United States
Department of
Agriculture

Forest Service

Northeastern Forest
Experiment Station

General Technical
Report NE-201

CNC Router Evaluation Procedures

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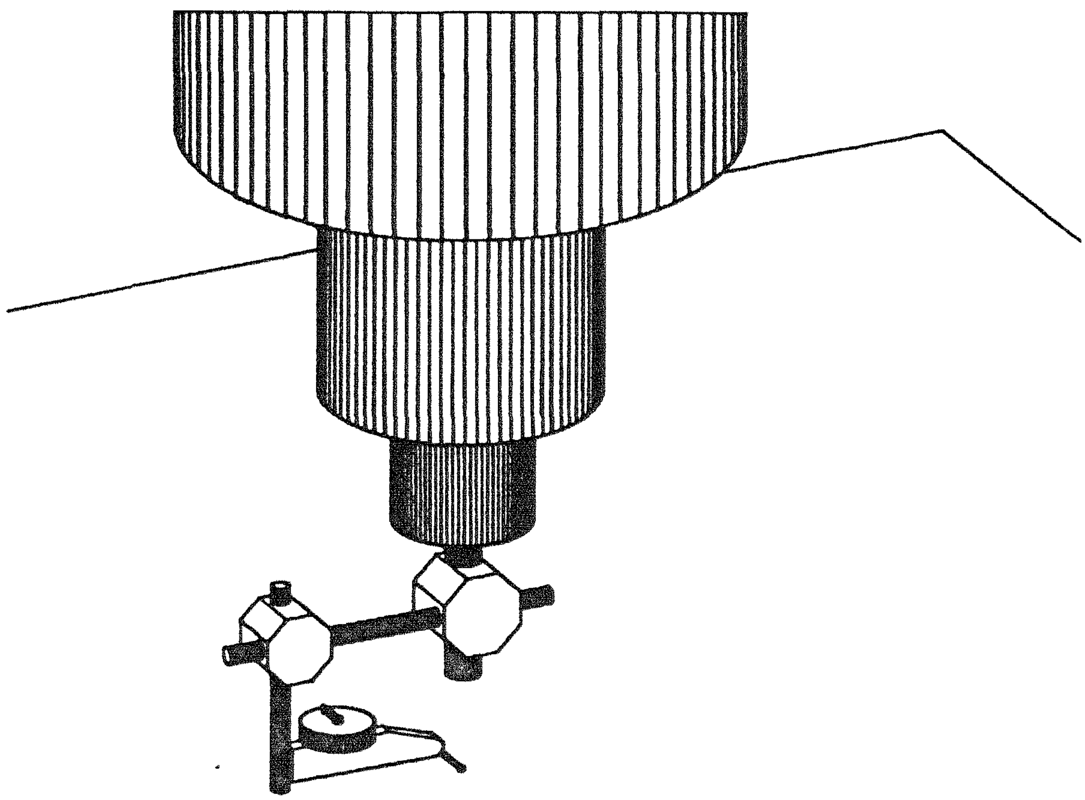

Abstract

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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Manuscript received for publication 30 June 1994

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June 1995

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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

1.0 Basic Evaluations

1.1 Spindle

1.1.1 Steady-state Temperature and Power

Purpose—This procedure determines the steady-state temperature of the lower spindle bearing housing, and the steady-state power (kW) required with the spindle running at maximum RPM's. Because it is difficult to measure the bearing temperature directly, a representative temperature is obtained by taping a thermocouple to the spindle housing as near as possible to the lower bearing. This steady-state condition must be reached for some of the other procedures.

Recommended equipment:

- Turned-ground-polished (TGP) rod that is 0.75 inch in diameter and 3 inches long. If the spindle will not accept a 0.75-inch-diameter tool shank, use a TGP rod with a diameter that matches the largest tool shank that the spindle will accept.

- Digital power analyzer that measures to 0.01 kW and will handle the frequency (HZ) range of the current being sent to the spindle. It also must handle both three- and four-wire, three-phase power connections. And, it should have an accuracy of ± 0.5 percent of the full range from 20 Hz to 5 kHz.

- Hand-held digital thermometer with thermocouple that will measure to 0.1 °F. The thermometer should have an accuracy of at least 0.1 percent of the reading.

Method—With the thermometer thermocouple and power analyzer attached to the spindle, the temperature and power (kW) requirements are recorded every 10 minutes until the temperature reaches a steady state. The following steps describe the procedure:

Step 1
Mount the TGP rod into the spindle collet/chuck.

Step 2
Tape the thermocouple to the spindle housing as near as possible to the lower spindle bearing.

Step 3
Connect the power analyzer to the power leads of the spindle motor. In making the connection, use a three-phase, three-wire or three-phase, four-wire hookup per the requirements of the spindle motor. This connection also must be made between the spindle motor and any transistor inverter used to control the speed (RPM) of the motor. Figure 1.1 shows a typical hookup.

Step 4
Record both the temperature and power every 10 minutes. The temperature is measured to 0.1 °F and the power measured to 0.01 kW. These values are recorded until the temperature, rounded to the nearest degree, does not change for two consecutive 10-minute periods. At that point, the spindle is considered to be at steady state.

Results—Figure 1.2 shows sample results for this procedure.

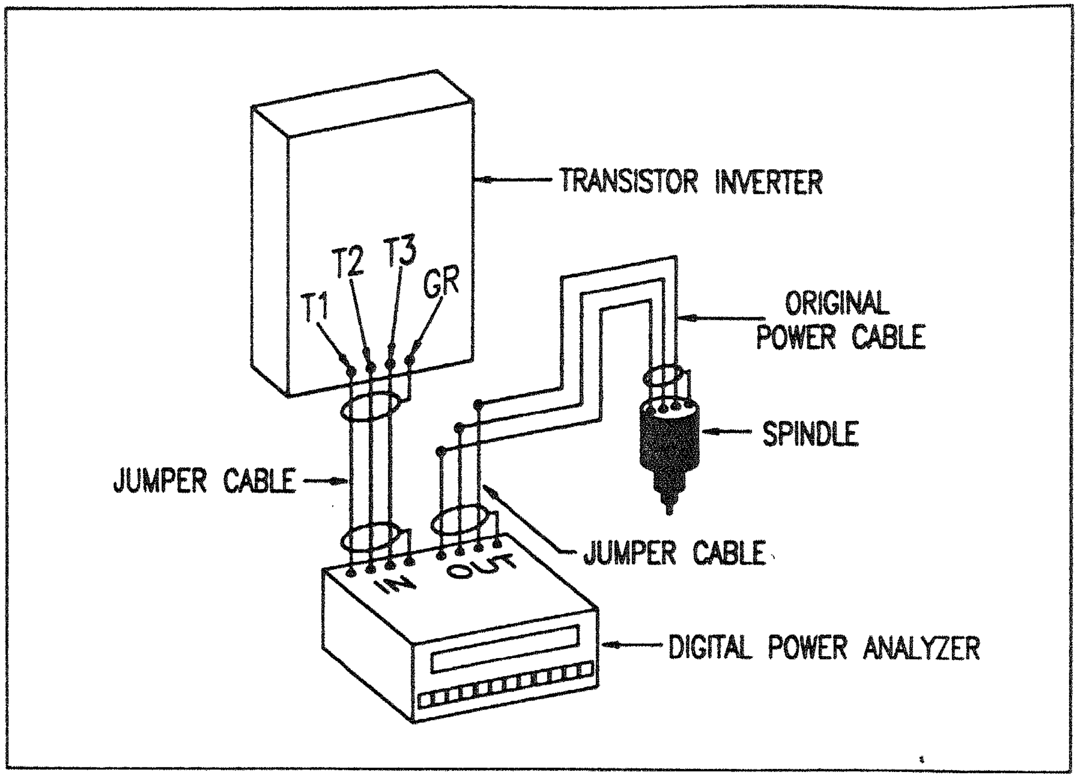

Figure 1.1—Power analyzer hookup for spindle warm-up procedure.

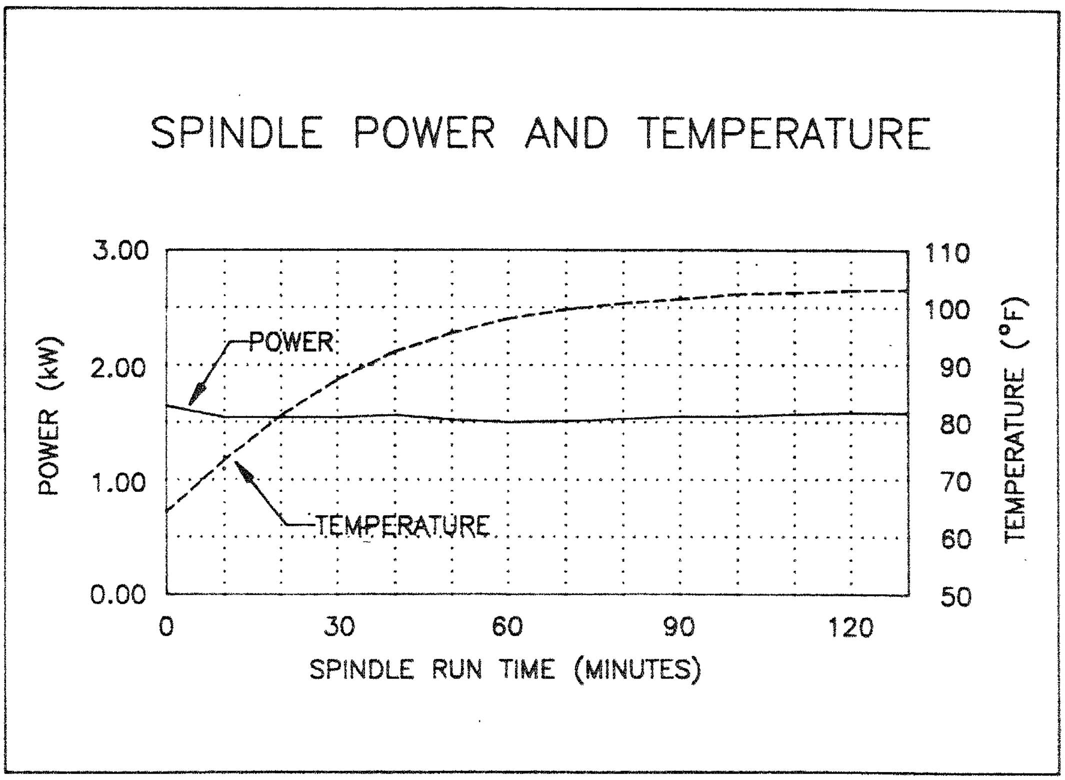

Figure 1.2—Temperature and power resulting from warm-up procedure.

1.1.2 RPM Accuracy

Purpose—This procedure evaluates the accuracy of the router controller and/or transistor inverter to set the RPM's of the spindle motor. Because the surface quality of the cut depends on the RPM of the tool, along with other factors such as tool vibration, part vibration, and sharpness of the tool, it is important that the spindle runs at the set RPM's.

Recommended equipment:

- Turned-ground-polished (TGP) rod that is 0.75 inch in diameter and 3 inches long. If the spindle will not accept a 0.75-inch-diameter tool shank, use a TGP rod with a diameter that matches the largest tool shank that the spindle will accept.
- Hand-held digital phototachometer with a range covering the maximum RPM of the router to be evaluated (accuracy ± 1 RPM).
- Reflective paint.

Method—Before beginning this evaluation, the spindle must be run until the steady-state temperature and power (kW) requirements are reached as discussed in procedure 1.1.1. After spindle warm-up, use the following steps. During the warm-up period, the voltage to the spindle motor should be checked for abnormal level and fluctuations. Abnormal voltage can affect the results from this procedure.

Step 1
Mount the TGP rod in the router spindle.

Step 2
Using reflective paint, paint a 1/2-inch square patch on the side of the TGP rod. The coat of paint should be as thin as possible to minimize its effect on spindle vibration that can be caused if the spindle is out-of-balance.

Step 3
Select a set of target RPM's covering the range of RPM's provided by the spindle motor.

Step 4
Set the router to run at each target RPM by manually adjusting the power cycles per second (Hz) on the transistor inverter or by programming the router controller. At each target RPM, measure and record the actual value to the nearest RPM.

Results—For the study router, the results were:

Spindle RPM	
Target	Actual
3,000	3,001
6,000	6,003
9,000	8,995
12,000	12,009
15,000	14,997
18,000	17,987

1.1.3 Tool Centering Ability

Purpose—This procedure determines the ability of the spindle collet/chuck to properly center a tool. The router accuracy depends on this ability. Also, if the tools are not centered to reasonable tolerances, vibrations can damage bearings.

Recommended equipment:

- A 3-inch-long TGP rod for each shank diameter collet/chuck to be used in the router.
- 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.

- Hardware to mount the dial gauge.

Method—Before beginning this evaluation, the spindle must be run until the steady-state temperature and power (kW) requirements are reached as discussed in procedure 1.1.1. After spindle warm-up, use one of the following procedures to measure the total runout of the TGP rod. The first set of procedures is for spindles with collet and nut mechanisms for mounting tools. The second set is for spindles with collet, nut, and quick-release mechanisms for mounting tools. The third set is for spindles with hydraulic chuck and quick-release mechanisms for mounting tools.

- Collet and Nut

Step 1
Insert a 3-inch-long TGP rod into the collet and make sure that it reaches the full depth of the collet. Insert the collet and rod into the router shank and tighten the collet nut as recommended by the router manufacturer.

Step 2
Mount the dial gauge to the table and position the gauge anvil (contact point) at a point tangent to the side of the TGP rod as shown in Figure 1.3. Then measure and record the total runout to the nearest 0.0001 inch on the TGP rod at a distance of 1-1/4 inches from the collet while turning the spindle by hand.

Step 3
Loosen the collet nut until the collet is forced out of the router shank. Rotate the collet 1/10 of a turn relative to the shank. Retighten the spindle nut. Measure and record total runout as discussed in Step 2.

Step 4
Repeat Step 3 until total runout has been measured and recorded 10 times. Then determine the minimum, maximum, and average total runout.

Step 5
Repeat Steps 1 through 4 for each collet size to be used in the spindle.

Results—For the study router, the results of this evaluation were:

Spindle Runout (Thou)		
(Collet & Nut) 3/4-Inch		
Minimum	Maximum	Average
0.1	0.5	0.4

- Quick-Release Chuck (w/Collet and Collet Nut)

Step 1
Insert a 3-inch-long TGP rod into the collet and make sure that it reaches the full depth of the collet. Insert the collet and rod into the quick-change chuck and tighten the collet nut as recommended by the router manufacturer.

Step 2
Using a felt-tipped pen, place positioning marks around the router shank at 90° intervals. Write the degrees of rotation by each mark (that is, 0, 90, 180, 270). Then place a mark on the quick-change chuck so that it can be aligned with the marks on the router shank.

Step 3
Insert the quick-change chuck into the router shank with the mark on the chuck aligned with the 0° mark on the shank. With a dial gauge mounted on the router table, measure

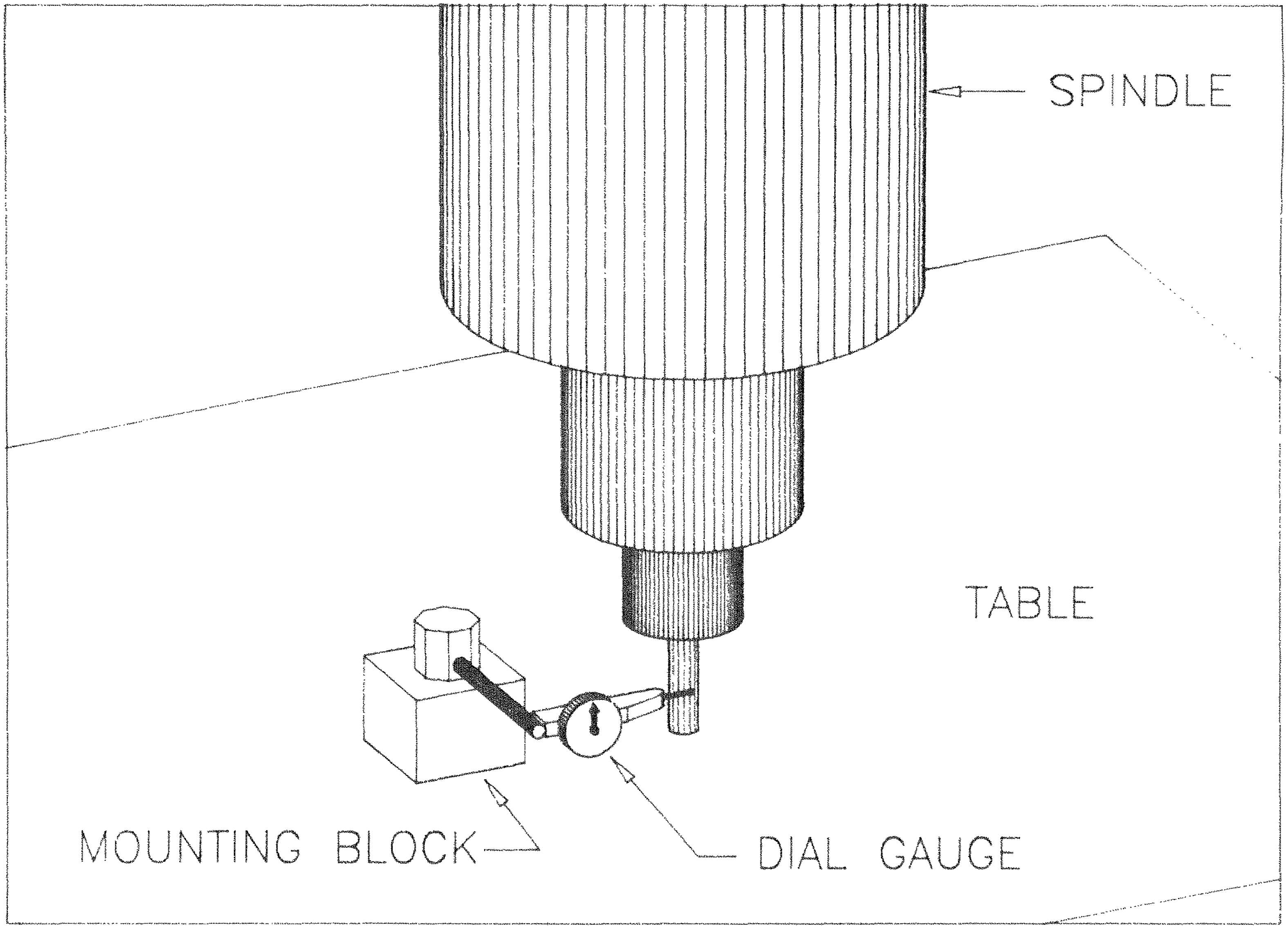

Figure 1 3--Equipment setup for measuring spindle runout.

and record the total runout to the nearest 0.0001 inch on the TGP rod at a distance of 1-1/4 inches from the collet while turning the spindle by hand.

Step 4

Remove the quick-change chuck and loosen the collet nut until the collet is forced out of the chuck. Rotate the collet one-tenth of a turn relative to the shank. Retighten the spindle nut.

Step 5

Repeat Steps 3 and 4 until the total runout has been measured and recorded 10 times with the chuck mark aligned with the 0° mark on the shank.

Step 6

Repeat Steps 4 and 5 with the mark on the chuck aligned with the 90°, 180°, and 270° marks on the spindle shank. Then determine the minimum, maximum, and average total runout.

Step 7

Repeat this entire procedure for each collet size to be used in the spindle.

Results—For the study router, the results of this evaluation were:

Spindle Runout (Thou) (Quick-Release Chuck - W/Collet & Nut) 3/4-Inch		
Minimum	Maximum	Average
0.3	0.5	0.4

- Quick-Release Chuck (Hydraulic)

Step 1

Install a 3-inch long TGP rod into the hydraulic chuck making sure that it is fully seated.

Step 2

Using a felt-tipped pen, place positioning marks around the router shank at 90° intervals. Write the degrees of rotation by each mark (that is, 0, 90, 180, 270). Then place a mark on the hydraulic chuck so that it can be aligned with the marks on the router shank.

Step 3

Insert the hydraulic chuck into the router shank with the mark on the chuck aligned with the 0° mark on the shank. With a dial gauge mounted on the router table, measure and record the total runout to the nearest 0.0001 inch on the TGP rod at a distance of 1-1/4 inches from the collet while turning the spindle by hand.

Step 4

Repeat Step 3 with the mark on the chuck aligned with the 90°, 180°, and 270° marks on the spindle shank. Then determine the minimum, maximum, and average runout.

Step 5

Repeat this entire procedure for each different size hydraulic chuck to be used on the router.

Results—For the study router, the results of this evaluation were:

Spindle Runout (Thou) (Quick-Release Chuck - Hydraulic) 3/4-Inch		
Minimum	Maximum	Average
0.0	0.2	0.1

1.1.4 Trueness of Rotation

Purpose—This procedure evaluates the trueness of rotation of the spindle about the Z-axis. This will indicate the ability of the spindle to drill holes or produce machined surfaces that are perpendicular to the X-axis and Y-axis of the router table.

Recommended equipment:

- Turned-ground-polished (TGP) rod that is 0.5 inch in diameter and 4 inches long.
- Bar or rod approximately 8 inches long with connector that can be attached to the TGP rod at 90°.
- Dial gauge that has graduations of 0.0005 inch, reading of 0-15-0, and range of 0.030 inch with an accuracy of at least 0.0004 inch over the full range.

Method—Before beginning this evaluation, the spindle must be run until the steady-state temperature and power (kW) requirements are reached as discussed in procedure 1.1.1. After spindle warm-up, use the following steps.

Step 1
Locate and mark points A, B, and C on the router table as shown in Figure 1.4. Point A is centered in the Y-axis and one-quarter of the distance from the -X end of the table. Point B is located in the center of the table. Point C is centered in the Y-axis and one-quarter of the distance from the +X end of the table.

Step 2
Install a 0.5-inch TGP rod into the spindle chuck with the rod extending 2 inches below the collet.

Step 3
Attach a crossbar or rod perpendicular to the TGP rod 1 inch below the collet/chuck and lower the spindle until the face of the collet/chuck is 2.25 inches above the table (Fig. 1.4). This positions the spindle at approximately the normal cutting height.

Step 4
Attach a dial gauge to the crossbar or rod so that the anvil (contact point) of the gauge is 6 inches from the center line of the TGP rod and lowered so that it gives a reading on the table (Fig. 1.4). Notice that the anvil of the dial gauge is positioned at 45°. If the anvil is not geared to allow this, it will be necessary to apply a correction factor to the readings obtained.

Step 5
Raise the spindle and position it so that the end of the TGP rod is directly above point A on the spindle table. Lower the spindle until the dial gauge registers near its mid-measurement range. Rotate the spindle shaft by hand until the dial gauge is at the -X position and adjust the gauge to read "0". Then rotate the spindle shaft by hand to the +X position and record the ± dial gauge reading to the nearest 0.001 inch at the new position. Next, rotate the spindle shaft by hand until the dial gauge is at the -Y position and adjust the gauge to read "0". Then rotate the spindle shaft by hand to the +Y position and record the ± dial gauge reading to the nearest 0.001 inch at the new position.

Step 6
Repeat Step 5 for points B and C as located in Step 1.

Results—Using the recorded deviations, calculate the tilt angles (degree, minutes, seconds) and errors (thou/inch) for the trueness of rotation axis of the spindle in both the X-axis and the Y-axis for all three points on the table.

To calculate the tilt angle, use the following equation:

TILT ANGLE = ARCTAN (GAUGE READING / 12)

The tilt angle is then converted to degrees, minutes, and seconds.

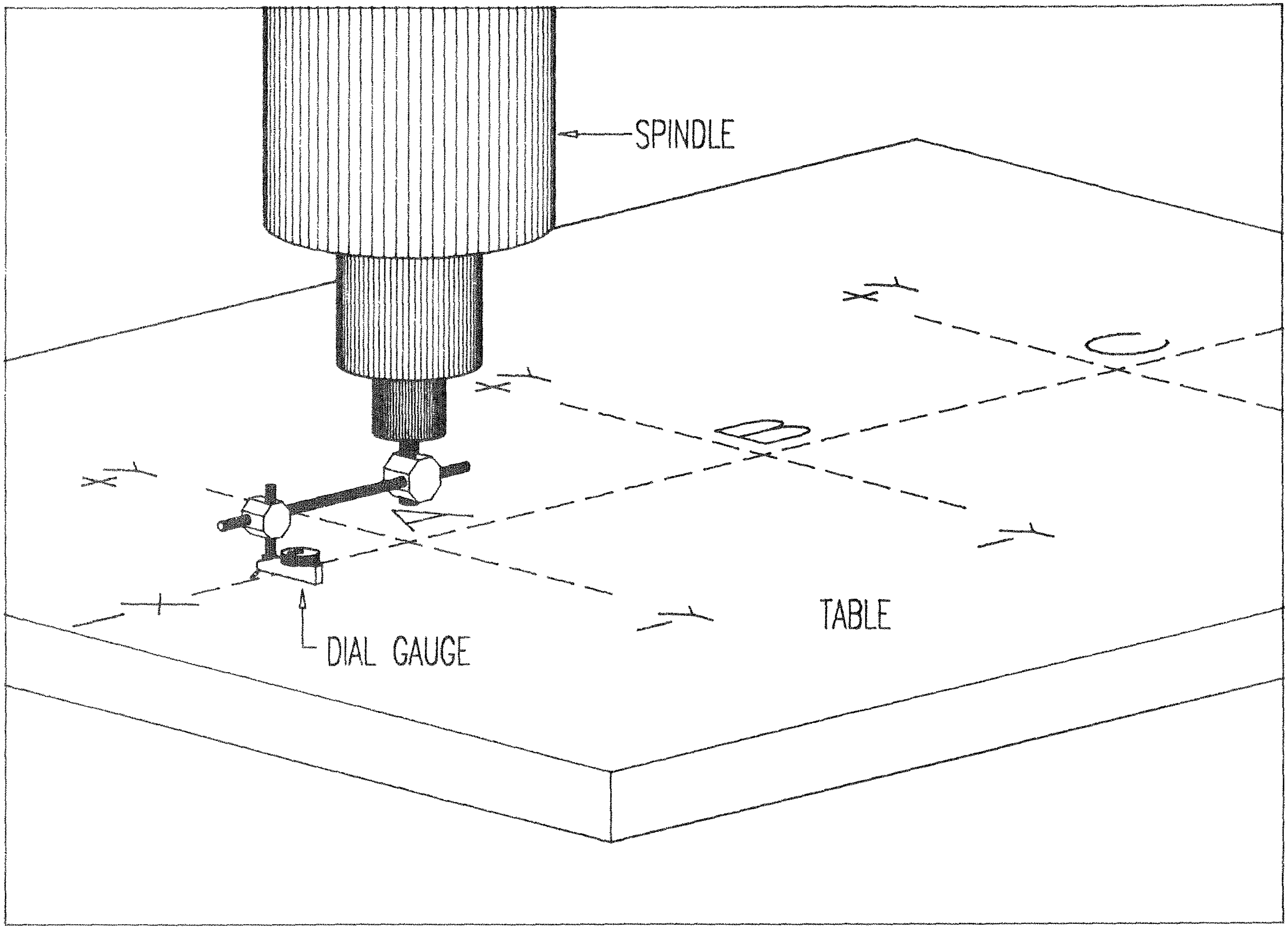

Figure 1.4—Data collection points and equipment setup for measuring spindle trueness of rotation.

The errors in trueness of rotation are calculated by dividing the deviations by 12 inches, which represent the distance between the two measurement points in each axis. The resulting error values are presented as thou/inch.

For the study router, the deviations in dial gauge readings along with the resulting tilt angles and errors were:

Spindle Trueness of Rotation

Table Position	Trueness Axis	Deviation (Inches)	Tilt Angle (Deg.,Min.,Sec.)	Error (Thou/Inch)
A	X	- 0.015	- 00 04'18"	- 1.2
	Y	0.005	00 01'26"	0.4
B	X	- 0.009	- 00 02'35"	- 0.7
	Y	0.008	00 02'18"	0.7
C	X	- 0.012	- 00 03'26"	- 1.0
	Y	0.003	00 00'52"	0.2

Positive deviations, tilt angles, and errors indicate that the top of the spindle rotational axis is tilted toward the positive end of the X-axis or Y-axis. Conversely, negative deviations, tilt angles, and errors indicate that the top of the spindle rotational axis is tilted toward the negative end of the X-axis or Y-axis.

1.1.5 Cutting Power

Purpose—This procedure evaluates the ability of the spindle to satisfactorily machine selected materials using specified tool sizes and configurations. The prospective buyer of the machine specifies the: (1) type of materials (MDF, plywood, oak, and so on), (2) depth and width of the cuts to be made, and (3) sizes and configurations of the tools to be used. This procedure will assure that the router spindle has the power required to meet the buyer's needs. If this procedure indicates that the available power (kW) is marginally adequate, a larger spindle motor or different milling procedure should be considered.

Recommended equipment:

- Balanced tool(s) of the specified size and configuration.
- 24-inch by 36-inch panel(s) of specified materials to be processed.
- Digital power analyzer that will handle the frequency (Hz) range of the current being sent to the spindle. It also must handle three-phase, three-wire or three-phase, four-wire requirements of the spindle motor. And, it must have an accuracy of ± 0.5 percent of the full range from 20 Hz to 5 kHz.
- Digital thermometer with thermocouple that can be taped to the spindle housing. The thermometer must have an accuracy of at least 0.1 percent of the reading.

Method—This evaluation compares the power (kW) required to make the designated cuts to the full load power (kW) requirements of the spindle motor.

Step 1

Using the data from the spindle motor name plate, determine the full load power requirement for the motor by using the following equation:

$$kW = (1.73 \times I \times E \times pf) / 1000$$

Where: kW = Full Load Kilowatts
I = Current
E = Voltage
pf = Power Factor

Step 2

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

Step 3

Turn off the spindle motor and remove the TGP rod. Then, mount a tool of the designated size and configuration in the spindle. Check the tool runout to assure that it does not exceed the manufacturer's specification.

Step 4

Make the desired cuts in the material to be processed. Record the average and maximum power required to make these cuts. When processing solid wood, generally the power requirements will be higher when the tool is traveling in the direction of the grain.

Step 5

Repeat Steps 1 through 4 for each tool size/configuration and material designated for evaluation.

Results—For this evaluation, cuts were made in MDF board with both a 1/2-inch diameter straight double-flute bit and a 1-inch diameter straight double-flute bit. With each bit, the cuts were full bit width and full depth in the 3/4-inch MDF board. The procedure started by cutting a large square and then cutting progressively smaller squares until 900 inches of cut had been made with each bit. For both cuts, the spindle speed was 18,000 RPM and the feed speed was 315 IPM. The results for this procedure were:

Full Load Power (15-hp Perske Spindle Motor)

FLP = (1.73 X 38 X 230 X 0.77) / 1000 = 11.64 kW

Required Spindle Power		
Bit Diameter	Average Kilowatts	Maximum Kilowatts
1/2-inch	2.48	2.60
1-inch	4.86	5.37

Comparing the maximum power required to make the test cuts to the spindle's full load power shows that the 15-hp spindle motor was more than adequate for making the required cuts with both bits.

1.1.6 Base Vibration Spectrum

Purpose—This procedure uses a vibration analyzer to provide a base frequency spectrum graph of the spindle vibrations resulting from rotational balance imperfections and bearings. This information can be used to detect major problems with the rotational balance and bearings of the spindle. The spectrum graph also can be compared to future spectrum graphs to evaluate the condition of the spindle bearings after the router has been in use for a period of time. This test is performed without a collet or chuck assembly attached to the spindle shank.

Recommended equipment:

- A vibration analyzer equivalent to Computational Systems Incorporated's Model 2110 Machinery Analyzer or Palomar Technology's Microlog Model 6210.

Method—With the thermocouple and power analyzer attached to the spindle as discussed in procedure 1.1.1., the spindle is operated until the steady-state temperature and power (kW) requirements are reached. After spindle warm-up, use the following steps.

Step 1

Remove the spindle collet or chuck assembly.

Step 2

Run the spindle motor at maximum RPM's.

Step 3

Using a vibration analyzer, develop a graph of the vibration spectrum (peak mm/second) covering 300 cycles per minute (CPM) to 120,000 CPM. The measurement is to be taken as near as possible to the lower spindle bearing. Before developing the spectrum graph, determine the position of maximum vibration by taking measurements every 45° around the lower spindle housing. This and all future vibration measurements should be taken at this point of maximum vibration.

Results—Figure 1.5 shows an example of a vibration spectrum graph for a router spindle motor.

```
POINT # 10   ROUTER 1   -1
  [ ,  ]

SIGNAL STATUS              : OK
LAST MEASUREMENT ON        : 10-JUN-94   09:34:20
RPM READING                : 18000.
LOAD                       :   100.
OVERALL =4.91      MM/SEC PEAK DIG
SPECTRUM=4.89      MM/SEC PEAK DIG
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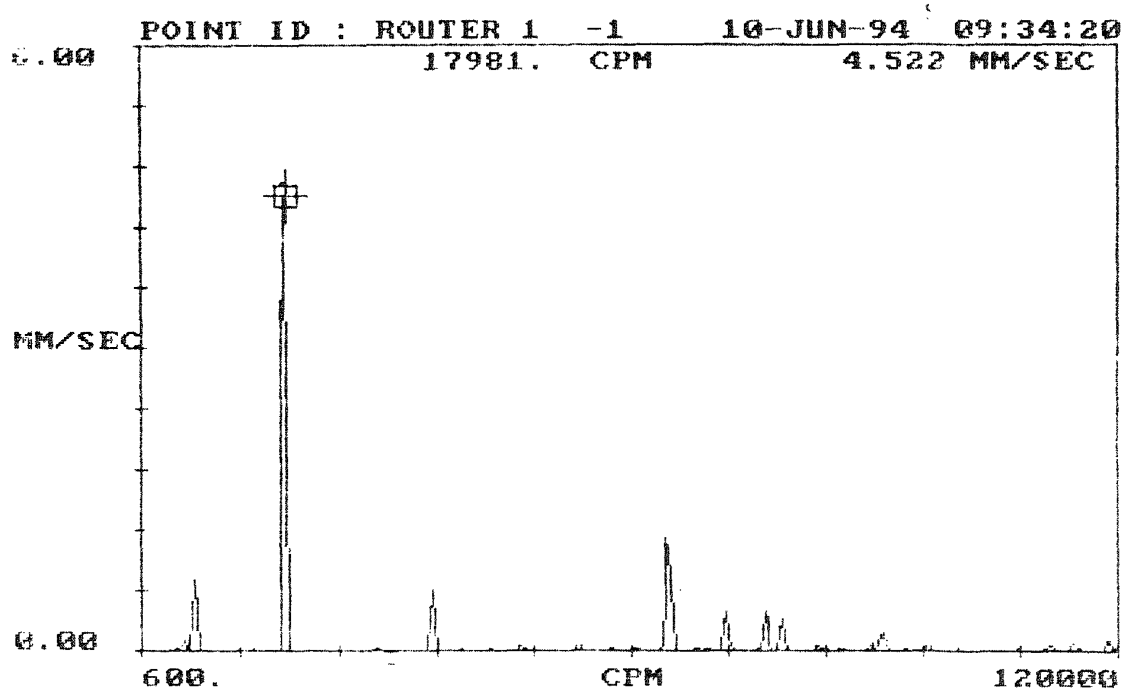

FREQUENCY	DATA	FREQUENCY	DATA	FREQUENCY	DATA	FREQUENCY	DATA
5949.	0.1097	53946.	0.1054	76878.	0.4186	91362.	0.2131
7208.	0.7193	60673.	.04786	78862.	0.3274	96836.	.09252
17981.	4.522	64922.	1.265	83280.	.06893	112016	.06998
35978.	0.6146	70030.	.05764	86640.	.04949	114720	.09848
46688.	.07905	71922.	0.4134	89866.	.09091	118946	0.1353

Figure 1.5—Frequency spectrum of spindle vibration.

1.2 Drill

1.2.1 RPM Accuracy

Purpose—This procedure evaluates RPM accuracy of the drill motor. Because the quality of the hole edges depends to some extent on the correct RPM of the drill motor, the drill should run at the rated RPM.

Recommended equipment:

- Turned-ground-polished (TGP) rod that is 0.5 inch in diameter and 4 inches long. If the drill collet/chuck will not take a 0.5-inch tool, use a TGP rod of the maximum diameter acceptable to the collet/chuck.
- Hand-held digital phototachometer with a range covering the maximum RPM of the drill (accuracy ± 1 RPM).
- Reflective paint.

Method—Before beginning this evaluation, run the drill through approximately 20 drilling cycles to assure that the drill bearings are fully lubricated. Once this is done, use the following steps.

Step 1
Paint a 1/2-inch square patch of the reflective paint on the collet/chuck. The coat of paint should be as thin as possible to minimize the effect on drill vibration that can be caused if the drill is out-of-balance.

Step 2
With the drill motor running, measure and record the RPM's with the hand-held phototachometer.

Results—For the study router, the results of this evaluation were:

Drill RPM	
Target	Actual
1200	1065

1.2.2 Tool Centering Ability

Purpose—This procedure determines the centering ability of the drill chuck by measuring the total runout of a TGP rod mounted in the chuck. Excessive runout can affect the smoothness and diameter of the holes to be drilled.

Recommended equipment:

- A turned-ground-polished (TGP) rod that is 0.5 inch in diameter and 6 inches long. If the drill collet/chuck will not take a 0.5-inch tool, use a TGP rod of the maximum diameter acceptable to the collet/chuck.
- 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.
- Hardware to mount the dial gauge to the router table.

Method—Before beginning this evaluation, run the drill through at least 20 cycles to assure that the drill bearings are fully lubricated. At that point, use the following steps.

Step 1
Mount the TGP rod securely in the drill chuck.

Step 2
Mount the dial gauge to the table and position the gauge anvil (contact point) at a point tangent to the side of the TGP rod and 3 inches below the collet/chuck as shown in Figure 1.6.

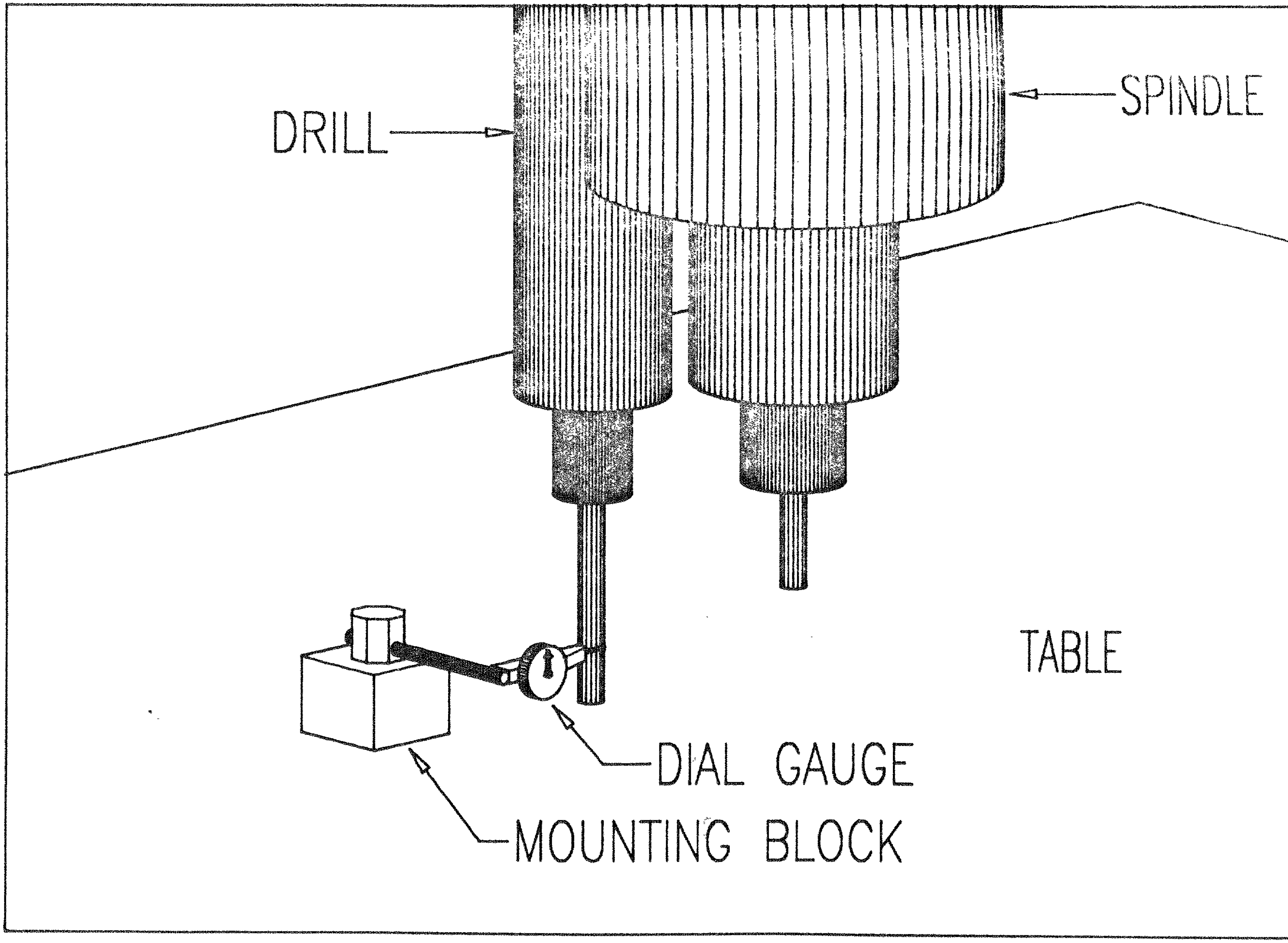

Figure 1.6—Equipment setup for drill runout.

Step 3

Turning the drill chuck by hand, observe and record the total runout of the TGP rod to the nearest 0.0001 inch.

Step 4

Loosen, reposition the TGP rod, and retighten the drill chuck.

Step 5

Repeat Steps 3 and 4 to obtain 10 total runout values. Then determine the minimum, maximum, and average total runout.

Results—For the study router, the results of this evaluation were:

Drill Runout (Thou)		
Minimum	Maximum	Average
0.7	1.2	0.9

.2.3 Trueness Of Rotation

Purpose—This procedure evaluates the trueness of rotation of the drill about its rotational axis. This will indicate the ability of the drill to machine holes that are perpendicular to the surface of the material to be machined.

Recommended equipment:

- Turned-ground-polished (TGP) rod that is 0.5 inch in diameter and 6 inches long. If the drill collet/chuck will not take a 0.5-inch tool, use a TGP rod of the maximum diameter acceptable for the collet/chuck.
- Bar or rod approximately 8 inches long with connector that can be attached to the TGP rod at 90°.
- A dial gauge that can be attached to the above bar or rod. The dial gauge should have graduations of 0.0005 inch, reading of 0-15-0, and range of 0.030 inch with an accuracy of at least 0.0004 inch over the full range.

Method—Before beginning this evaluation, the drill should be run through approximately 20 drilling cycles to assure that the drill bearings are fully lubricated. At that point, use the following steps.

Step 1

Locate and mark points A, B, and C on the router table as indicated in Figure 1.7.

Step 2

Install the 0.5-inch TGP rod into the drill collet/chuck.

Step 3

Attach a crossbar or rod perpendicular to the TGP rod 3 inches below the collet/chuck (Fig. 1.7).

Step 4

Attach a dial gauge to the crossbar or rod and lower so that the anvil (contact point) of the gauge is 6 inches from the center line of the TGP rod (Fig. 1.7). Notice that the anvil of the dial gauge is positioned at 45°. If the anvil is not geared to allow this, it will be necessary to apply a correction factor to the readings obtained.

Step 5

Position the drill until the end of the rod is above the table at point A. Lower the drill until the dial gauge registers near its mid-measurement range. Rotate the drill shaft by hand until the dial gauge is at the -X position and adjust the gauge to read "0". Then rotate the drill shaft by hand to the +X position and record the ± dial gauge reading to the nearest 0.001 inch at the new position. Next, rotate the drill shaft by hand until the

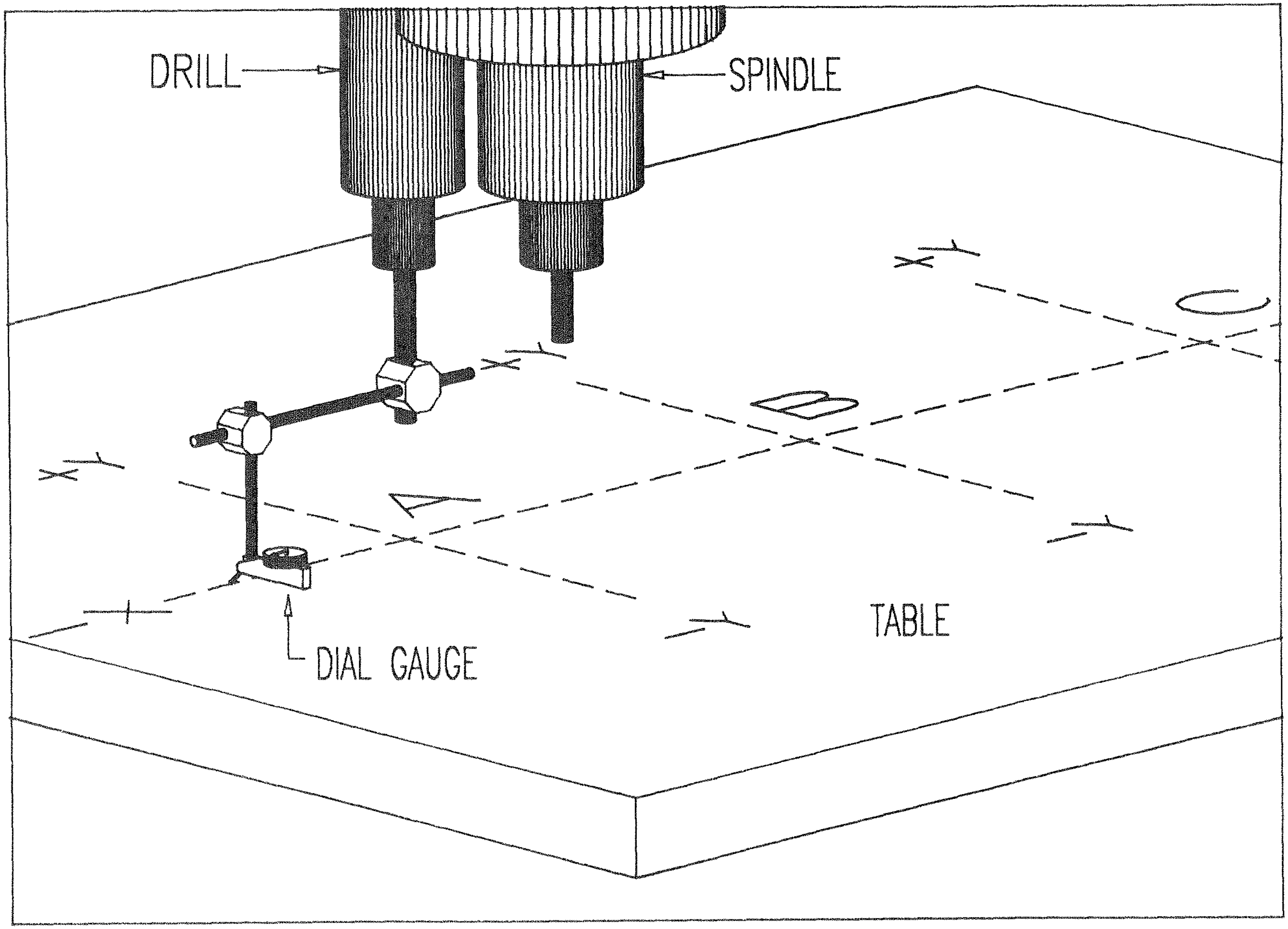

Figure 1.7—Data collection points and equipment setup for measuring drill trueness of rotation.

dial gauge is at the -Y position and adjust the gauge to read "0". Then rotate the drill shaft by hand to the +Y position and record the ± dial gauge reading to the nearest 0.001 inch at the new position.

Step 6

Repeat Step 5 for points B and C as located in Step 1.

Results—Using the recorded deviations, calculate the tilt angles (degree/minute/seconds) and errors (thou/inch) for the trueness of rotation axis of the drill in both the X-axis and the Y-axis for all three points on the table.

To calculate the tilt angle, use the following equation:

TILT ANGLE = ARCTAN (GAUGE READING / 12)

The tilt angle is then converted to degrees, minutes, and seconds. The errors in trueness of rotation are calculated by dividing the deviations by 12 inches, which represent the distance between the two measurement points in each axis. The resulting error values are presented in thou/inch.

For the study router, the deviations in dial gauge readings along with resulting tilt angles and errors were:

Drill Trueness of Rotation				
Table Position	Trueness Axis	Deviation (Inches)	Tilt Angle (Deg.,Min.,Sec.)	Error (Thou/Inch)
A	X	- 0.028	- 00 08'01"	- 2.3
	Y	- 0.003	- 00 00'52"	- 0.2
B	X	- 0.027	- 00 07'44"	- 2.2
	Y	0.001	00 00'17"	0.1
C	X	- 0.027	- 00 07'44"	- 2.2
	Y	- 0.006	- 00 01'43"	- 0.5

A positive deviation and tilt angle indicate that the top of the spindle rotational axis is tilted toward the positive end of the X-axis or Y-axis. Conversely, negative deviations, tilt angles, and errors indicate that the top of spindle rotational axis is tilted toward the negative end of the X-axis or Y-axis.

1.3 Router Table

1.3.1 Table Flatness

Purpose—This procedure uses a laser interferometer system to determine the flatness of the router table. Table flatness is important when machining in axes other than the X and Y. This includes the drilling of holes as well as the machining of surfaces. However, this lack of flatness might not be a problem if the spindle is used to grind the table top to provide a consistent table to spindle distance.

Recommended equipment:

- Class II helium-neon laser (interferometer) system with optics for measuring angular (pitch and yaw) deviations. The optics include an angular interferometer, angular reflector, and two flatness turning mirrors. It is also necessary to have a flatness base with foot spacing that will miss the grooves in the table. Flatness measurements do not require environmental compensations for air temperature, barometric pressure, and relative humidity. And, it is not necessary to make adjustments for the thermal expansion of the scale material, which in this situation is the ball screw used to drive the router table or spindle in the axis to be measured. The laser system must be equivalent to the Renishaw Laser Interferometer System (ML10)[1] by Renishaw Transducer Systems Limited or the HP5528A Laser Measurement System by Hewlett Packard.

- Microcomputer (PC) and software to record and plot the table flatness. Although the PC and software are not necessary, they greatly facilitate data collection and plotting for this procedure.

Method—If the router has a vacuum table, insert screws into each vacuum port in the table and apply vacuum for this procedure. At that point, use the following steps.

Step 1
Lay out the lines for a Moody flatness test on the router table as shown in Figure 1.8.

Step 2
Set up the laser system as instructed in the system user's manual for a Moody flatness procedure. Figure 1.8 also shows a typical setup for this procedure.

Step 3
Collect the required data.

Step 4
If the maximum closure error is greater than 0.5 thou, repeat Steps 1 and 2 until an acceptable error is achieved.

Results—Figure 1.9 is a graphic plot of the table flatness along with the total range in elevation between the high and low point of the table and the two Moody closure errors. The first closure error represents the mismatch of elevations at the intersection of the diagonal lines AE and GC (Fig. 1.8). The second closure error represents the mismatch of elevations at the intersection of lines HD and FB (Fig. 1.8). The maximum closure errors should be less than 0.5 thou. Figure 1.10 shows the actual deviations along the Moody measurement lines.

1.3.2 Spindle to Table Distance Variation

Purpose—This procedure uses a dial gauge to determine the spindle to table distance variations of a router. This variation is important when machining accuracy in the Z-axis is critical.

Recommended equipment:

- Dial gauge that has graduations of 0.0005 inch, reading of 0-15-0, and range of 0.030 inch with an accuracy of at least 0.0004 inch over the full range.

- Hardware for mounting the dial gauge that will fit into the collet and allow the gauge to be mounted so that the ball of the anvil is centered at the point of spindle rotation.

Method—Before beginning this evaluation, insert screws into each vacuum port in the table and apply vacuum. At that point, use the following steps.

Step 1
Insert the dial gauge hardware into the collet and tighten the spindle nut. Rotate the anvil (contact point) of the dial gauge down at a 45° angle. Then, mount the dial gauge so that the ball of the anvil is centered at the point of spindle rotation. In other words, when the spindle is turned by hand, the ball remains at the same point in the XY-plane. Figure 1.11 shows this setup.

[1] 1989. Laser interferometer system—PC10 user manual. Renishaw Transducer Systems Limited. Printed in the United Kingdom by S.A.C.Technographic Ltd.

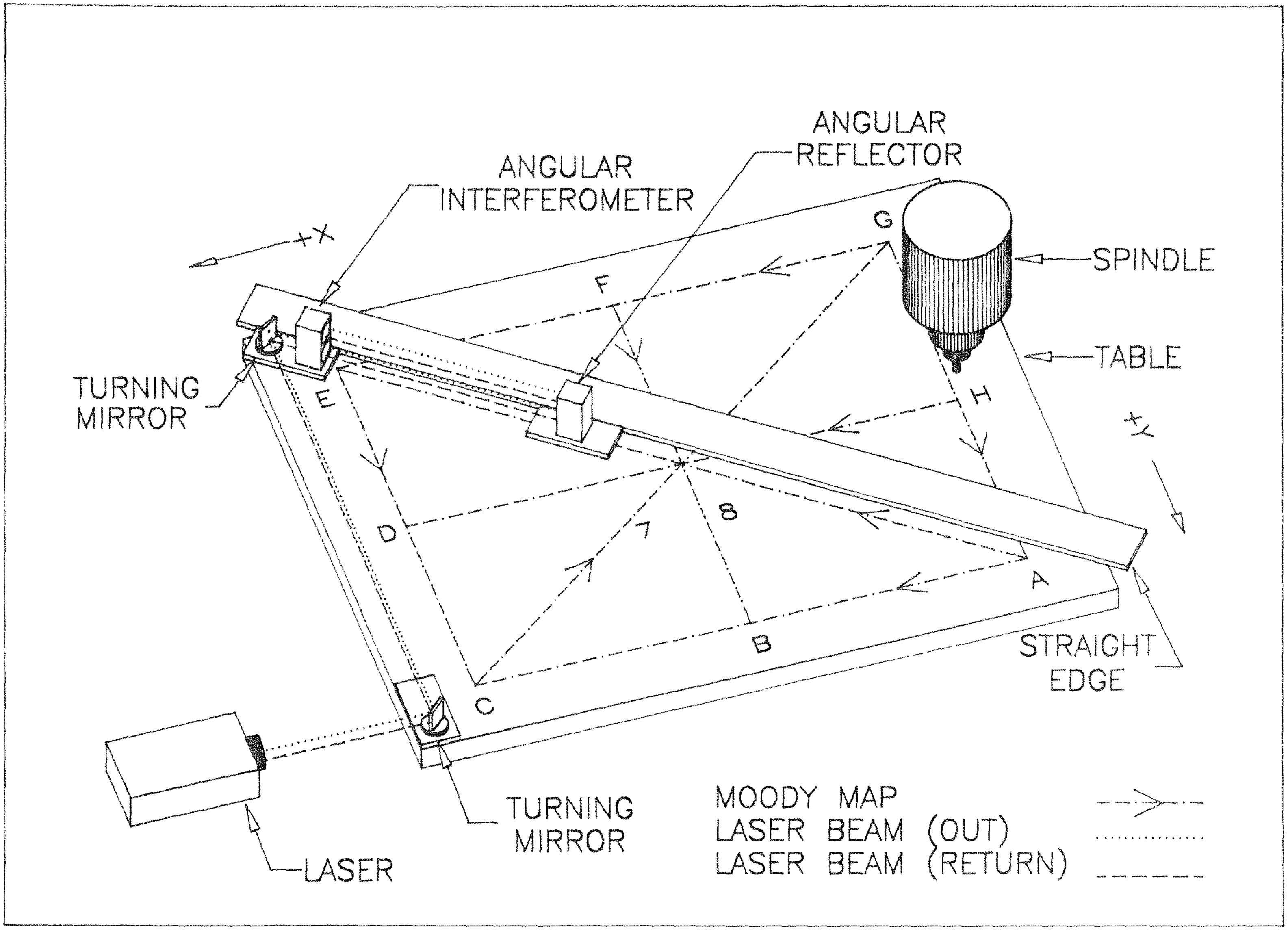

Figure 1.8—Data collection lines and a typical laser setup for a Moody flatness test.

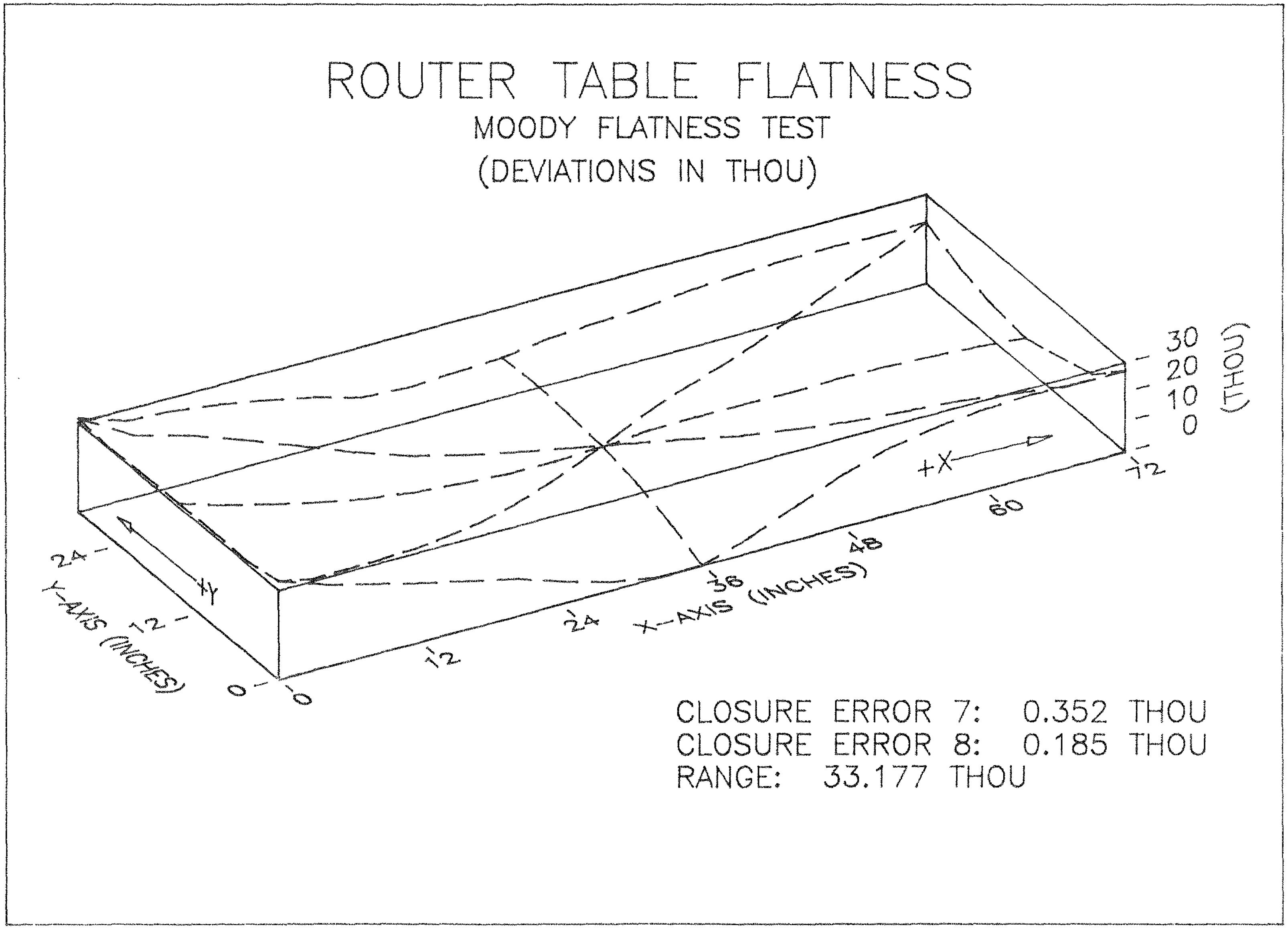

Figure 1.9—Graph showing router table deviations as determined by a Moody flatness test.

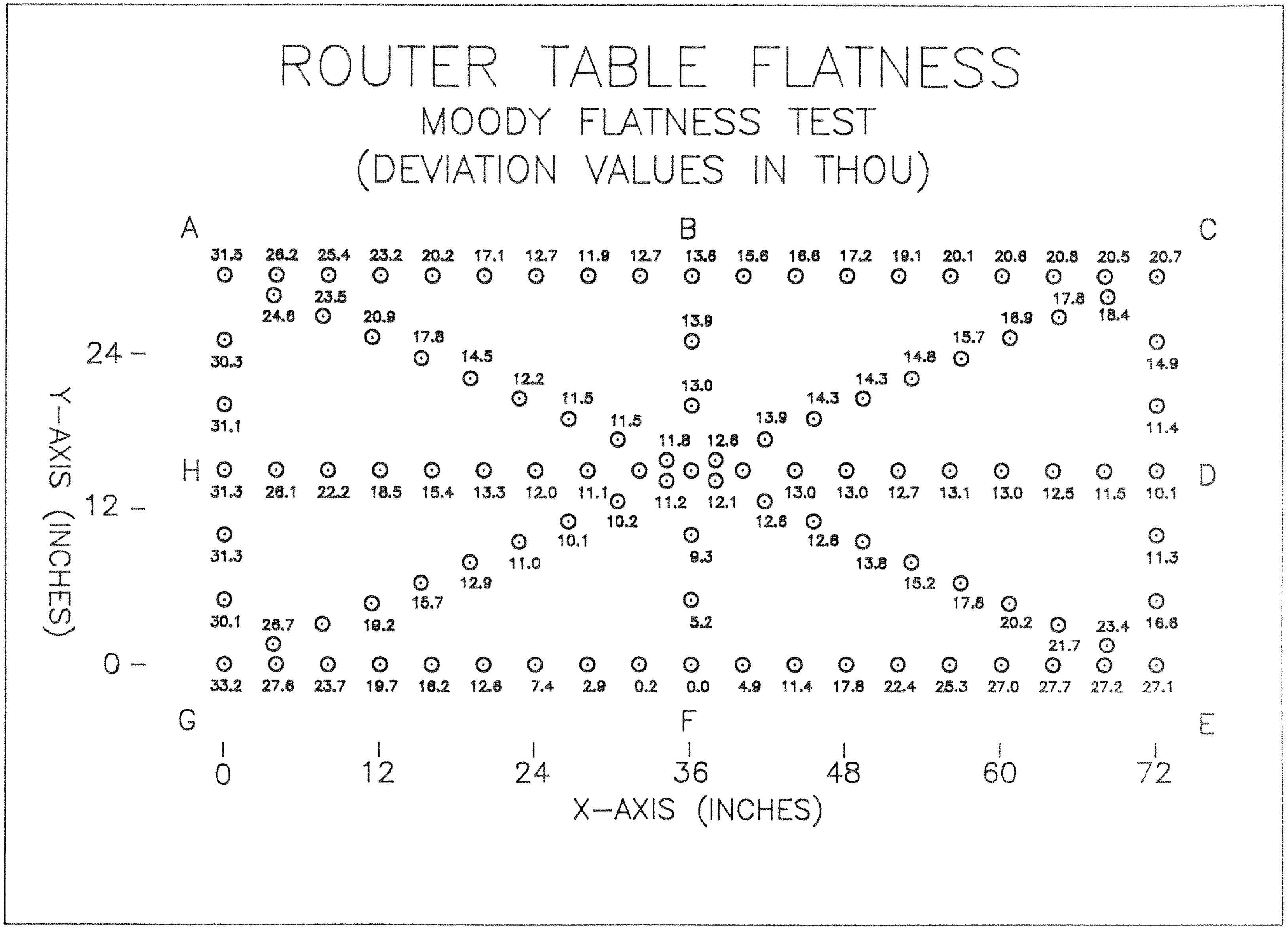

Figure 1.10—Actual table deviations as determined by a Moody flatness test.

Step 2

Using a felt-tipped marker, lay out a system of equally spaced dots on the table. Space the dots 6 inches apart and center in both the X-axis and Y-axis. The rows and columns should be numbered as shown in Figure 1.12. If slots in the table will not allow the 6-inch spacing of the measurement points, use spacing as near as possible to 6 inches.

Step 3

Move the spindle so that the dial gauge anvil is directly over point (0,0) and lower it until the dial gauge needle is at the mid-point of its scale. Rotate the dial gauge face so that it provides a reading of "0".

Step 4

Without raising the spindle, move the spindle/table to the various points as located in Step 2 and record the ± dial gauge readings to the nearest 0.001 inch. Before moving the spindle to each point, rotate it by hand if necessary to assure that the dial gauge anvil is drawn to the point without jamming into the grooves of the table.

Step 5

If the dial gauge is not constructed to allow true readings to be taken with the anvil set at 45°, apply a correction factor to the readings obtained in the above step. The manufacturer or distributor of the gauge can provide this correction factor.

Results—The resulting variations in distances between the spindle and table are then presented as either a graph (Fig. 1.13) or a table (Fig. 1.14).

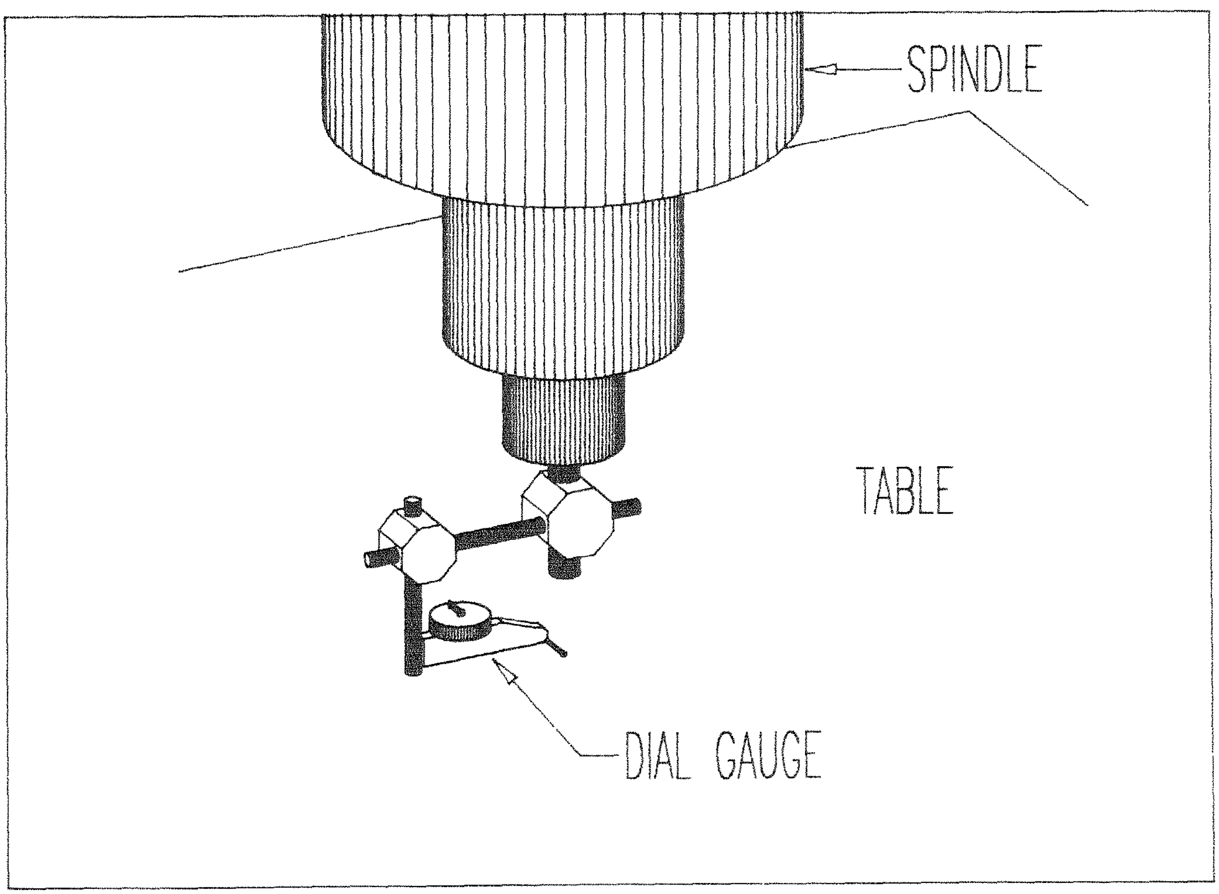

Figure 1.11—Equipment setup for measuring spindle to table distance variations.

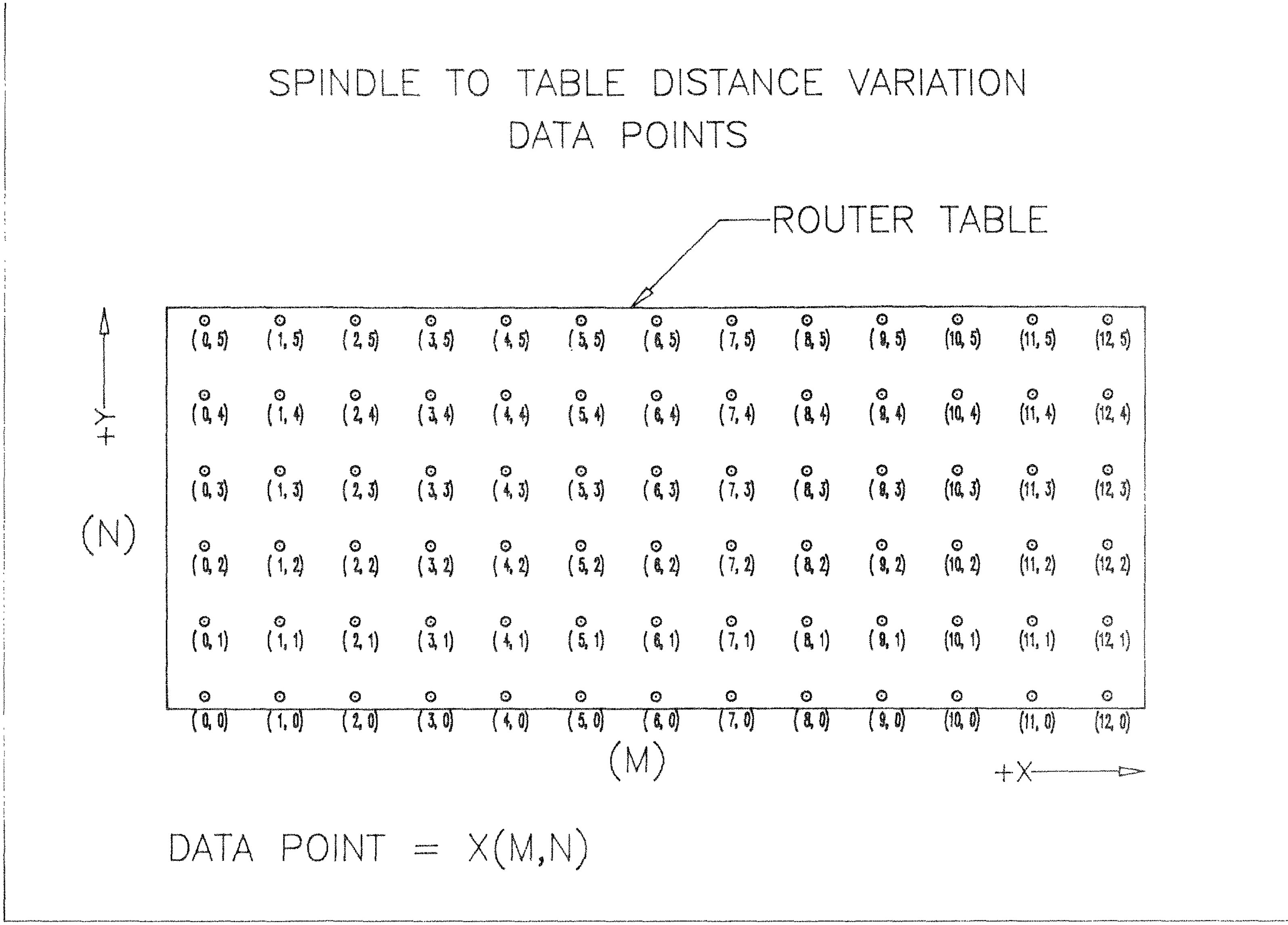

Figure 1.12—Data point layout for measuring spindle to table distance variations.

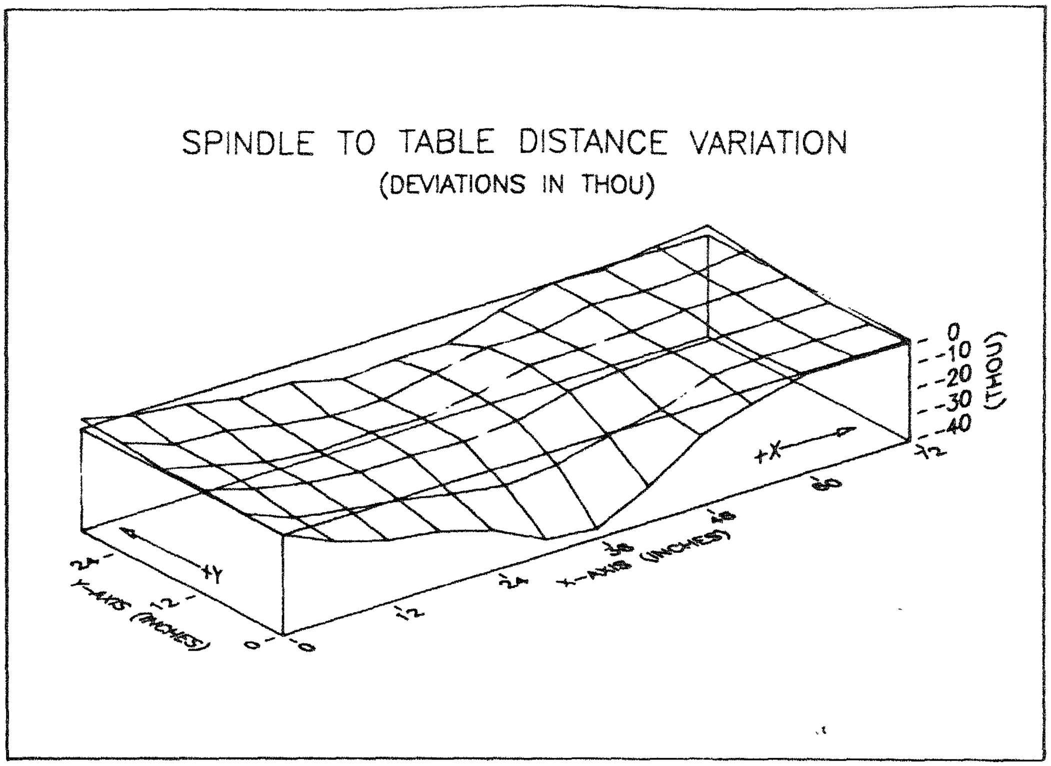

Figure 1.13—Graph showing spindle to table distance variations.

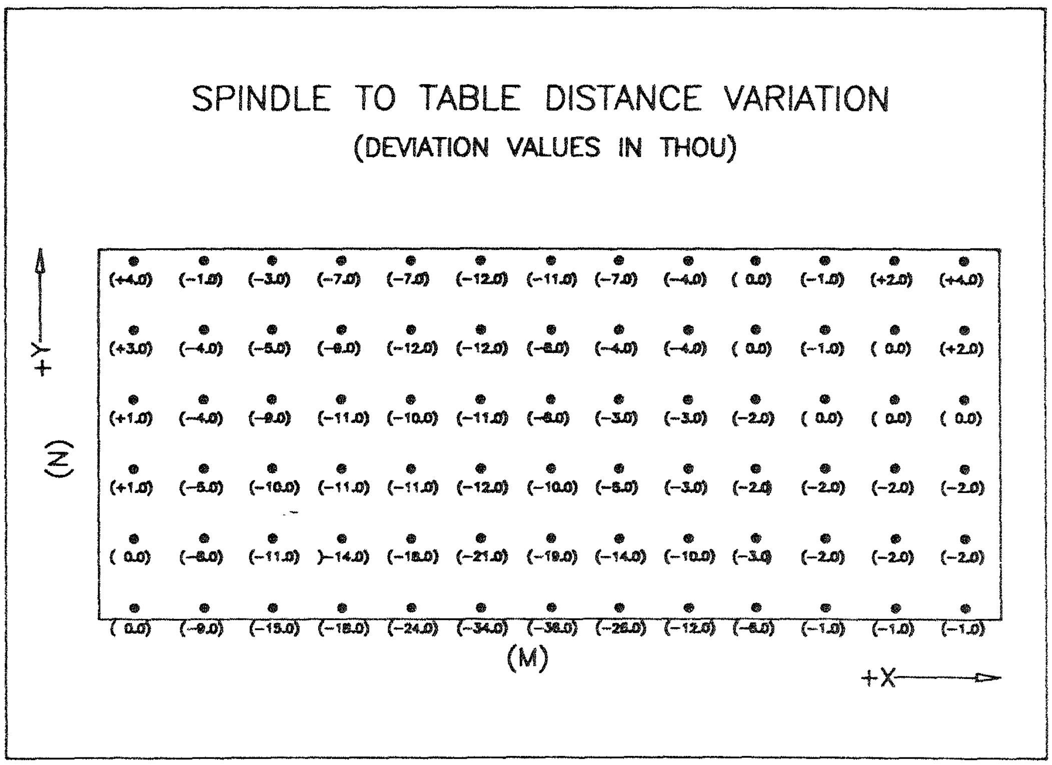

Figure 1.14—Actual spindle to table distance variations.

1.3.3 Tool/Table Deflection from Cutting Side Pressures

Purpose—This procedure determines the tool deflection that occurs if 75 pounds of side pressure is applied between the tool and the table. The 75 pounds represents the side pressures that can occur as the tool cuts material. Factors that might contribute to these deflections include: (1) spindle bearings and shaft play, (2) spindle mounting hardware, (3) spindle way shafts and bushings, (4) spindle ball screw assembly, (5) table way shafts and bushings, and (6) table ball screw assembly. These deflections can produce unsatisfactory cutting accuracy if they are too great.

Recommended equipment:

- Turned ground polished (TGP) rod at least 0.5 inch in diameter.
- Tension scale with a capacity of at least 75 pounds.
- Hydraulic cylinder and hydraulic hand pump.
- Mounting hardware for mounting hydraulic cylinder to router table.
- A dial gauge that can be mounted to the router table. The dial gauge should have graduations of 0.0005 inch, readings of 0-15-0, and range of 0.030 inch with an accuracy of at least 0.0004 inch over the full range.

Method—Before beginning this evaluation, the spindle must be run until the steady-state temperature and power (kW) requirements are reached as discussed in Procedure 1.1.1. The router table and spindle must be exercised in all axes at least 20 cycles. At that point, use the following steps.

Step 1
Mount the TGP rod into the collet/chuck. Then, with the dial gauge mounted on the table, position the anvil (contact point) 1.25 inches below the collet and tanget to the TGP rod as shown in Figure 1.15.

Step 2
Assemble the scales, hydraulic cylinder, and cylinder hardware as shown in Figure 1.15. Then, hook the cylinder hardware over the -X end of the table and apply 75 pounds of pressure in the -X direction on the TGP rod at approximately 1.25 inches from the face of the collet.

Step 3
Record the deflection of the TGP rod as shown on the dial gauge.

Step 4
Repeat the above steps for the +X, -Y, and +Y directions.

Results—The total deflections for study router were:

Tool to Table	
Pressure Direction	Deflection (Thou)
+X	0.8
-X	0.8
+Y	0.2
-Y	0.2

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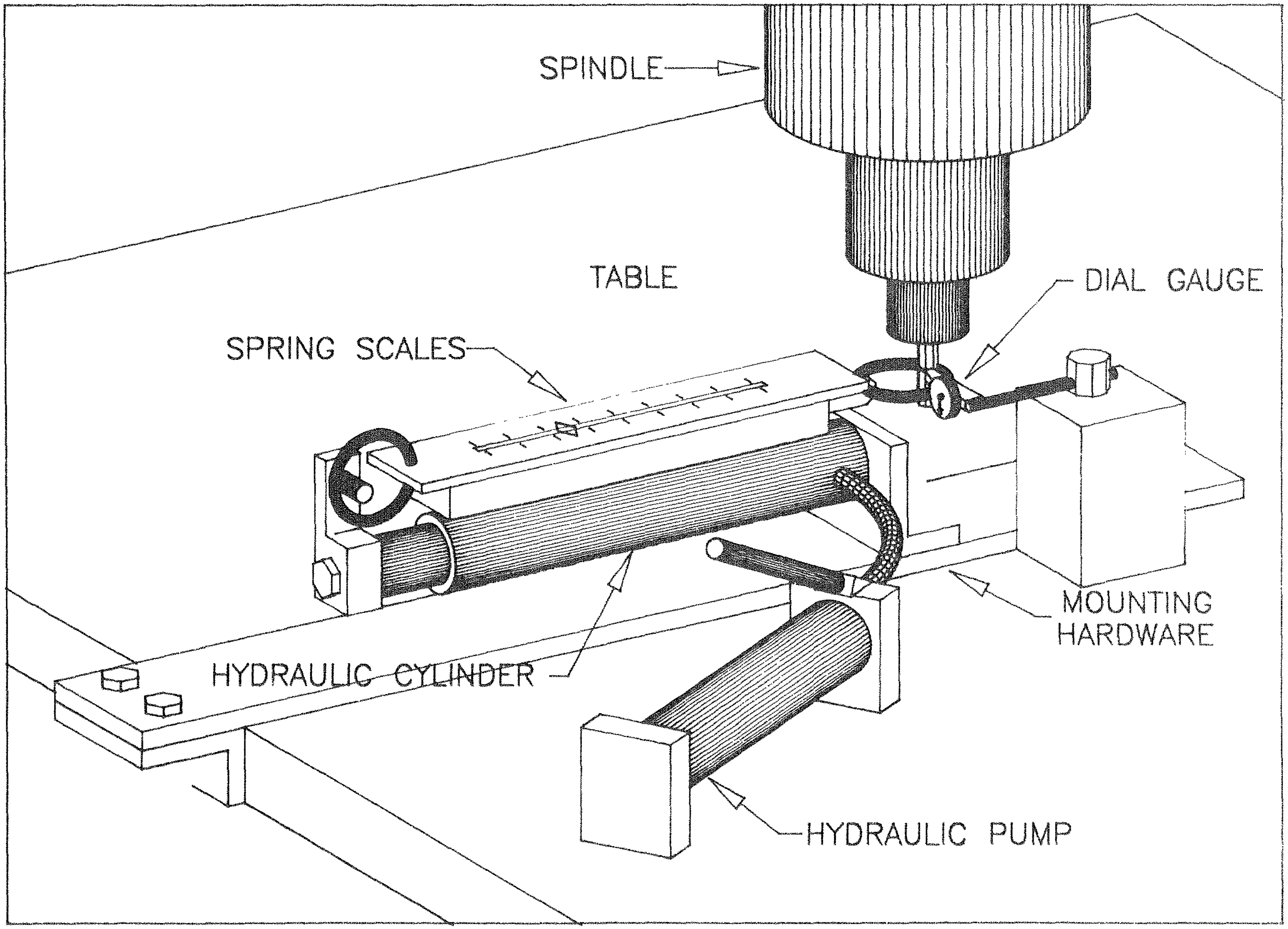

Figure 1.15—Equipment setup for measuring tool/table deflections resulting from cutting side pressures.