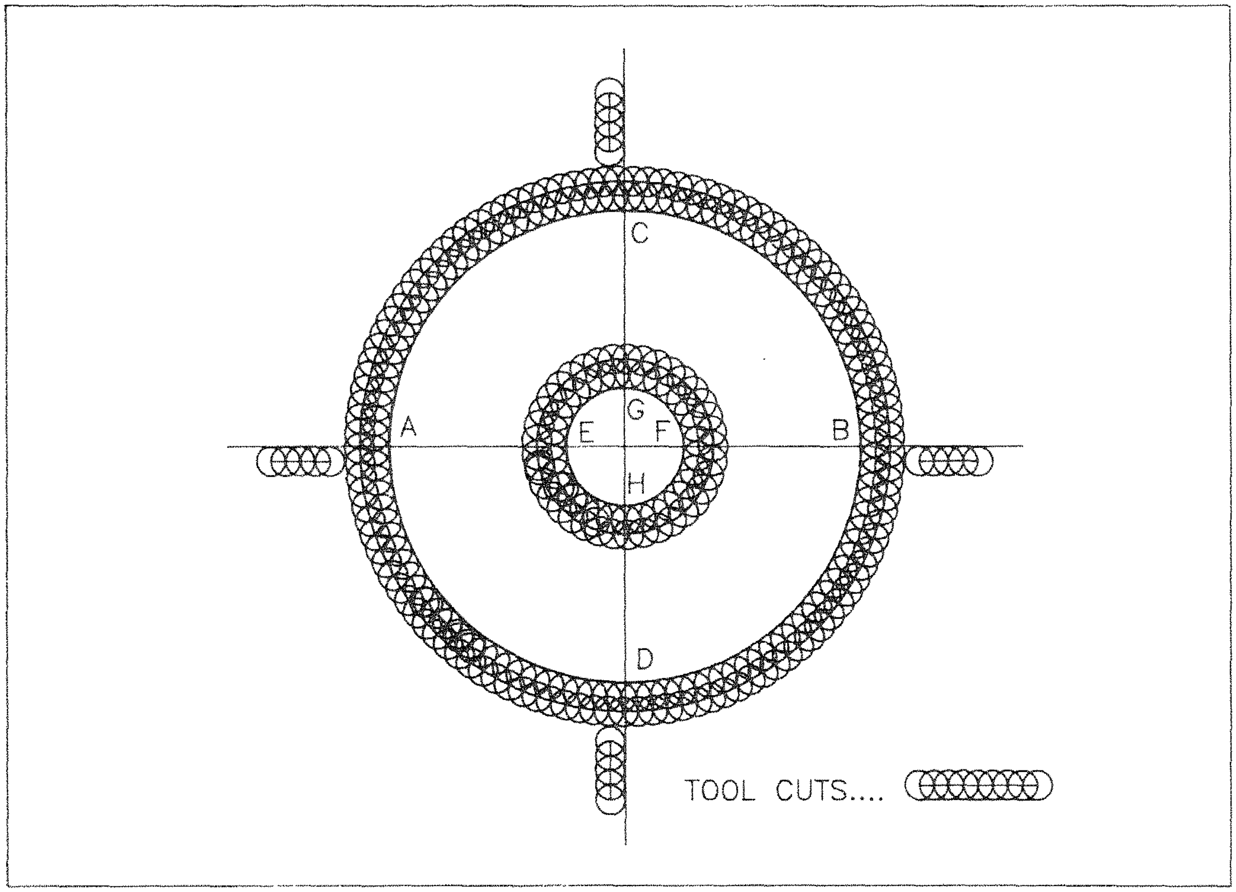


Figure 3.4—Drawing showing accuracy cuts in specified raw material and measurement points for both the 2-inch and 8-inch circles.

3.2.2 Squares Cut in Specified Raw Material

Purpose—This procedure determines the ability of the router to accurately cut squares in specified raw material at specified feed rates.

Recommended equipment:

- A 3/4-inch-thick, 12-inch-square piece of the specified raw material is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the squares used in the procedure. This is discussed later.
- A tool/bit with a 0.5-inch diameter cutting head.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) and raw material used in the procedure will be specified by the potential user of the machine. For each feed rate, the squares are cut in the 3/4-inch-thick raw material. The final cuts remove material from only one side of the tool. The resulting side pressure is transferred to the spindle. This procedure measures how the side pressure affects cutting accuracy. The following steps describe the procedure in detail.

Step 1
Develop and load a program into the CNC controller for cutting two squares with sides of 2 and 8 inches with 0.5-inch lead-in and lead-out cuts of "0°" at the start and end of the cut for each square. First, roughing cuts are made with an offset from the finish squares' dimensions to a depth of 0.625 of an inch. Then, the final cuts are made to the target dimensions to a depth of 0.625 of an inch. The program also must provide for cutting 1.5-inch slots with the center of the tool starting 1 inch from the outer square and radiating out at 0°, 90°, 180°, and 270°. The center of the tool should be offset to the right for the 0° and 270° slots and offset to the left for the 90° and 180° slots. These slots are used as guides for a straightedge to mark the squares for measurements. Figure 3.5 shows the cuts made in the material. Appendix A.7 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification. Notice in the program that there is a G4 exact stop code at each corner of the square when making the finish cuts. These stop codes must be used to assure that the corners of the square are not rounded off.

Step 2
Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3
Mount the 0.5-inch tool into the collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4
Using a proper fixture, attach a 12-inch-square panel to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the square program and cut the first group of squares. Be sure to mark the feet rate used on the acrylic sheet.

Step 5
Repeat Step 4 with a new raw material panel for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.5-inch slots as guides, mark or scratch lines through the center of the squares in both the X-axis and Y-axis on the raw material panels as shown in Figure 3.5.

Identify the points where the lines intersect the squares and the corners of the squares with letters of the alphabet as shown in the figure. Measure and record dimensions A-B, C-D, E-F, and G-H of the large square and dimensions I-J, K-L, M-N, and O-P of the small square. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each raw material panel representing the different feed speeds. Here is an example of the study router's square cutting accuracy in the specified raw material at a feed rate of 315 inches per minute.

Square Cutting Accuracy		
Measurement Location	Target	Actual
	- Dimension (*Inches*) -	
A-B	8.000	8.015
C-D	8.000	8.025
E-F	11.314	11.332
G-H	11.314	11.332
I-J	2.000	2.018
K-L	2.000	2.022
M-N	2.828	2.845
O-P	2.828	2.842

Note: The above procedure evaluates the cutting accuracy only at the center of the router table. However, if accuracy is a critical factor, the same procedure can be done at other locations on the table.

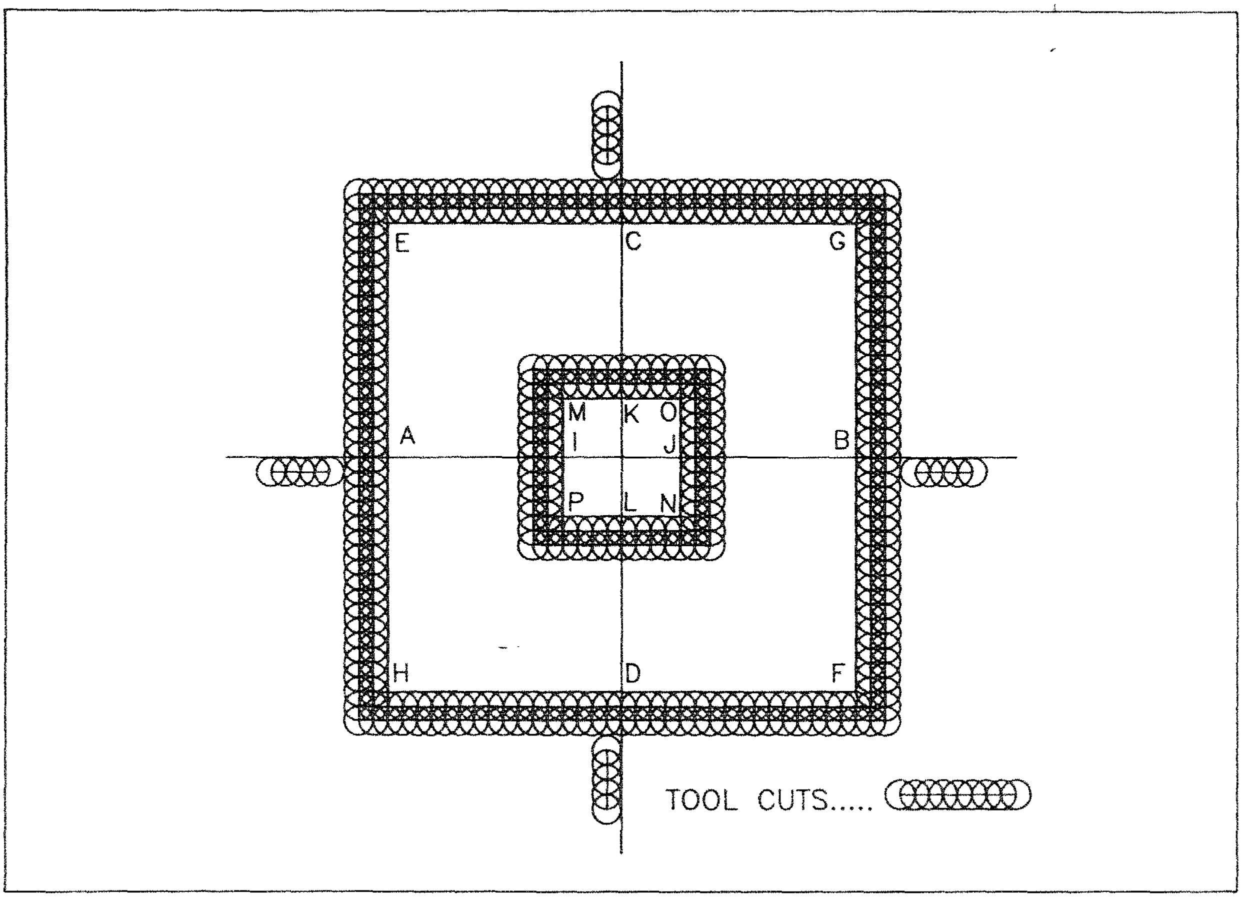


Figure 3.5—Drawing showing accuracy cuts in specified raw material and measurement points for both the 2-inch and 8-inch squares.

3.2.3 Diamonds Cut in Specified Raw Material

Purpose—This procedure determines the ability of the router to accurately cut diamonds in specified raw material at specified feed rates.

Recommended equipment:

- A 3/4-inch-thick, 12-inch-square piece of the specified raw material is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the diamonds used in the procedure. This is discussed later.
- A tool/bit with a 0.5-inch diameter cutting head.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) and raw material used in the procedure will be specified by the potential user of the machine. For each feed rate, the diamonds are cut in the 3/4-inch-thick raw material. The final cuts remove material from only one side of the tool. The resulting side pressure is transferred to the spindle. This procedure measures how this side pressure affects cutting accuracy. The following steps describe the procedure in detail.

Step 1
Develop and load a program into the CNC controller for cutting two diamonds with sides of 2 and 8 inches with 0.5-inch lead-in and lead-out cuts of "0°" at the start and end of the cut for each diamond. First, roughing cuts are made with an offset from the finish diamonds' dimensions to a depth of 0.625 of an inch. Then, the final cuts are made to the target dimensions to a depth of 0.625 of an inch. The program also must provide for cutting 1.5-inch slots, with the center of the tool starting 1 inch from the outer diamond and radiating out from the center of the diamonds at 45°, 135°, 225°, and 315°. The center of the tool should be offset to the right for the 225° and 315° slots and offset to the left for the 45° and 135° slots. These slots are used as guides for a straightedge to mark the diamonds for measurements. Figure 3.6 shows the cuts made in the material. Appendix A.8 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification. Notice in the program that there is a G4 exact stop code at each corner of the diamond when making the finish cuts. These stop codes must be used to assure that the corners of the diamond are not rounded off.

Step 2
Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3
Mount the 0.5-inch-tool into the collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4
Using a proper fixture, attach a 12-inch-square raw material panel to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the diamond program and cut the first group of diamonds. Be sure to mark the feed rate used on the acrylic sheet.

Step 5
Repeat Step 4 with a new raw material panel for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.5-inch slots as guides, mark or scratch lines through the center of the diamonds on the raw material panels as shown in Figure 3.6. Identify the points where the lines intersect the diamonds and the corners of the diamonds with letters of the alphabet as shown in the figure. Measure and record dimensions A-B, C-D, E-F, and G-H of the large diamond and dimensions I-J, K-L, M-N, and O-P of the small diamond. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each raw material panel representing the different feed speeds. Here is an example of the study router's diamond cutting accuracy in the specified raw material at a feed rate of 315 inches per minute:

Diamond Cutting Accuracy		
Measurement Location	Target	Actual
	- Dimension (*Inches*) -	
A-B	8.000	8.021
C-D	8.000	8.022
E-F	11.314	11.325
G-H	11.314	11.338
I-J	2.000	2.020
K-L	2.000	2.020
M-N	2.828	2.840
O-P	2.828	2.847

Note: The above procedure evaluates the cutting accuracy only at the center of the router table. However, if accuracy is a critical factor, the same procedure can be done at other locations on the table.

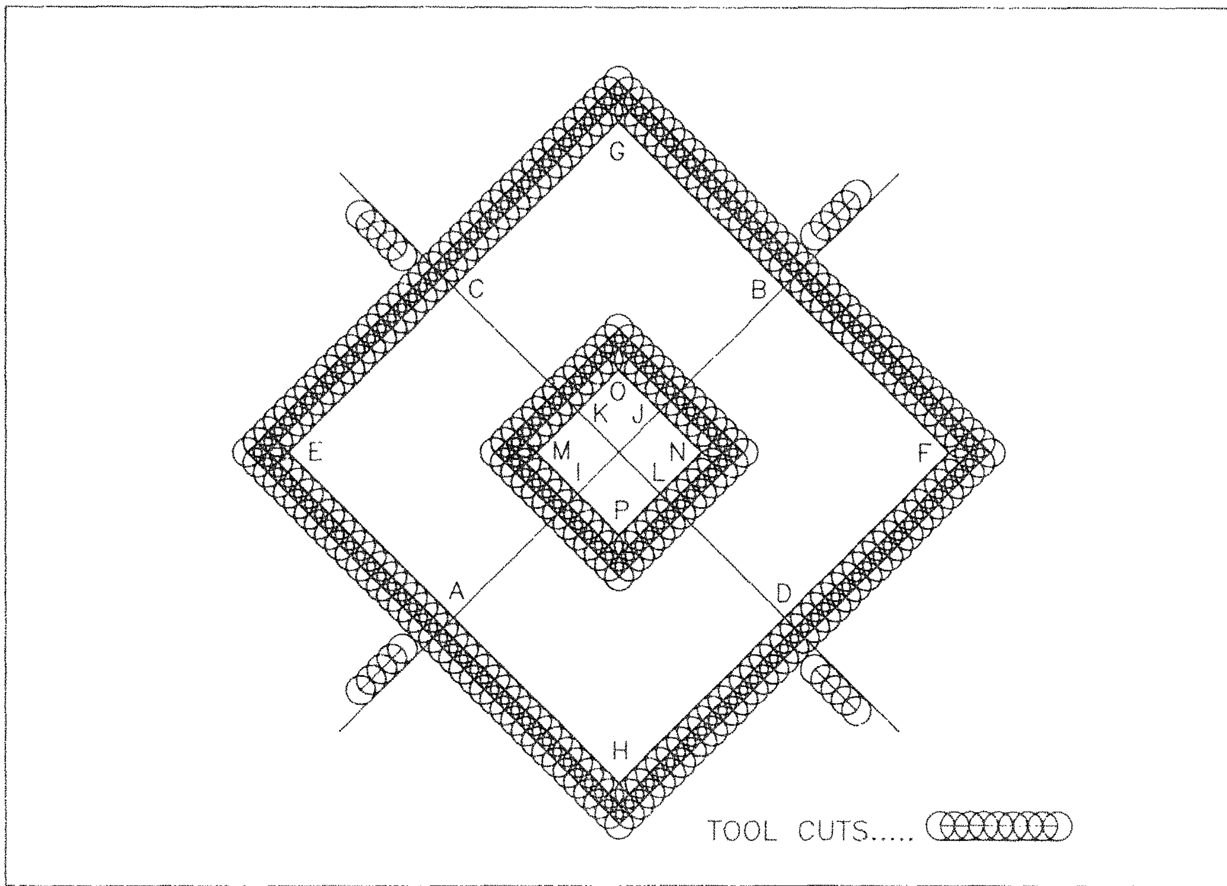


Figure 3.6—Drawing showing accuracy cuts in specified raw material and measurement points for both the 2-inch and 8-inch diamonds.

3.3 Repeatability (Cuts in Acrylic Sheets)

3.3.1 Circles Cut in Acrylic Sheets

Purpose—This procedure determines the repeatability of the router when cutting circles in acrylic sheets at specified feed rates.

Recommended Equipment:

- A 1/4-inch-thick, 12-inch-square sheet of cast acrylic (Lucite'L or equivalent) is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the circles used in the procedure. This is discussed later.
- A 0.25-inch collet and 0.25-inch upcut spiral tool for cutting the acrylic.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) used in the procedure will be specified by the potential user of the machine. For each feed rate, the circles are cut in 1/4-inch-thick cast acrylic sheets. The following steps describe the procedure in detail.

Step 1
Develop and load a program into the CNC controller for cutting two circles with diameters of 2 and 8 inches with 0.5-inch lead-in and lead-out cuts of "0°" at the start and end of the cut for each circle. First, roughing cuts are made with an offset of 0.0625 inch from the finish circles' diameters to a depth of 0.1875 of an inch. Then, cuts are made to the target dimensions to a depth of 0.1562 of an inch. At that point, the cuts to target dimensions are repeated 50 times. The program also must provide for cutting 1.25-inch slots with the center of the tool starting 1 inch from the outer circle and radiating out at 0°, 90° 180°, and 270°. The center of the tool should be offset to the right for the 0° and 270° slots and offset to the left for the 90° and 180° slots. These slots are used as guides for a straightedge to mark the circles for measurements. Figure 3.7 shows the cuts made in the material. Appendix A.9 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification.

Step 2
Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3
Mount the 0.25-inch tool for cutting the acrylic into the spindle collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4
Using a proper fixture, attach a 12-inch-square, 1/4-inch-thick acrylic square to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the circle program and cut the first group of circles. Be sure to mark the feed rate used on the acrylic sheet.

Step 5
Repeat Step 4 with a new acrylic sheet for each feed rate for which the cutting repeatability is to be evaluated.

Results—Using the 1.25-inch slots as guides, mark or scratch lines through the center of the circles in both the X-axis and Y-axis on the acrylic squares as shown in Figure 3.7. Identify the points where the lines intersect the circles with letters of the alphabet as shown in the figure. Measure and record diameters A-B and C-D of the large circle and diameters E-F and G-H of the small circle. These measurements are made with the blunt-nosed calipers. This procedure is repeated for each acrylic square representing the different feed speeds. Any significant difference between the two diameters for a given circle indicates drift in the computer's control system. Here is an example of the study router's circle cutting repeatability at three different feed rates:

Circle Cutting Repeatability						
	Feed Speed					
Measurement	100 IPM		200 IPM		300 IPM	
Location	Target	Actual	Target	Actual	Target	Actual
	- - - - - - - - - Diameter (*Inches*) - - - - - - - - - -					
A-B	8.000	7.978	8.000	7.975	8.000	7.972
C-D	8.000	7.982	8.000	7.980	8.000	7.978
E-F	2.000	1.992	2.000	1.985	2.000	1.973
G-H	2.000	1.993	2.000	1.986	2.000	1.974

Note: The above procedure evaluates the cutting repeatability only at the center of the router table. However, if repeatability is a critical factor, the same procedure can be done at other locations on the table.

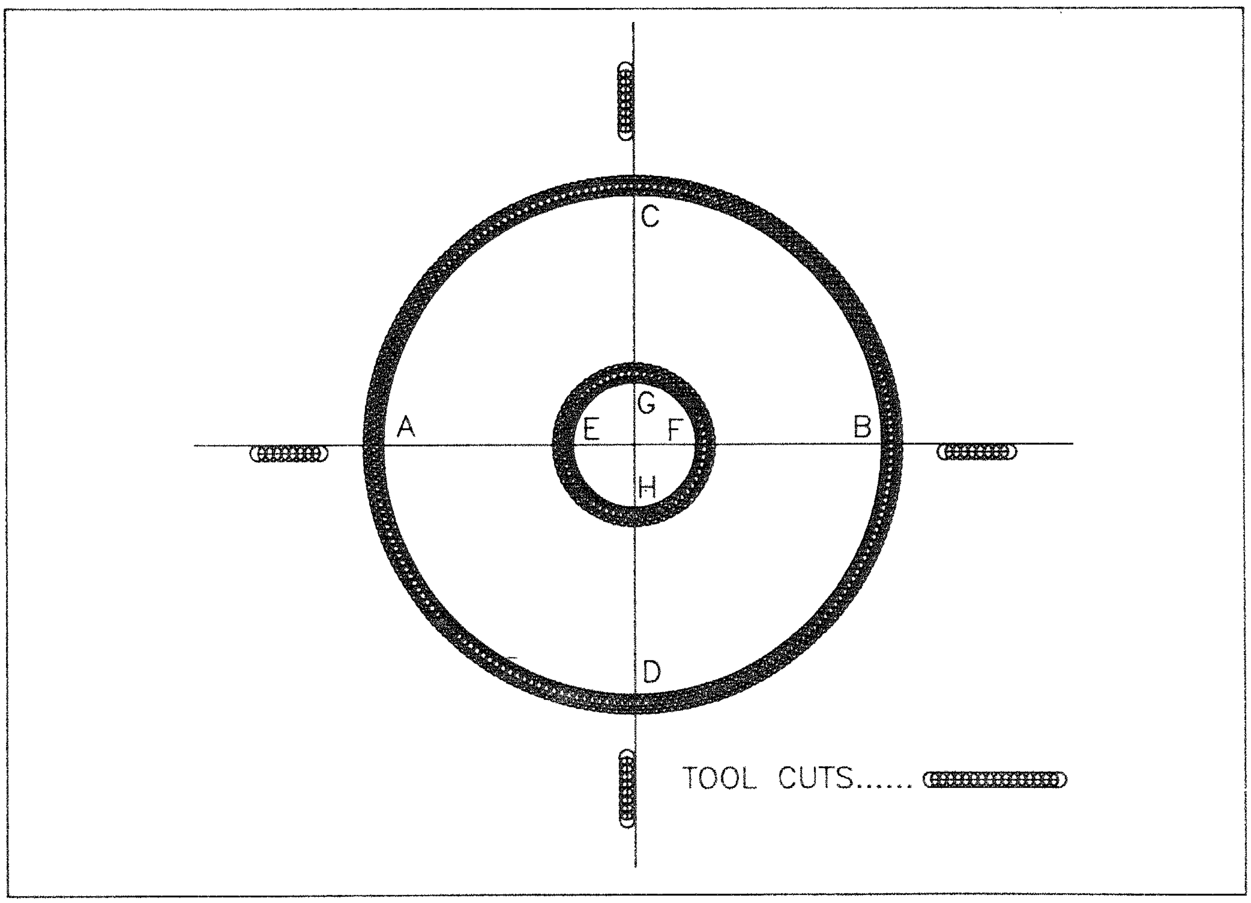


Figure 3.7—Drawing showing repeatability cuts in acrylic sheet and measurement points for both the 2-inch and 8-inch circles.

3.3.2 Squares Cut in Acrylic Sheets

Purpose—This procedure determines the repeatability of the router when cutting squares in acrylic sheets at specified feed rates.

Recommended Equipment:

- A 1/4-inch-thick, 12-inch-square sheet of cast acrylic (Lucite'L or equivalent) is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the squares used in the procedure. This is discussed later.
- A 0.25-inch collet and 0.25-inch upcut spiral tool for cutting the acrylic.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) used in the procedure will be specified by the potential user of the machine. For each feed rate, the squares are cut in 1/4-inch-thick cast acrylic sheets. The following steps describe the procedure in detail.

Step 1

Develop and load a program into the CNC controller for cutting two squares with sides of 2 and 8 inches with 0.5-inch lead-in and lead-out cuts of "0°" at the start and end of the cut for each square. First, roughing cuts are made with an offset of 0.0625 inch from the finish squares' dimensions to a depth of 0.1875 of an inch. Then, cuts are made to the target dimensions to a depth of 0.1562 of an inch. At that point, the cuts to target dimensions are repeated 50 times. The program also must provide for cutting 1.25-inch slots with the center of the tool starting 1 inch from the outer square and radiating out at 0°, 90°, 180°, and 270°. The center of the tool should be offset to the right for the 0° and 270° slots and offset to the left for the 90° and 180° slots. These slots are used as guides for a straightedge to mark the squares for measurements. Figure 3.8 shows the cuts made in the material. Appendix A.10 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification. Notice in the program that there is a G4 exact stop code at each corner of the square when making the finish cuts. These stop codes must be used to assure that the corners of the square are not rounded off.

Step 2

Using procedure 1.1.1, warm up the spindle motor to the steady state temperature and power (kW) condition.

Step 3

Mount the 0.25-inch tool for cutting the acrylic into the spindle collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4

Using a proper fixture, attach a 12-inch-square, 1/4-inch-thick acrylic square to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the square program and cut the first group of squares. Be sure to mark the feed rate used on the acrylic sheet.

Step 5

Repeat Step 4 with a new acrylic sheet for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.25-inch slots as guides, mark or scratch lines through the center of the squares in both the X-axis and Y-axis on the acrylic squares as shown in Figure 3.8. Identify the points where the lines intersect the squares and the corners of the squares with letters of the alphabet as shown in the figure. Measure and record dimensions A-B, C-D, E-F, and G-H of the large square and dimensions I-J, K-L, M-N, and O-P of the small square. These measurements are made with the blunt-nosed calipers. Repeat this procedure for each acrylic square representing the different feed speeds. Any significant difference between the width and height measurements and/or the two diagonal measurements indicates drift in the computer's control system. Here is an example of the study router's square cutting repeatability at three different feed rates:

Square Cutting Repeatability						
	Feed Speed					
Measurement	100 IPM		200 IPM		300 IPM	
Location	Target	Actual	Target	Actual	Target	Actual
	Dimension (*Inches*)					
A-B	8.000	8.003	8.000	8.003	8.000	8.002
C-D	8.000	8.006	8.000	8.007	8.000	8.007
E-F	11.313	11.316	11.312	11.311	11.314	11.315
G-H	11.314	11.317	11.311	11.317	11.313	11.317
I-J	2.000	2.002	2.000	2.001	2.000	2.001
K-L	2.000	2.001	2.000	2.001	2.000	2.002
M-N	2.828	2.828	2.828	2.827	2.827	2.828
O-P	2.828	2.828	2.827	2.827	2.828	2.828

Note: The above procedure evaluates the cutting repeatability only at the center of the router table. However, if repeatability is a critical factor, the same procedure can be done at other locations on the table.

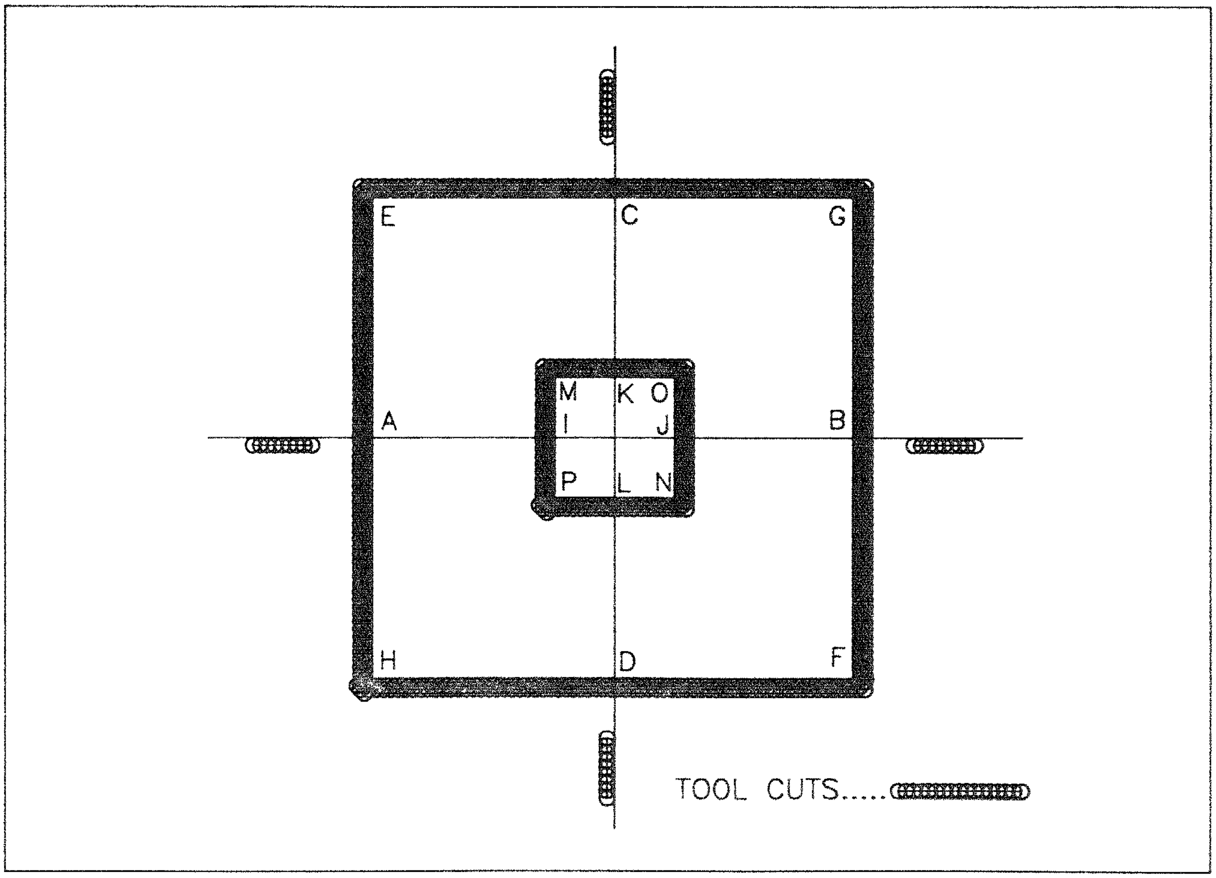


Figure 3.8—Drawing showing repeatability cuts in acrylic sheet and measurement points for both the 2-inch and 8-inch squares.

3.3.3 Diamonds Cut in Acrylic Sheets

Purpose—This procedure determines the repeatability of the router when cutting diamonds in acrylic sheets at specified feed rates.

Recommended equipment:

- A 1/4-inch-thick, 12-inch-square sheet of cast acrylic (Lucite'L or equivalent) is required for each feed rate to be evaluated.
- Blunt-nosed calipers that read to 0.001 of an inch and have a jaw opening of 12 inches. The calipers must meet national standards.
- Program for the CNC controller to cut the diamonds used in the procedure. This is discussed later.
- A 0.25-inch collet and 0.25-inch upcut spiral tool for cutting the acrylic.
- Dial gauge that has graduations of 0.0001 inch, reading of 0-4-0, and range of 0.008 inch with an accuracy of at least 0.00008 inch over the full range.

Method—The feed rate(s) used in the procedure will be specified by the potential user of the machine. For each feed rate, the diamonds are cut in 1/4-inch-thick cast acrylic sheets. The following steps describe the procedure in detail.

Step 1

Develop and load a program into the CNC controller for cutting two diamonds with sides of 2 and 8 inches with 0.5-inch lead-in and lead-out cuts of "0°" at the start and end of the cut for each diamond. First, roughing cuts are made with an offset of 0.0625 of an inch from the finish diamonds' dimensions to a depth of 0.1875 of an inch. Then, cuts are made to the target dimensions to a depth of 0.1562 of an inch. At that point, the cuts to target dimensions are repeated 50 times. The program also must provide for cutting 1.25-inch slots with the center of the tool starting 1 inch from the outer diamond and radiating out at 45°, 135°, 225°, and 315°. The center of the tool should be offset to the right for the 225° and the 315° slots and offset to the left for the 45° and 135° slots. These slots are used as guides for a straightedge to mark the diamonds for measurements. Figure 3.9 shows the cuts made in the material. Appendix A.11 provides a procedure for developing the program along with a sample program that will work on most computer controllers with little or no modification. Notice in the program that there is a G4 exact stop code at each corner of the diamond when making the finish cuts. These stop codes must be used to assure that the corners of the diamond are not rounded off.

Step 2

Using procedure 1.1.1, warm up the spindle motor to the steady-state temperature and power (kW) condition.

Step 3

Mount the 0.25-inch tool for cutting the acrylic into the spindle collet/chuck. Measure and record both the actual tool diameter and total runout to 0.0001 of an inch. Add these two values to determine the offset value required by the CNC controller. Note that some controllers use the tool radius instead of the diameter to set the offset. In that situation, one-half of the tool runout would be added to the actual tool radius.

Step 4

Using a proper fixture, attach a 12-inch-square, 1/4-inch-thick acrylic square to the router table (centered in both the X-axis and the Y-axis). Enter the first feed rate into the diamond program and cut the first group of diamonds. Be sure to mark the feed rate used on the acrylic sheet.

Step 5

Repeat Step 4 with a new acrylic sheet for each feed rate for which the cutting accuracy is to be evaluated.

Results—Using the 1.25-inch slots as guides, mark or scratch lines through the center of the diamonds on the acrylic squares as shown in Figure 3.9. Identify the points where the lines