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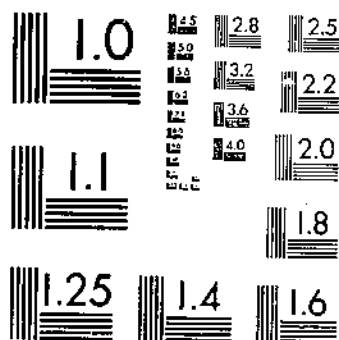
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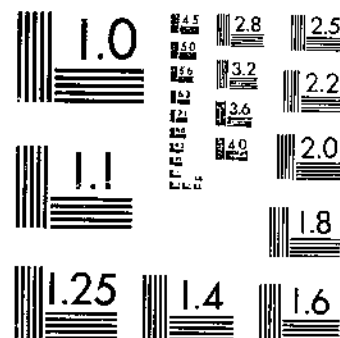
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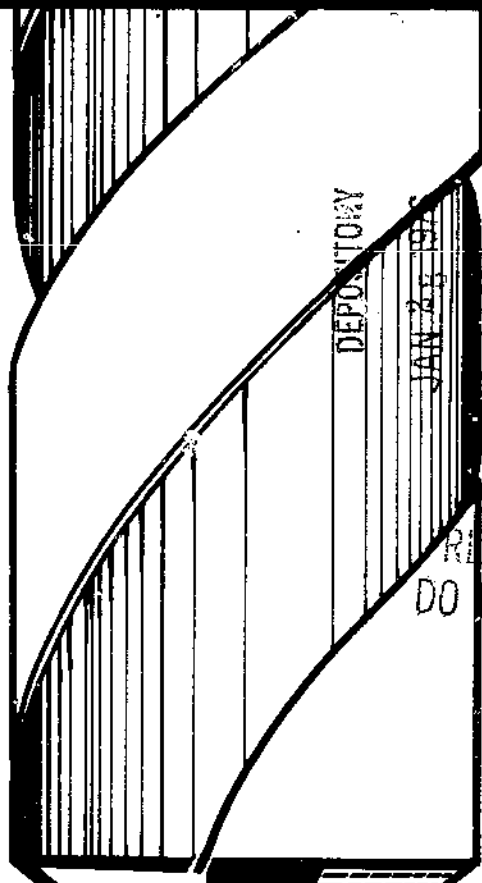
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MACHINE DOMINANT SOUTHERN RINE

WILLIAM W. WOODSON
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McMillin, C. W., and Woodson, G. E.

1974. Machine boring of southern pine. U.S. Dep. Agric. Tech. Bull. 1496, 46 p.

To provide data for the operation and design of boring machines, a study was made to delineate effects of seven variables on torque, thrust, and hole quality when holes are bored in southern pine with brad-point bits of four types commonly used in commercial practice.

Oxford 823.4 Keywords: machining, boring, borers, bits, boring speed, diameter, chip thickness, arbor speed, cutting direction, moisture content, specific gravity, torque, thrust, power requirements, surface quality, Pinus Sp., southern pine.

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Machine Boring of Southern Pine

By

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Southern Forest Experiment Station

USDA Forest Service

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Machine Boring of Southern Pine

By

Charles W. McMillin and George E. Woodson¹

INTRODUCTORY SUMMARY

This bulletin delineates the factors affecting torque, thrust, and hole quality when southern pine (*Pinus* spp.) wood is bored by machine. The data are from a comprehensive study evaluating the seven wood and machine variables likely to prove most significant in commercial operations. Holes were made with brad-point bits of four common types (fig. 1). The variables were bit diameter (0.50, 1.00, and 1.25 inches); spindle speed (1,200, 2,400, and 3,600 r.p.m.); chip thickness (0.010, 0.020, and 0.030 inch); wood specific gravity (less than 0.52 and more than 0.55); moisture content (dry and wet); depth of hole (1, 2, and 3 inches); and boring direction (tangential, radial, and longitudinal).

¹ Principal Wood Scientist and Wood Scientist respectively, Southern Forest Experiment Station, USDA Forest Service.

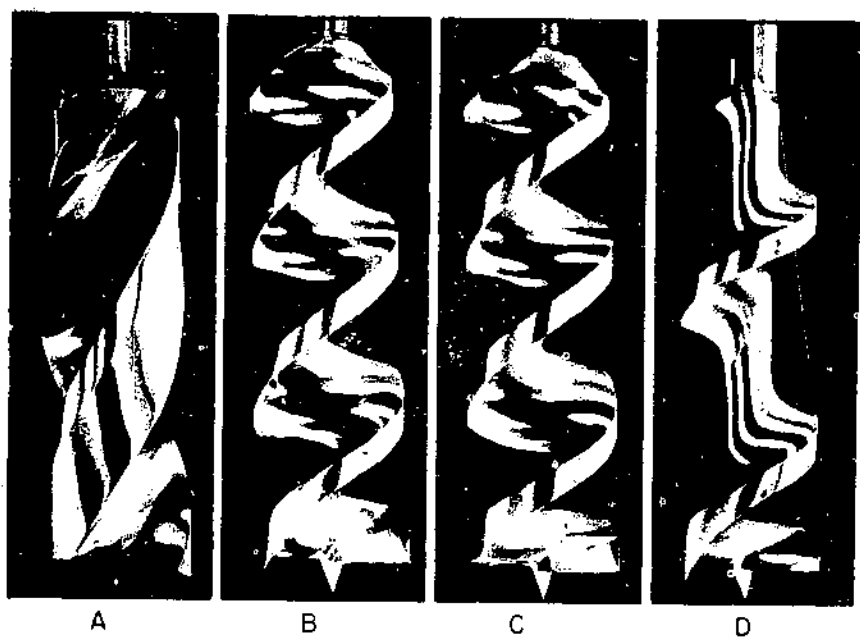


Figure 1.—Bit types: A, Spur machine; B, double-spur, double-twist; C, flat-cut, double-twist; D, double-spur, single-twist, solid-center. All bits had brad points.

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For all boring directions, neither thrust nor torque differed with spindle speed when chip thickness was held constant. In cross-grain boring, thrust and torque did not differ between the radial and tangential directions.

For both cross-grain and longitudinal boring, torque increased with increasing bit diameter. For a given diameter, it increased with chip thickness and was greater in wood of high than of low specific gravity. In general, torque increased with depth of hole for 0.50-inch bits but was unrelated to depth for larger bits. For most bits, torque was greater in dry than in wet wood when samples were bored across the grain.

Thrust increased with increasing bit diameter (except in the longitudinal direction with the flat-cut bit) and was greater in wood of high than of low specific gravity. It was also greater in dry than in wet samples. For 1.00- and 1.25-inch bits of all types except the flat-cut bit, thrust decreased with increasing depth of holes. In general, thrust was positively correlated with chip thickness.

The torque and thrust requirements for each bit type and diameter are summarized in table 1. The values listed are averages for all specific gravities, moisture contents, chip thicknesses, depths, and spindle speeds. The table shows that torque was generally less and thrust was greater when boring across than along the grain. For most combinations tested, torque and thrust were least with the flat-cut, double-twist bit.

Hole quality (smoothness) improved with decreasing chip thickness. For chips of constant thickness, it was unaffected by spindle speed and

Table 1.--Torque and thrust requirements when boring with four types of bits

Bit type and direction	0.50 in. diam.		1.00 in. diam.		1.25 in. diam.	
	Torque	Thrust	Torque	Thrust	Torque	Thrust
	In.-lbs.	Lbs.	In.-lbs.	Lbs.	In.-lbs.	Lbs.
Spur machine bit						
Along	15.6	51.7	45.6	101.6	77.2	152.0
Across	15.0	73.1	30.9	127.3	52.9	177.8
Double-spur, double-twist						
Along	13.5	46.7	50.1	111.4	72.3	143.2
Across	19.3	100.6	37.3	139.1	45.4	174.8
Flat-cut, double-twist						
Along	13.6	32.2	40.2	45.2	54.8	40.8
Across	18.4	56.0	29.3	60.2	36.4	57.3
Double-spur, single-twist, solid center						
Along	17.5	67.7	51.2	111.3	73.0	132.3
Across	12.3	73.1	33.1	129.6	46.6	164.9

wood specific gravity. In general, the single-twist, solid-center bit yielded holes of poorest quality when boring along the grain. Across the grain, quality was inferior when holes were bored with the flat-cut bit, although torque and thrust were minimized.

GENERAL CONSIDERATIONS

Machine boring is a common operation whenever dowels, rungs, or screws are required in assembling wood components. Bored holes are also needed for bolted connections in poles, crossarms, trusses, and structural beams. The quality of the holes may affect product performance and their rate of production influences manufacturing costs.

World literature on wood machining is digested in a book by Koch (1964) and in abstracts by Koch and McMillin (1966a,b), Koch (1968, 1973), and McMillin (1970). Though research on such operations as sawing and veneer cutting has been pursued vigorously, these reviews disclosed few references on machine boring. The southern pines are used for a variety of purposes that require bored holes, but, with the exception of two recent publications by the present authors (McMillin and Woodson 1972, Woodson and McMillin 1972), no data are available.

From the standpoint of machinability, second-growth wood of the major southern pines is indistinguishable by species. Variation in specific gravity is wide, and the ranges for the four species are similar. A value of 0.49 (green volume and oven-dry weight) is sometimes stated as a general average. The data from the present study may be taken as applicable to wood of all four species: longleaf (*Pinus palustris* Mill.), loblolly (*P. taeda* L.), shortleaf (*P. echinata* Mill.), and slash (*P. elliotii* Engelm. var. *elliotii*).

Holes are usually bored in one of three primary directions illustrated in figure 2. The power required to rotate and advance the bit can be resolved into two components—torque and thrust. Generally, torque is greater and thrust is less when boring is done along the grain (longitudinal direction) than across the grain (radial and tangential directions).

Torque is related to the parallel tool force component of the lips and, to a lesser extent, to torsional forces exerted by the spurs and brad. When boring along the grain, the lips cut perpendicular to the long axes of the tracheids. In cross-grain boring, by contrast, tracheids are cut in a plane parallel to their axes. Since tracheids are stronger when severed in the perpendicular direction, greater torque would be expected when boring along rather than across the grain.

Thrust is related chiefly to the force required to advance the spurs and brad into the work. The normal force exerted by the cutting lips is usually small. Along the grain, the spurs separate fibers parallel to their long axes. In cross-grain boring, the spurs cut in a direction which continuously alternates between the parallel and the perpendicular axes of the fibers; thrust forces are consequently increased.

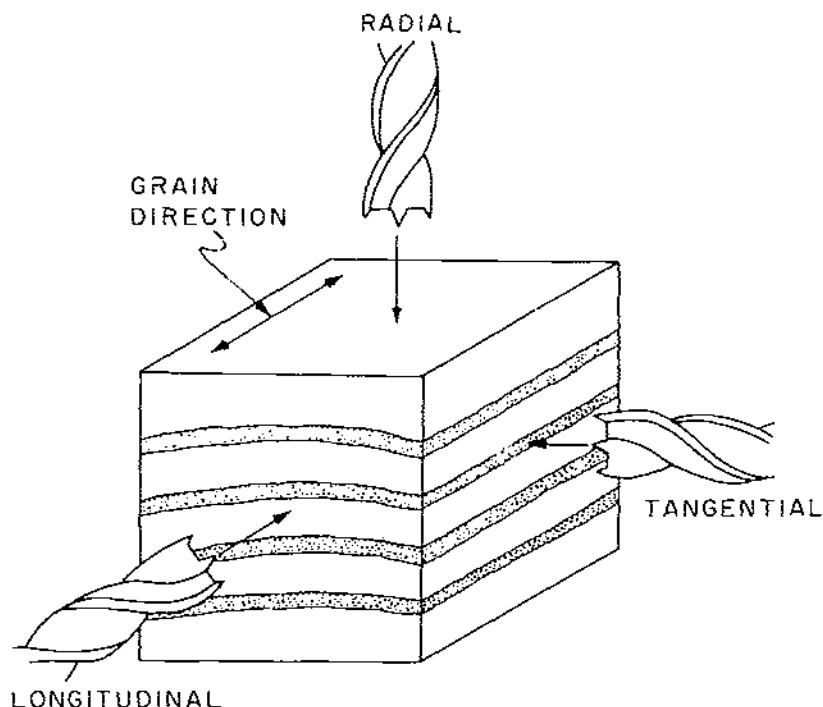


Figure 2.—Designation of the main boring directions.

Both in the text and in the appendix, the experimental data are reported only as torque and thrust. Torque values may be converted to horsepower by the equation:

$$P = \frac{nT}{63,024} \quad (1)$$

where:

P = Horsepower required at the spindle

n = Spindle speed, r.p.m.

T = Torque on spindle, inch-pounds

Power required to advance the bit is not included in the equation, but rarely exceeds a fraction of a horsepower. Thrust forces are important chiefly because of the strain they apply to bits and other components of the spindle assembly. The equation also ignores no-load idling losses of the motor and spindle assembly.

In some applications specific cutting energy is of chief concern, since it expresses the efficiency of the cutting action. It may be calculated from the equation:

$$E_s = \frac{T}{(3,988,861) \pi N D^2} \quad (2)$$

where: E_s = Specific cutting energy, kilowatt hours per cubic inch of wood removed
 t = Undeformed chip thickness, inches
 N = Number of cutting lips per revolution
 D = Bit diameter, inches

EXPERIMENTAL DESIGN AND PROCEDURE

A factorial experiment with three replications was designed with seven variables:

Bit diameter—0.50, 1.00, and 1.25 inches

Spindle speed—1,200, 2,400, and 3,600 r.p.m.

Undeformed chip thickness—0.010, 0.020, and 0.030 inch

Wood specific gravity (ovendry weight and volume at 10.4 percent moisture content)—Less than 0.52 (avg. 0.48); more than 0.55 (avg. 0.60)

Moisture content—Dry (avg. 10.4 percent); wet (avg. 73.0 percent)

Boring (feed) direction—Tangential, radial, and longitudinal

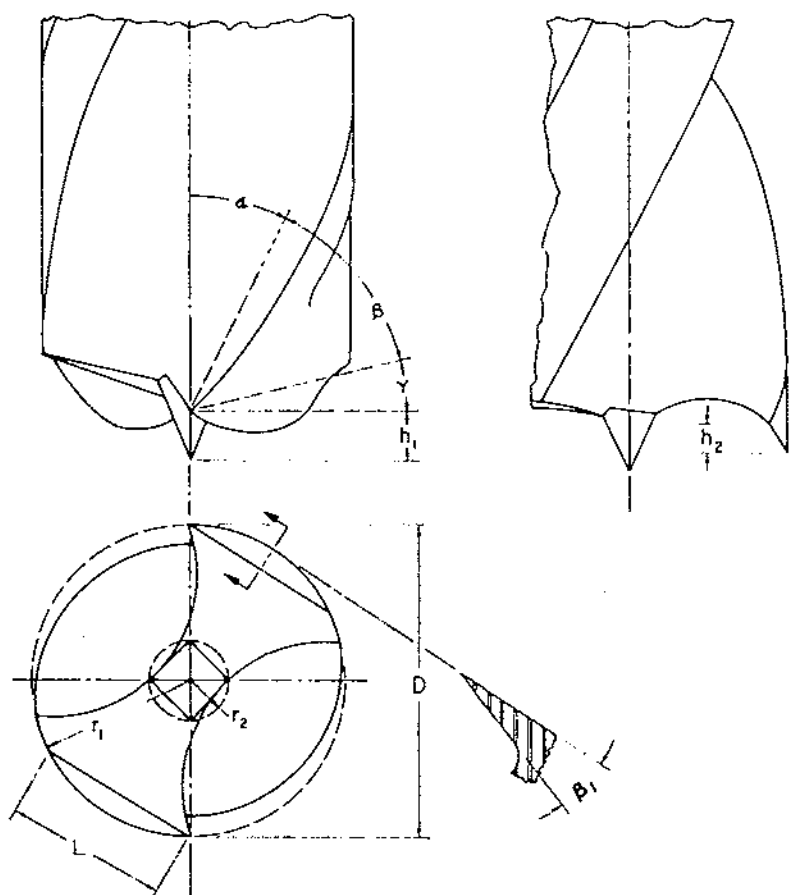
Depth of hole—1, 2, and 3 inches

The four bit types were designated as: spur machine bit; double-spur, double-twist; flat-cut, double-twist; and double-spur, single-twist, solid center. All but the flat-cut bit had outlining spurs extending below the cutting lip. In this bit, side lips severed the end surface of the chip simultaneously with the cutting action of the horizontal lips.

All bits had brad points, 1/2-inch shanks, two cutting lips, and 4-inch twists. They were purchased directly from the manufacturer and were representative of his production stock. In general, they were used in the condition received, although some minor imperfections were corrected by hand honing. Schematic drawings and geometrical specifications are provided in figures 3 through 6. Geometrical specifications are based on a 33-percent sample of the bits used.

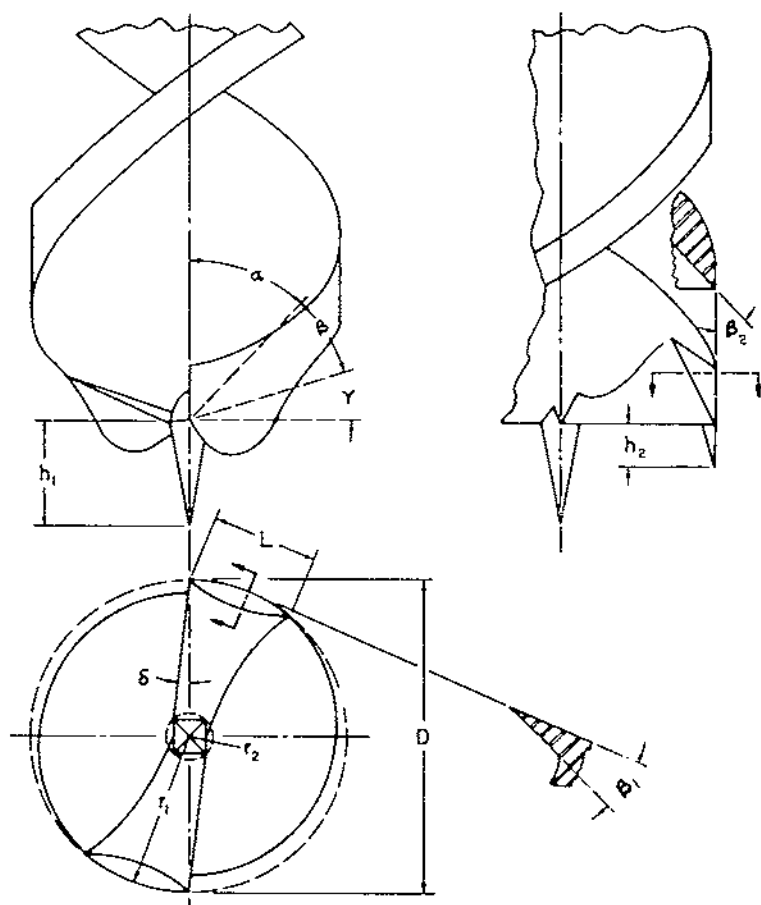
Bits were changed for each replication, and only 12 holes were drilled with each bit. Thus, effects associated with tool wear and variation between bits of the same type were minimized.

Five thousand board feet of rough-sawn southern pine 4 by 4's were kiln-dried to approximately 12 percent moisture content and accurately surfaced on four sides to 3 1/2 by 3 1/2 inches. They were then crosscut to form about 8,500 3 1/2-inch cubes; only clear, defect-free wood was accepted. The cubes were placed on stickers with end grain exposed in a room maintained at 60 percent relative humidity and 73° F. Fans assured adequate air circulation throughout the stacks until the samples reached constant weight. A 2-percent sample of the total population indicated that moisture content averaged 10.4 percent; the standard deviation was 0.55. Average volume of the cubes was 693.80 cc. with a standard deviation of 6.71.



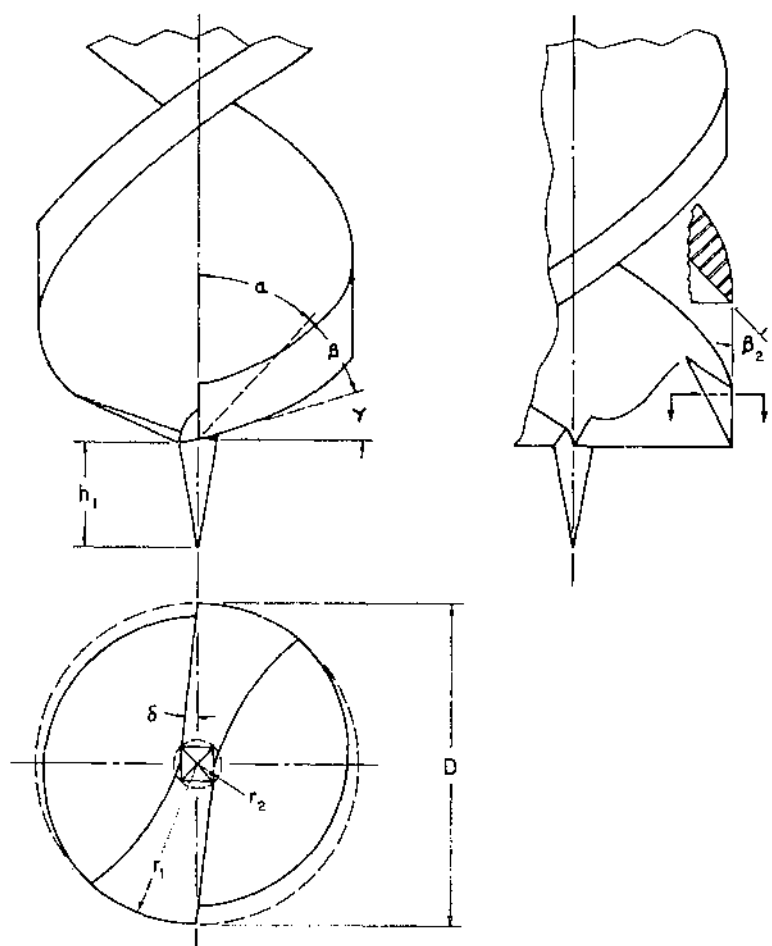
Symbol	Definition	Bit diameter (D) in inches		
		0.50	1.00	1.25
α	Rake angle, degrees	20.2	19.3	18.6
β	Sharpness angle of lips, degrees	54.4	60.6	61.4
β_1	Sharpness angle of spurs, degrees	37.3	35.1	36.3
γ	Clearance angle of lips, degrees	15.4	10.1	10.0
h_1	Brad height below lip, inch	.10	.20	.20
h_2	Height of spur below lip, inch	.03	.10	.11
L	Spur length at root, inch	.21	.53	.62
r_1	Bit radius, inch	.250	.500	.625
r_2	Effective radius of point, inch	.07	.09	.11

Figure 3.—Spur machine bit. For this bit, α , β , and γ were measured at midpoint of the bit radius.



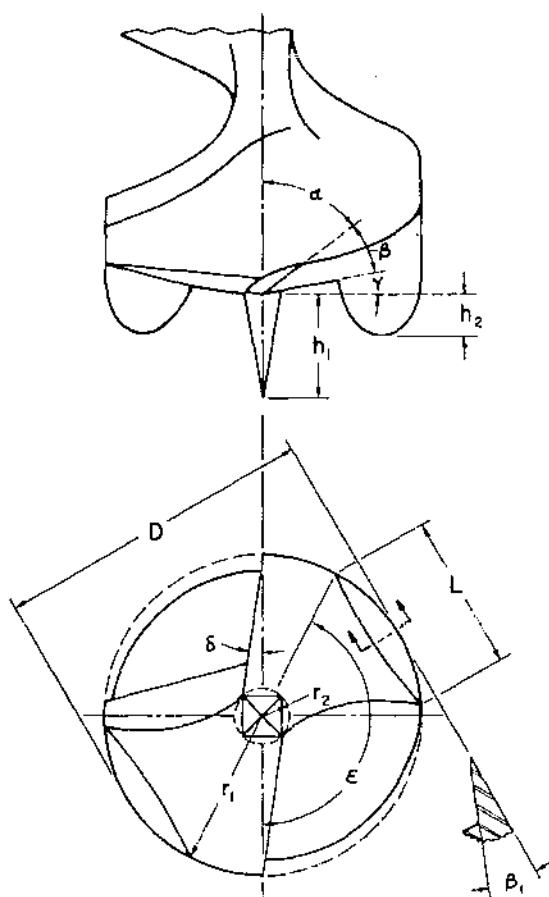
Symbol	Definition	Bit diameter (D) in inches		
		0.50	1.00	1.25
α	Rake angle, degrees	30.6	33.5	31.8
β	Sharpness angle of lips, degrees	44.9	45.6	47.7
β_1	Sharpness angle of spurs, degrees	31.9	29.6	29.7
β_2	Sharpness angle of side-cutting spurs, degrees	33.2	32.4	35.9
γ	Clearance angle of lips, degrees	14.6	10.9	10.4
δ	Skew angle of lips, degrees	18.2	14.8	12.1
h_1	Grad height below lip, inch	.11	.21	.22
h_2	Height of spur below lip, inch	.05	.11	.12
L	Spur length at root, inch	.23	.45	.55
r_1	Bit radius, inch	.250	.500	.625
r_2	Effective radius of point, inch	.08	.14	.14

Figure 4.—Double-spur, double-twist bit.



Symbol	Definition	Bit diameter (D) in inches		
		0.50	1.00	1.25
α	Rake angle, degrees	29.6	35.7	33.3
β	Sharpness angle of lips, degrees	45.1	40.9	42.7
β_2	Sharpness angle of side-cutting spurs, degrees	31.1	35.2	33.7
γ	Clearance angle of lips, degrees	15.3	13.4	14.1
δ	Skew angle of lips, degrees	17.8	13.2	10.9
h_1	Grind height below lip, inch	.13	.23	.24
r_1	Bit radius, inch	.250	.500	.625
r_2	Effective radius of point, inch	.08	.11	.12

Figure 5.—Flat-cut, double-twist bit.



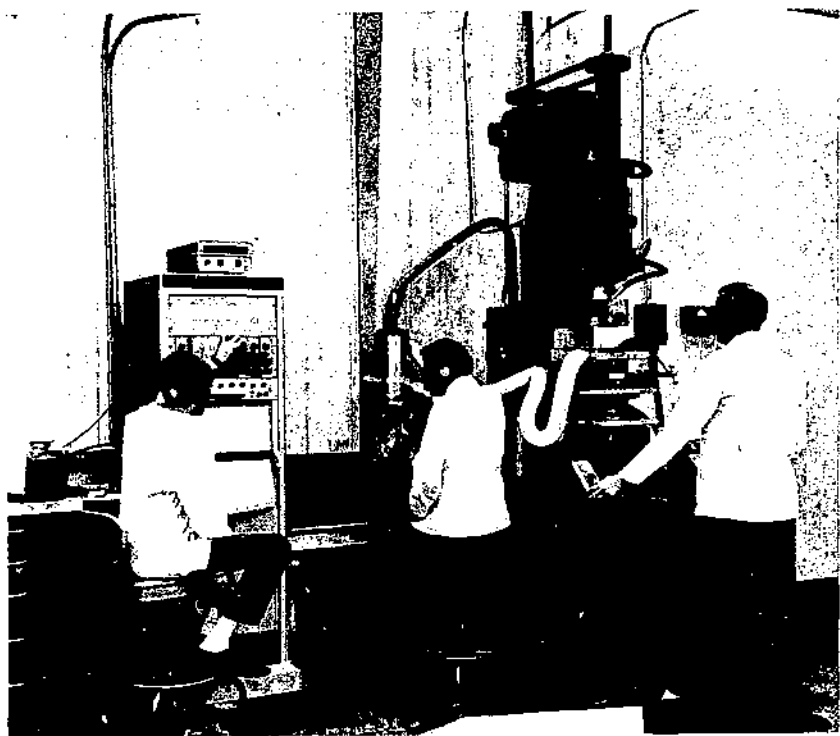
Symbol	Definition	Bit diameter (D) in inches		
		0.50	1.00	1.25
α	Rake angle, degrees	30.0	27.4	31.8
β	Sharpness angle of lips, degrees	47.8	51.6	46.1
β_1	Sharpness angle of spurs, degrees	29.8	28.2	27.8
γ	Clearance angle of lips, degrees	12.2	11.0	12.1
δ	Skew angle of lips, degrees	15.5	12.8	11.7
ϵ	Angle of lead (spur to lip measured at circumference), degrees	151.5	148.3	152.3
h_1	Brad height below lip, inch	.10	.22	.23
h_2	Height of spur below lip, inch	.04	.12	.12
L	Spur length at root, inch	.25	.46	.58
r_1	Bit radius, inch	.250	.500	.625
r_2	Effective radius of point, inch	.09	.13	.15

Figure 6.—Double-spur, single-twist, solid-center bit.

Because the blocks were essentially uniform in moisture content and volume, it was possible to place them into specific gravity classes by weight. Those weighing 400 g. or less were classified as low in specific gravity (0.52 or less) while those weighing 420 g. or more were designated as high in specific gravity (0.55 or more). All specific gravities were based on computed oven-dry weight and average volume at 10.4 percent moisture content.

The samples in each specific gravity class were then assigned to the radial, tangential, and longitudinal boring directions by visual inspection of the end grain. Half the samples in each resulting factorial combination were selected at random and maintained at 10.4 percent moisture content. The remaining half were soaked in water-filled holding tanks.

Holes were made in random order with an especially designed research boring machine (fig. 7). A 5-horsepower, synchronous-speed, 3,600 r.p.m., alternating-current motor with timing belt drive assured constant spindle speed. Speeds were varied by changing the diameters of the motor and spindle pulleys. The spindle rotated in a hydraulically operated quill assembly, and a flow-control valve (compensated for temperature and pressure) was used to maintain accurate axial feed



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Figure 7.—The boring machine, with oscillograph at left. Technician in the center is collecting chips.

speeds. The feed speed was set and monitored by an electronic timer, actuated by a photosensitive relay system at the beginning and end of a 12-inch stroke.

Specimens were clamped in a vise attached to a strain-gauge dynamometer designed to isolate the thrust force and torque exerted on the workpiece. The output of the dynamometer was charted on a two-channel oscillograph having a frequency response of 100 Hz. A photo-sensitive relay system momentarily actuated an auxiliary pen on the oscillograph when the tip of the brad was engaged in the work at depths of 1, 2, and 3 inches. A typical recording is illustrated in figure 8. Torque and thrust were calculated at each depth by applying a calibration factor to the average pen deflection over a $\frac{1}{2}$ -inch length of the oscillographic trace. The dynamometer and recording system

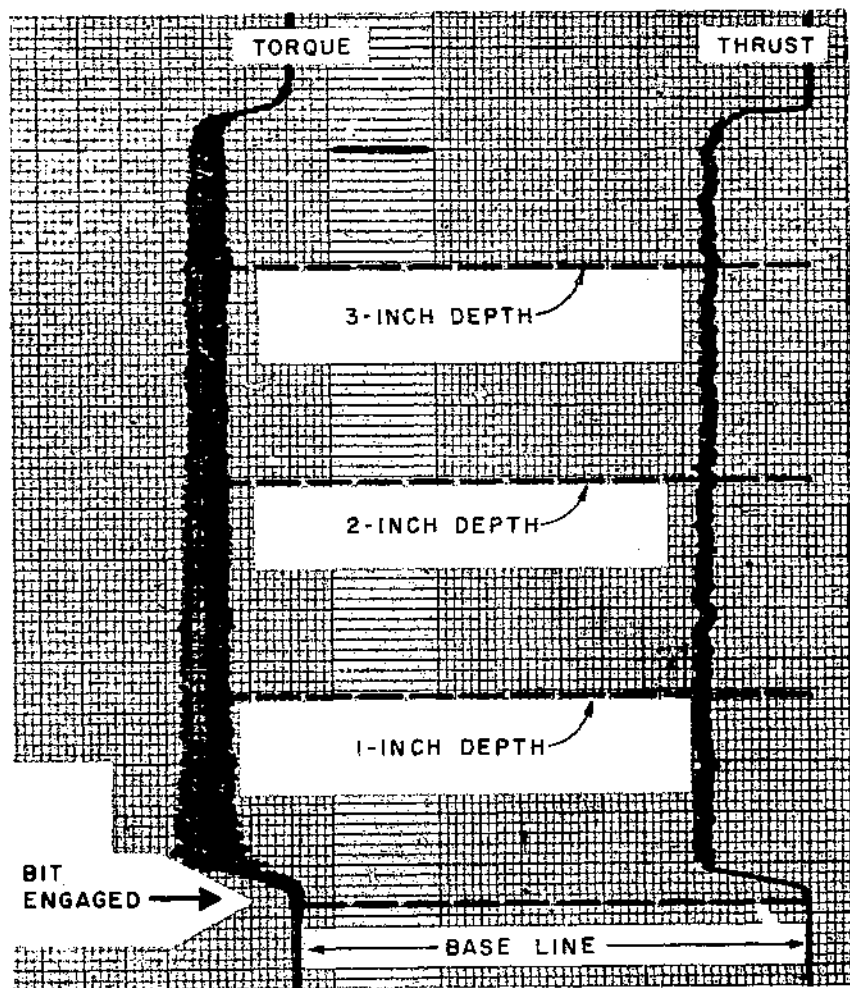


Figure 8.—Typical oscillographic recording of thrust and torque during boring.

permitted accurate measurement of torque to 0.25 inch-pound; thrust was accurate to the nearest pound.

It was not practical to evaluate hole quality at each of the three depths where thrust and torque were measured. Rather, surface smoothness of the entire hole was rated by visual inspection. A smooth hole was rated 1, a very rough hole was rated 3, and intermediate holes were ranked as 2. Thus, the smoothest holes had low numerical ratings. Figure 9 illustrates representative surfaces for each boring direction in wet and dry wood.

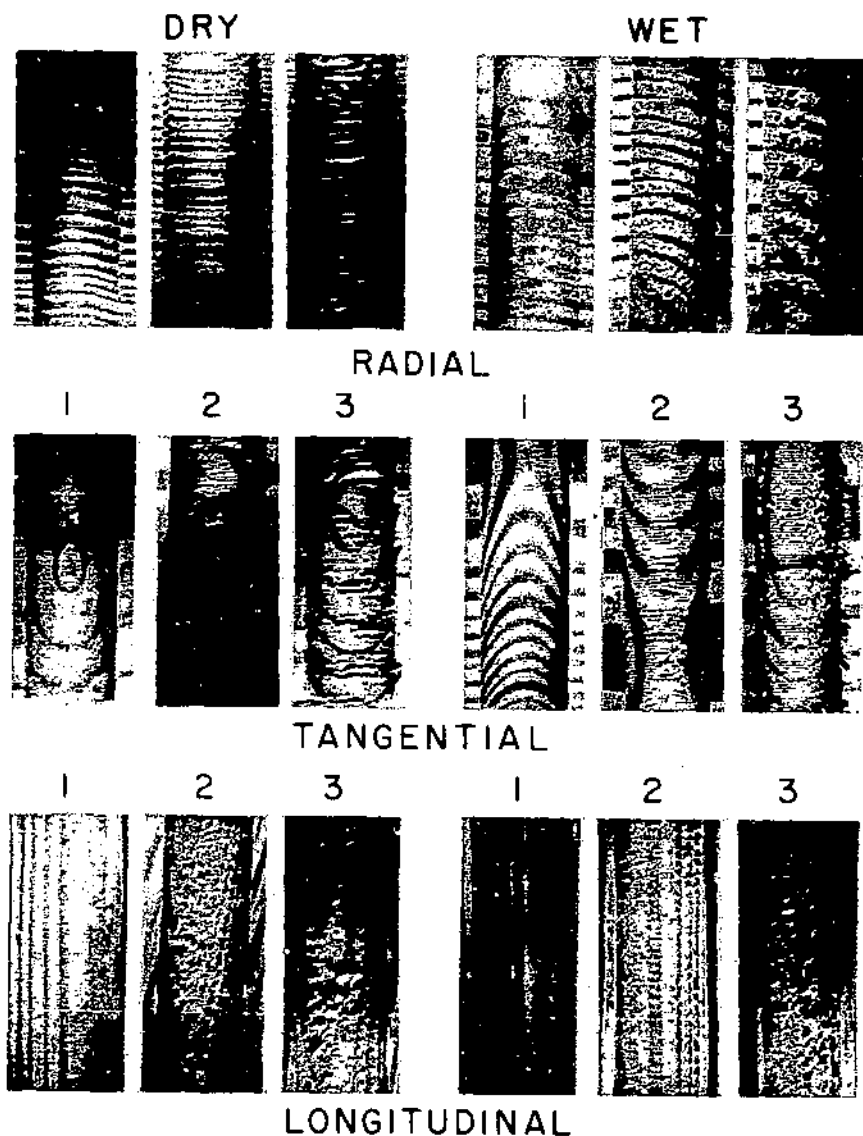


Figure 9.—Surface quality rating (smoothness) for the three principal boring directions.

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The data were interpreted by analysis of variance at the 0.01 level of probability. Interactions were evaluated by Duncan's multiple range test (0.01 level). All following discussion is limited to differences that proved statistically significant and were of practical importance.

For a given undeformed chip thickness, observed values of torque, thrust, and hole quality proved substantially unrelated to spindle speed. Individual means in both text and appendix tables are therefore averaged over all three speeds.

When spindle speed is fixed and chips of a given undeformed thickness are desired, it is necessary to select the proper axial feed speed, as calculated from the equation:

$$f = tnN \quad (3)$$

where:

f = Feed speed, inches per minute

n = Spindle speed, r.p.m.

N = Number of cutting lips per revolution

t = Undeformed chip thickness, inches

BORING ALONG THE GRAIN

Torque

Torque requirements for each of the four bits are detailed in tables 15 through 18 of the Appendix. Since torque did not vary with spindle speed for chips of a given thickness, the values in the tables are averages of 9 observations (3 replications and 3 spindle speeds).

Table 2 compares the torque demand for each bit type when the data were averaged over all levels of depth, moisture content, specific gravity, chip thickness, and spindle speed. As the table shows, torque increased rapidly with increasing bit diameter; the trend was curvilinear. With 0.50-inch bits, torques were essentially the same for all types. However, for bits 1.00 and 1.25 inches in diameter, the flat-cut, double-twist, bit required least torque.

Table 2.—Torque requirements for boring along the grain

Bit type	Diameter, inches		
	0.50	1.00	1.25
	<i>Inch-pounds</i>		
Spur machine bit	15.6	45.6	77.2
Double-spur, double-twist	13.5	50.1	72.3
Flat-cut, double-twist	13.6	40.2	54.8
Double-spur, single-twist, solid-center	17.5	51.2	73.0

In applying this and other summary tables, as well as subsequent tabulations of interactions, the reader is cautioned to recognize the possible effects of other study variables. For example, the torques in table 2 are valid estimates (for engineering applications) for chips of mean thickness, 0.020 inch. Since it will be shown that torque is positively correlated with chip thickness, torque demand will be less than the value in the table when 0.010-inch chips are being cut and greater when chip thickness is 0.030 inch.

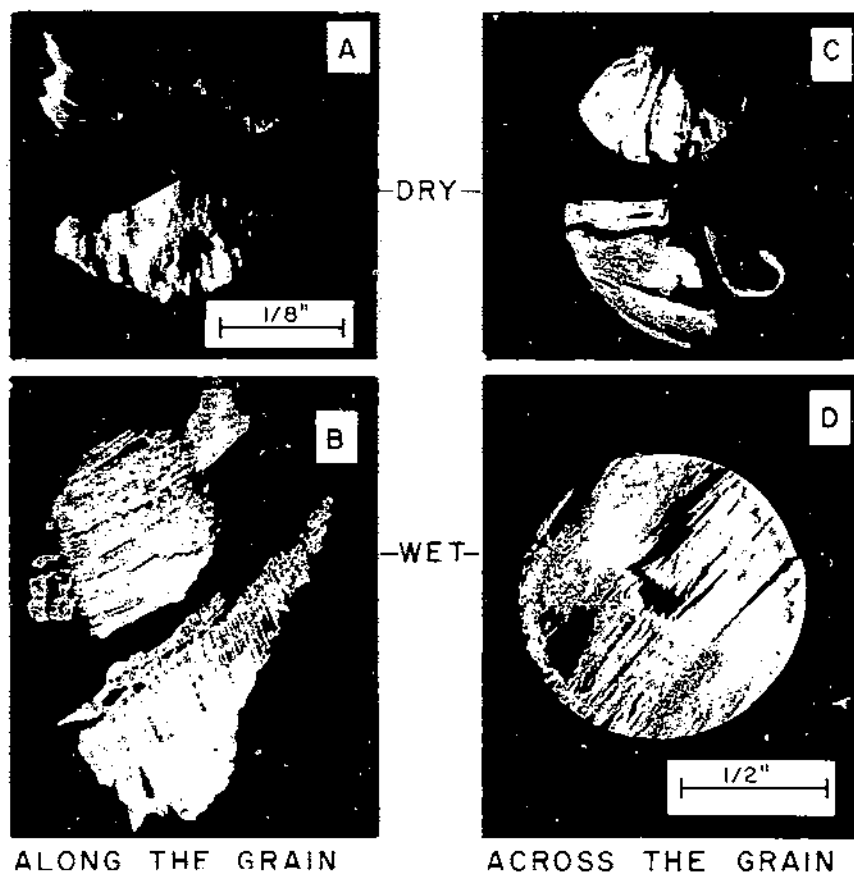
Because of the number of study variables and because of numerous differences in the level and nature of interactions between bit types, it is necessary to analyze torque separately for each type.

Spur machine bit

By analysis of variance, torque differed with all study variables except spindle speed. As the values in table 3 show, torque increased with increasing diameter for all depths and moisture contents. For a given diameter, torque did not differ with depth in dry wood. Average values were 14.1, 48.6, and 79.0 inch-pounds for the 0.50-, 1.00-, and 1.25-inch bits, respectively. In wet wood, torque increased with increasing depth when the 0.50-inch bit was used. Figure 10A-B shows that chips formed in dry wood are fragmented into small particles while those formed in wet wood are larger and remain relatively intact (McMillin and Woodson 1972). Probably the rise in torque with increasing depth in wet wood is associated with difficulty in exhausting such intact chips from small holes.

Table 3.—*Torque requirements when boring along the grain with a spur machine bit*

Bit diameter and depth of hole	Moisture content	
	Dry	Wet
<i>Inches</i>	<i>Inch-pounds</i>	
0.50 inch		
1	12.9	11.9
2	14.0	16.4
3	15.4	23.1
1.00 inch		
1	48.6	41.5
2	48.7	42.6
3	48.5	43.7
1.25 inch		
1	78.1	70.8
2	79.8	76.3
3	79.2	79.0



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Figure 10.—Typical chips formed when boring in two directions at two moisture contents. The scale shown in A is applicable to B as well; the scale in D is applicable to C.

As the following tabulation shows, torque did not differ between specific gravities for holes bored with the 0.50-inch bit (avg. 15.6 inch-pounds). With the 1.00- and 1.25-inch bits, torque was substantially greater in wood of high than of low density. The magnitude of the difference was greatest for the 1.25-inch diameter bit.

Bit diameter	Specific gravity		Chip thickness, inch		
	Low	High	0.010	0.020	0.030
Inches	Inch-pounds				
0.50	14.1	17.1	10.6	15.3	21.0
1.00	39.7	51.5	32.3	46.1	57.8
1.25	64.6	89.9	56.3	78.2	97.1

Torque also increased with increasing chip thickness for all bits, but the slope of the relationship increased with diameter.

Double-spur, double-twist bit

For this bit, torque varied primarily with diameter, chip thickness, and specific gravity.

Bit diameter	Specific gravity		Chip thickness, inch		
	Low	High	0.010	0.020	0.030
Inches	Inch-pounds				
0.50	11.7	15.3	11.1	13.0	16.4
1.00	43.9	56.2	39.9	48.7	61.7
1.25	61.7	82.9	52.0	76.6	88.3

The tabulation shows that torque increased with diameter for wood of all gravities. With the 0.50-inch bit, torque did not vary with density (avg. 13.5 inch-pounds). With the 1.00- and 1.25-inch bits, torques were greater in wood of high than of low density; the difference was larger for the 1.25- than for the 1.00-inch bit. For a given diameter, torque increased with chip thickness; the slope of the relationship increased with bit diameter. Additional analysis showed that the slope of this relationship also was greater in wood of high than of low density.

Flat-cut, double-twist bit

The flat-cut, double-twist bit resembles the double-spur, double-twist bit except that it lacks outlining spurs. As with the double-spur, double-twist bit, torque differed with diameter, chip thickness, and specific gravity. Significant differences associated with moisture content and depth were small.

Torque increased with increasing bit diameter for wood of all specific gravities. For a given diameter, torque was greater in wood of high than of low density; the magnitude of the difference increased with bit diameter. The slope of the positive relationship between torque and specific gravity was greater in dry than in wet wood. Torque was also positively correlated with chip thickness; the slope of the relationship increased with bit diameter.

Bit diameter	Specific gravity		Chip thickness, inch		
	Low	High	0.010	0.020	0.030
Inches	Inch-pounds				
0.50	11.9	15.3	8.9	13.1	18.8
1.00	35.6	44.7	27.0	42.9	50.6
1.25	46.9	62.7	40.4	58.9	65.2

A small but significant increase in torque with increasing depth was detected when boring wet wood with the 0.50-inch bit. Average values were 11.7, 14.2, and 16.4 inch-pounds for 1-, 2-, and 3-inch depths.

Double-spur, single-twist, solid-center bit

Torque increased with diameter for wood of all specific gravities. For a given diameter, torque was greater in wood of high than of low density. It also was positively correlated with chip thickness; the slope of the relationship increased with diameter. Torque did not differ with spindle speed, depth, or moisture content.

Bit diameter	Specific gravity		Chip thickness, inch		
	Low	High	0.010	0.020	0.030
Inches	Inch-pounds				
0.50	14.2	20.8	11.5	16.6	24.4
1.00	43.8	58.6	37.7	53.5	62.3
1.25	62.7	83.2	54.3	73.2	91.4

Thrust

Thrust requirements (in pounds) for each of the four bits studied are detailed in tables 19 through 22 of the Appendix. As with torque, analysis indicated that thrust did not vary with spindle speed when chip thickness was constant. Values in the tables are therefore averages of 9 observations.

Table 4 compares the thrust requirements for each bit type when the data were averaged over all depths, moisture contents, specific gravities, chip thicknesses, and spindle speeds. The table shows thrust force increased with increasing diameter for all types except the flat-cut, double-twist. For this bit, thrust averaged 39.4 pounds. Thrust is principally a function of the force required to advance the spurs and brad into the work. Since the flat-cut bit does not have outlining spurs (figure 4), its advantage was predictable.

Table 4.—*Thrust requirements for boring along the grain*

Bit type	Diameter, inches		
	0.50	1.00	1.25
	Pounds		
Spur machine bit	51.7	101.6	152.0
Double-spur, double-twist	46.7	111.4	143.2
Flat-cut, double-twist	32.2	45.2	40.8
Double-spur, single-twist, solid-center	67.7	111.3	132.3

Spur machine bit

By analysis of variance, thrust differed with all study variables except spindle speed. It increased with diameter (table 5), and was consistently greater in wood of high than of low density. For the 0.50-inch bit, thrust was greater for 3-inch-deep holes than for holes 1 or 2 inches deep. However, the trend reversed for the 1.00- and 1.25-inch bits; thrust was less for 3-inch holes than for holes 1 or 2 inches deep.

Table 5.—*Thrust requirements when boring along the grain with a spur machine bit*

Bit diameter and depth of hole	Specific gravity	
	Low	High
<i>Inches</i>	<i>Pounds</i>	
0.50 inch		
1	38.1	51.6
2	43.6	57.6
3	52.1	67.6
1.00 inch		
1	92.2	121.9
2	90.3	115.5
3	84.9	104.7
1.25 inch		
1	129.3	189.7
2	127.9	190.4
3	117.9	157.1

With the 0.50-inch bit, the analysis for torque suggested that chips tend to clog the flutes when holes become deep. If the chips cannot be rapidly removed from the hole, an increase in thrust would be expected. With the 1.00- and 1.25-inch bits, little clogging occurs. However, friction between the surface of the hole and the severed chips exerts a force component that tends to lift the workpiece and hence causes an apparent decrease in thrust. The lifting effect is greatest in deep holes, since the total areas in contact increase with depth.

As the tabulation shows, thrust was greater in dry than in wet samples. It also increased with increasing chip thickness, although the effect was slight.

Bit diameter	Moisture content		Chip thickness, inch		
	Dry	Wet	0.010	0.020	0.030
<i>Inches</i>	<i>Pounds</i>				
0.50	58.3	45.0	41.5	49.7	63.8
1.00	128.1	75.0	98.8	100.8	105.3
1.25	148.8	119.2	141.1	156.3	159.7

Double-spur, double-twist bit

For this bit, thrust increased with diameter for wood of all specific gravities and moisture contents. For a given diameter, forces were greater in wood of high than of low specific gravity, and greater for dry than for wet samples. These differences became greater with increasing diameter.

Bit diameter	Specific gravity		Moisture content	
	Low	High	Dry	Wet
<i>Inches</i>			<i>Pounds</i>	
0.50	39.9	53.4	55.4	37.9
1.00	94.1	123.7	127.3	95.5
1.25	119.7	166.7	169.2	117.1

Thrust was unrelated to depth for the 0.50-inch bit, but with larger bits it was less for 3-inch deep holes than for holes 1 or 2 inches deep.

Bit diameter	Depth, inches		
	1	2	3
<i>Inches</i>			<i>Pounds</i>
0.50	46.6	47.0	46.3
1.00	115.3	114.8	104.0
1.25	150.9	149.0	129.6

Flat-cut, double-twist bit

Although diameter proved a significant factor for the flat-cut bit, the data in Appendix table 21 suggest that the trends were weak and inconsistent by comparison with those for other bits. When averaged, over all other study variables, thrusts were 32.2, 45.2, and 40.8 pounds for the 0.50-, 1.00-, and 1.25-inch bits, respectively.

Thrusts were somewhat less in wood of low than of high specific gravity, and less in wet than in dry samples.

Bit diameter	Specific gravity		Moisture content	
	Low	High	Dry	Wet
<i>Inches</i>			<i>Pounds</i>	
0.50	26.6	37.7	39.2	25.1
1.00	41.4	49.0	53.1	37.2
1.25	36.6	45.0	49.8	31.7

Double-spur, single-twist, solid-center bit

For the solid-center bit, thrust differed with all variables except spindle speed. It increased with increasing diameter for all depths. For the 1.00- and 1.25-inch bits, it was less for holes 3 inches deep than for holes of 1 and 2 inches. Thrust was unrelated to depth for the 0.50-inch bit.

Bit diameter	Depth, inches		
	1	2	3
<i>Inches</i>			<i>Pounds</i>
0.50	69.9	68.6	64.6
1.00	115.9	113.2	104.7
1.25	139.2	137.2	120.6

Thrust increased with chip thickness in dry wood but was unrelated to thickness in wet wood.

Chip thickness	Moisture content	
	Dry	Wet
<i>Inch</i>	<i>Pounds</i>	
0.010	101.5	87.2
0.020	124.1	88.6
0.030	131.7	89.6

As with the flat-cut bit, forces were less in wood of low than of high density, and less in wet than in dry samples.

Bit diameter	Specific gravity		Moisture content	
	Low	High	Dry	Wet
<i>Inches</i>	<i>Pounds</i>			
0.50	54.0	81.4	76.1	59.3
1.00	94.8	127.7	129.2	93.4
1.25	110.6	154.0	151.9	112.7

Hole Quality

The quality of holes (rated with respect to smoothness) bored along the grain is summarized in table 6. A rating of 1 indicates a smooth hole; a rating of 3 indicates a very rough hole; 2 is intermediate (figure 9). If smoothness of the machined surface is of primary importance, the bit or bits having the lowest numerical ratings should be given preference. If minimal thrust and torque are desired, the flat-cut bit should be selected if the numerical ratings for hole quality are similar.

Although not shown in table 6, the data generally indicated that hole quality improved with decreasing chip thickness. Quality was unaffected by spindle speed (for chips of a given thickness) and wood specific gravity.

Table 6.—Hole quality ratings for boring along the grain

Bit type	0.50 in. diam.		1.00 in. diam.		1.25 in. diam.	
	Dry	Wet	Dry	Wet	Dry	Wet
<i>Smoothness rating</i>						
Spur machine bit	1.6	2.5	1.2	2.1	1.4	2.2
Double-spur, double-twist	1.7	2.3	1.6	2.6	1.6	2.2
Flat-cut, double-twist	1.6	2.6	1.7	2.2	1.5	2.1
Double-spur, single-twist, solid-center bit	2.1	2.9	1.6	2.6	1.6	2.6

BORING ACROSS THE GRAIN

Torque

Variance analysis revealed that torque did not differ between the tangential and radial boring directions, nor did it differ with spindle speed for chips of a given thickness. The former result is in agreement

with the findings of Goodchild (1955). The analyses here are therefore based on data pooled from the radial and tangential directions and the result considered as boring across the grain. Thus, the values for torque listed in tables 23 through 26 of the Appendix are averages of 18 observations (3 replications, 3 spindle speeds, and 2 directions).

Table 7 compares the torque demand by bit types and diameters—the values are averages for all depths, moisture contents, specific gravities, chip thicknesses, and spindle speeds. As the table shows, torque increased rapidly with diameter for all types; the trend was curvilinear. With 0.50- and 1.00-inch bits, there was little practical difference between types. Among the 1.25-inch bits, the flat-cut, double-twist bit required the least torque.

Table 7.—Torque requirements for boring across the grain

Bit type	Diameter, inches		
	0.50	1.00	1.25
	<i>Inch-pounds</i>		
Spur machine bit	15.0	30.9	52.9
Double-spur, double-twist	19.3	37.3	45.4
Flat-cut, double-twist	18.4	29.3	36.4
Double-spur, single-twist, solid-center	12.3	33.1	46.6

Spur machine bit

Torque demand increased with increasing diameter for all chip thicknesses and at all depths (table 8).

Table 8.—Torque requirements when boring across the grain with a spur machine bit

Bit diameter and depth of hole	Chip thickness, inch		
	0.010	0.020	0.030
<i>Inches</i>	<i>Inch-pounds</i>		
0.50 inch			
1	7.9	10.1	14.0
2	9.3	14.3	19.5
3	12.7	20.8	26.7
1.00 inch			
1	22.2	30.4	39.0
2	22.2	30.9	38.4
3	22.6	32.1	39.8
1.25 inch			
1	35.6	53.1	65.8
2	36.6	54.1	67.5
3	36.4	57.0	69.5

For a given chip thickness, torque was unrelated to depth for holes bored with 1.00- and 1.25-inch bits. Averages for the 1.00-inch bit were 22.3, 31.1, and 39.1 inch-pounds for chips 0.010, 0.020, and 0.030 inch thick. Corresponding values for 1.25-inch bit were 36.2, 54.7, and 67.6 inch-pounds. With the 0.50-inch bit, torque increased with increasing depth for all chip thicknesses; the slope of the relationship was greater for thick than for thin chips. As shown in figure 10C-D, chips tend to remain intact when bits are cutting across the grain (McMillin and Woodson 1972). With the 0.50-inch bit it is probable that the rise in torque with increasing depth is associated with difficulty in exhausting intact chips.

For a given diameter and depth, torque increased with increasing chip thickness; the slope of the relationship was greater for large than for small bits. Further, the positive effect of chip thickness on torque was greater in wood of high than of low specific gravity.

Torque differed with moisture content and specific gravity.

Bit diameter	Moisture content		Specific gravity	
	Dry	Wet	Low	High
Inches	Inch-pounds			
0.50	13.3	16.8	13.3	16.7
1.00	33.9	27.8	27.9	33.8
1.25	55.6	50.1	47.7	58.1

With the 0.50-inch bit, slightly greater torque was needed in wet than in dry wood. With the 1.00- and 1.25-inch bits, the trend reversed and torques were less for wet than for dry samples. For all diameters, torque was greater in wood of high than of low specific gravity.

Double-spur, double-twist bit

For this bit, all variables except spindle speed were significant in cross grain boring. As table 9 shows, torque increased with increasing diameter and was less in wood of low than of high specific gravity. With the 0.50-inch bit, but not with larger bits, torque increased with depth in samples of both gravity classes. For wood of low gravity, torque averaged 33.9 and 41.2 inch-pounds for the 1.00- and 1.25-inch bits, respectively. Corresponding values for wood of high gravity were 40.7 and 49.6 inch-pounds.

Table 9 also shows that torques were less in wet than in dry samples. With the 0.50-inch bit, but not with larger bits, torque increased with depth in dry and in wet wood. Torques for the 1.00- and 1.25-inch bits averaged 39.0 and 50.6 inch-pounds in dry wood and 35.6 and 40.3 inch-pounds in wet wood.

Table 9.—*Torque requirements when boring across the grain with a double-spur, double-twist bit*

Bit diameter and depth of hole	Specific gravity		Moisture content	
	Low	High	Dry	Wet
<i>Inches</i>	<i>Inch-pounds</i>			
0.50 inch				
1	9.2	11.5	11.7	8.9
2	15.1	21.0	19.9	16.3
3	23.8	35.4	33.5	25.7
1.00 inch				
1	35.1	42.2	40.7	36.5
2	34.1	40.4	38.6	35.9
3	32.6	39.5	37.6	34.4
1.25 inch				
1	41.4	50.2	51.4	40.2
2	41.3	50.0	50.6	40.7
3	41.0	48.8	49.7	40.0

As shown in the following tabulation, torque increased with chip thickness. The slope of the relationship was greater for the larger bits.

Bit diameter	Chip thickness, inch		
	0.010	0.020	0.030
<i>Inches</i>	<i>Inch-pounds</i>		
0.50	15.3	19.7	22.9
1.00	31.2	36.3	44.4
1.25	34.8	45.9	55.7

Analysis also indicated that the slope of the relationship between chip thickness and torque was greater in dry than in wet samples, and greater in wood of high than of low specific gravity.

Flat-cut, double-twist bit

In torque demand, the flat-cut bit resembled the double-spur, double-twist bit. Table 10 shows that torque increased with increasing diameter and was less in wood of low than of high specific gravity. For 0.50, but not for larger bits, torque increased with depth. For 1.00- and 1.25-inch bits, it averaged 26.4 and 33.7 inch-pounds in wood of low specific gravity and 32.2 and 39.1 inch-pounds in wood of high specific gravity.

Table 10 also indicates that for 0.50-inch holes, but not for larger ones, torque increased with depth in dry and in wet wood. In dry wood, it averaged 27.7 and 36.0 inch-pounds for the 1.00- and 1.25-inch bits, while in wet wood values were 30.9 and 36.8 inch-pounds. Torque was unrelated to moisture content.

Table 10.—*Torque requirements when boring across the grain with a flat-cut, double-twist bit*

Bit diameter and depth of hole	Specific gravity		Moisture content	
	Low	High	Dry	Wet
<i>Inches</i>	<i>Inch-pounds</i>			
0.50 inch				
1	12.3	14.2	12.0	14.5
2	16.1	19.9	17.2	18.7
3	20.2	28.0	26.0	22.2
1.00 inch				
1	26.3	32.4	28.8	30.0
2	26.8	32.6	27.9	31.5
3	25.9	31.7	26.3	31.3
1.25 inch				
1	34.4	39.9	37.3	37.0
2	34.2	39.5	36.4	37.3
3	32.5	38.0	34.4	36.0

Torque increased with increasing chip thickness, but the slope of the relationship was least for 0.50-inch bits.

Bit diameter	Chip thickness, inch		
	0.010	0.020	0.030
<i>Inches</i>	<i>Inch-pounds</i>		
0.50	15.1	18.5	21.7
1.00	20.6	30.0	37.3
1.25	27.3	36.4	45.4

Double-spur, single-twist, solid-center bit

For the solid-center bit, torque differed with all study variables except spindle speed and depth. It increased with increasing diameter for all chip thicknesses. For a given diameter, it became greater as the thickness of chips increased.

Bit diameter	Chip thickness, inch		
	0.010	0.020	0.030
<i>Inches</i>	<i>Inch-pounds</i>		
0.50	9.2	12.5	15.3
1.00	24.1	34.9	40.0
1.25	35.5	47.7	56.7

Further analyses indicated that for a hole of given diameter the slope of the relationship between chip thickness and torque was greater for dry than for wet samples, and greater for wood of high than low density.

Torque was consistently greater for wood of high than of low specific gravity and greater for dry than for wet samples. The magnitude of these differences increased with diameter.

Bit diameter	Specific gravity		Moisture content	
	Low	High	Dry	Wet
Inches	Inch-pounds			
0.50	11.0	13.6	14.1	10.5
1.00	29.5	36.8	36.2	30.1
1.25	42.5	50.8	52.0	41.2

Thrust

Variance analysis revealed that thrust did not differ between holes bored in the tangential and radial directions. The analysis was therefore based on pooled data from the radial and tangential directions and considered as boring across the grain.

In the pooled analysis there was some evidence that, for chips of a given thickness, thrust may be slightly greater at 3,600 r.p.m. than at 1,200 r.p.m. To cut chips of a given thickness, the feed speed must increase with increasing spindle speed (equation 3). A possible reason for the greater thrust at high feed speeds may be that the strength of wood increases with rate of loading. However, trends within interactions were inconsistent and for this reason, and because differences were small, it was decided to neglect effects associated with spindle speed.

Tables 27 through 30 of the Appendix give thrust requirements for all bits. The values are averages of 18 observations (3 replications, 3 spindle speeds, and 2 directions).

Table 11 compares the thrust requirements for each bit when the data were averaged over all variables. As in boring along the grain, thrust increased with diameter for all types except the flat-cut, double-twist bit for which the average was 57.8 pounds. Diameter by diameter, the flat-cut bit required less thrust than the other types.

Table 11.—*Thrust requirements for boring across the grain*

Bit type	Diameter, inches		
	0.50	1.00	1.25
	Pounds		
Spur machine bit	73.1	127.3	177.8
Double-spur, double-twist	100.6	139.1	174.8
Flat-cut, double-twist	56.0	60.2	57.3
Double-spur, single-twist, solid-center	73.1	129.6	164.9

Spur machine bit

By analysis of variance, thrust differed with diameter, depth, specific gravity, chip thickness, and moisture content.

As shown in table 12, thrust increased with increasing diameter for all depths and specific gravities. For a given diameter and depth, it

Table 12.—*Thrust requirements when boring across the grain with a spur machine bit*

Bit diameter and depth of hole	Specific gravity	
	Low	High
<i>Inches</i>	<i>Pounds</i>	
0.50 inch		
1	52.0	77.3
2	56.3	81.6
3	70.3	101.1
1.00 inch		
1	110.1	157.2
2	104.7	150.1
3	100.3	141.6
1.25 inch		
1	155.4	220.3
2	147.0	211.3
3	140.1	192.8

was consistently greater when boring wood of high than of low density; the magnitude of the difference increased with diameter. Analysis also indicated that the slope of the relationship between thrust and specific gravity was greater for dry than for wet samples. The table further shows that thrust increased with depth for the 0.50-inch bit but decreased with depth for larger bits.

As seen in the tabulation below, thrust was greater for holes in dry than in wet samples; the magnitude of the difference increased with bit diameter. Thrust was also greater for thick than for thin chips, and the difference increased with bit diameter. Analysis also indicated that the slope of the relationship with chip thickness was greater in wood of high than of low specific gravity.

Bit diameter	Moisture content		Chip thickness, inch		
	Dry	Wet	0.010	0.020	0.030
<i>Inches</i>	<i>Pounds</i>				
0.50	80.8	65.3	56.9	75.7	86.6
1.00	158.3	96.3	111.2	124.0	146.7
1.25	218.4	137.2	137.9	188.3	207.2

Double-spur, double-twist bit

For this bit, thrust increased with diameter in dry and in wet samples (table 13). For a given depth and diameter, thrust was less in wet than in dry samples; the magnitude of the difference increased with bit diameter. With the 0.50-inch bit, thrust increased substantially with depth; with the 1.00- and 1.25-inch bits, this trend reversed and thrust decreased with increasing depth.

Table 13.—*Thrust requirements when boring across the grain with a double-spur, double-twist bit*

Bit diameter and depth of hole	Moisture content	
	Dry	Wet
<i>Inches</i>	<i>Pounds</i>	
0.50 inch		
1	85.9	51.1
2	119.0	75.2
3	167.5	105.2
1.00 inch		
1	183.0	112.4
2	172.0	105.0
3	163.0	98.9
1.25 inch		
1	228.3	137.7
2	219.5	130.8
3	210.1	122.5

Thrust was greater in wood of high than of low density; the size of this difference increased with bit diameter.

Bit diameter	Specific gravity	
	Low	High
<i>Inches</i>	<i>Pounds</i>	
0.50	80.8	120.4
1.00	111.9	166.2
1.25	145.2	204.4

Analysis also indicated that the slope of the relationship was greater in dry than in wet wood.

Thrust increased with chip thickness, and the magnitude of the difference became greater with bits of large diameter.

Bit diameter	Chip thickness, inch		
	0.010	0.020	0.030
<i>Inches</i>	<i>Pounds</i>		
0.50	83.4	105.1	113.3
1.00	109.3	140.6	167.3
1.25	140.5	176.9	207.0

Analysis further indicated that the slope of the relationship between thrust and chip thickness was greater in dry than in wet samples; it was also greater for wood of high than of low density.

Flat-cut, double-twist bit

For the flat-cut bit, thrust was unrelated to diameter but was less in wood of low than of high specific gravity and less in wet than in dry samples.

Bit diameter	Specific gravity		Moisture content	
	Low	High	Dry	Wet
<i>Inches</i>			<i>Pounds</i>	
0.50	42.9	69.1	71.8	40.2
1.00	50.0	70.4	76.4	44.0
1.25	47.0	67.5	71.3	43.2

For the 0.50-inch bit, thrust was unrelated to chip thickness (avg. 56.0 pounds) but for the larger bits, it increased with chip thickness.

Bit diameter	Chip thickness, inch		
	0.010	0.020	0.030
<i>Inches</i>			<i>Pounds</i>
0.50	55.1	56.4	56.6
1.00	45.2	60.5	74.8
1.25	43.3	60.9	67.5

Double-spur, single-twist, solid-center bit

For this bit, thrust increased with diameter for all depths. For 1.00- and 1.25-inch bits, it decreased with increasing depth, but was unrelated to depth for the 0.50-inch bit (avg. 73.1 pounds).

Bit diameter	Depth, inches		
	1	2	3
<i>Inches</i>			<i>Pounds</i>
0.50	71.6	71.9	75.7
1.00	136.9	129.8	121.9
1.25	173.6	165.7	153.3

For a given diameter, thrust was greater in wood of high than of low density. The difference increased with diameter.

Bit diameter	Specific gravity	
	Low	High
<i>Inches</i>		<i>Pounds</i>
0.50	60.3	85.9
1.00	102.7	156.4
1.25	130.6	190.2

Analysis also indicated that the positive effect of density on thrust was greater in dry than in wet samples.

Thrust was less when samples were wet than when they were dry, and the difference increased with bit diameter.

Bit diameter	Moisture content		Chip thickness, inch		
	Dry	Wet	0.010	0.020	0.030
<i>Inches</i>			<i>Pounds</i>		
0.50	90.0	53.1	57.9	74.2	87.1
1.00	158.6	100.4	98.2	146.0	144.4
1.25	205.4	124.3	135.7	168.1	190.9

Thrust also increased with chip thickness. Analyses further indicated that the slope of the relationship between thrust and chip thickness was greater in dry than in wet wood; it was also greater for wood of high than of low specific gravity.

Hole Quality

Table 14 summarizes the quality (rated with respect to smoothness) of holes bored in the tangential and in the radial directions. Where smoothness of the machined surface is of primary importance, the bit or bits having the lowest numerical ratings should be given preference. For cross-grain boring, the flat-cut bit yielded holes of inferior quality, although torque and thrust were minimal. Where low power demand is required, holes of poor quality can be expected.

Although not shown in table 14, the data generally indicated that hole quality improved with decreasing chip thickness. It did not vary with spindle speed or wood specific gravity.

Table 14.—Quality ratings for holes bored in two directions across the grain

Bit type and diameter	Boring (feed) direction			
	Tangential		Radial	
	Dry	Wet	Dry	Wet
<i>Inches</i>	<i>Smoothness rating</i>			
Spur machine bit				
0.50	1.1	1.4	1.0	1.6
1.00	1.0	1.0	1.1	1.1
1.25	1.1	1.1	1.3	1.2
Double-spur, double-twist				
0.50	1.1	1.4	1.6	1.6
1.00	1.1	1.2	1.1	1.3
1.25	1.1	1.1	1.2	1.3
Flat cut, double-twist				
0.50	1.5	2.7	1.6	2.8
1.00	1.3	2.5	1.5	2.5
1.25	1.3	2.3	1.5	2.4
Double-spur, single-twist, solid-center				
0.50	1.0	1.1	1.2	1.3
1.00	1.1	1.4	1.3	1.4
1.25	1.3	1.4	1.3	1.4

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APPENDIX: BASIC DATA

Torque along the grain (Tables 15-18)

Table 15.—*Torque when boring along the grain with a spur machine bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Inch-pounds</i>					
DRY							
0.50							
	1	7.7	10.3	10.2	14.2	16.5	18.4
	2	8.5	11.6	11.1	15.1	17.0	20.8
	3	10.0	12.4	12.4	15.4	18.1	24.1
1.00							
	1	29.1	41.9	40.8	61.3	51.9	66.7
	2	29.2	44.7	41.4	59.3	52.2	65.6
	3	29.7	44.0	41.1	58.5	52.5	65.1
1.25							
	1	43.8	66.4	62.3	94.5	79.8	122.0
	2	45.0	68.8	63.4	96.7	83.8	121.0
	3	44.4	68.4	63.4	96.1	83.5	119.5
WET							
0.50							
	1	7.6	8.7	11.3	12.2	13.6	18.3
	2	8.7	10.9	16.2	17.3	21.1	23.6
	3	12.3	17.2	23.1	25.4	28.1	32.5
1.00							
	1	25.9	29.4	38.9	44.2	47.8	62.6
	2	26.1	30.2	39.8	46.4	48.7	64.5
	3	27.3	30.6	41.4	46.5	51.6	64.8
1.25							
	1	45.9	56.0	63.2	84.8	76.0	98.9
	2	50.4	64.5	66.0	89.8	82.0	105.3
	3	55.7	66.6	67.5	91.2	85.1	107.1

Table 16.—*Torque when boring along the grain with a double-spur, double-twist bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Inch-pounds</i>					
DRY							
0.50							
	1	9.8	12.6	10.7	14.1	14.0	18.3
	2	10.9	14.1	10.8	14.8	14.5	19.7
	3	12.9	17.5	11.4	16.2	13.6	19.9
1.00							
	1	36.1	48.0	45.5	54.6	53.8	71.9
	2	35.5	45.9	45.8	53.4	52.4	72.5
	3	33.7	45.3	42.8	50.6	51.6	68.9
1.25							
	1	44.3	62.3	66.9	87.6	73.0	107.7
	2	44.9	64.0	68.1	89.5	74.7	111.8
	3	44.0	60.9	65.1	88.2	73.3	109.3
WET							
0.50							
	1	6.3	9.5	10.4	12.1	14.6	16.8
	2	7.1	12.1	12.3	12.8	14.0	17.5
	3	8.2	12.3	15.0	15.1	14.5	19.7
1.00							
	1	35.1	42.8	44.3	53.7	52.1	68.6
	2	35.3	43.4	44.1	55.3	53.4	71.3
	3	35.0	43.1	41.6	53.0	53.0	70.9
1.25							
	1	44.0	55.3	67.0	81.6	72.2	94.5
	2	44.0	59.4	69.5	84.6	75.0	87.8
	3	43.1	57.6	68.2	82.7	73.6	97.2

Table 17.—Torque when boring along the grain with a flat-cut, double-twist bit

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i> Inch-pounds</i>					
		DRY					
0.50	1	6.7	9.5	10.2	12.6	13.1	22.0
	2	7.3	9.7	11.6	13.5	13.8	22.5
	3	8.5	11.0	12.0	14.2	14.2	22.7
1.00	1	22.9	33.9	36.4	48.1	45.2	60.4
	2	22.7	33.6	36.8	51.9	45.8	62.3
	3	22.8	33.3	36.8	50.9	45.5	61.9
1.25	1	34.3	45.0	52.8	68.7	56.0	80.7
	2	33.7	45.2	55.7	76.0	55.3	81.3
	3	33.3	43.7	54.1	71.9	54.1	79.4
		WET					
0.50	1	6.8	8.1	10.6	14.2	14.5	15.8
	2	7.5	10.1	12.9	16.0	19.1	19.8
	3	8.4	12.9	12.7	16.9	24.4	23.4
1.00	1	22.5	27.7	42.2	40.1	41.4	52.4
	2	22.8	29.3	44.3	41.6	43.0	53.5
	3	22.8	29.5	44.2	42.0	43.2	52.7
1.25	1	35.4	45.8	46.8	60.3	54.6	69.4
	2	35.4	49.3	48.6	61.8	56.0	70.7
	3	34.6	49.5	48.3	61.5	55.7	69.4

Table 18.—*Torque when boring along the grain with a double-spur, single-twist, solid-center bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Inch-pounds</i>					
DRY							
0.50	1	8.7	14.4	12.5	19.0	15.8	25.5
	2	8.3	15.0	12.9	19.7	16.6	26.2
	3	8.6	15.1	13.6	21.9	17.7	26.0
1.00	1	23.4	43.0	42.0	64.0	56.3	68.2
	2	28.0	43.3	42.1	63.8	57.4	69.8
	3	27.4	43.1	41.1	62.8	56.0	67.8
1.25	1	42.8	65.7	60.9	78.9	79.9	106.3
	2	42.7	66.5	61.0	82.6	78.9	106.9
	3	41.1	62.7	60.9	83.3	78.3	103.1
WET							
0.50	1	10.1	12.4	11.8	18.5	21.3	28.6
	2	9.7	12.8	13.4	19.9	24.1	31.4
	3	10.0	13.6	14.9	21.1	26.4	33.1
1.00	1	36.4	45.4	49.4	59.6	52.1	71.5
	2	35.6	45.0	48.7	60.3	52.8	72.6
	3	34.9	44.0	48.1	60.1	52.2	71.4
1.25	1	48.8	61.9	65.9	84.3	79.6	102.1
	2	49.1	61.2	64.7	86.1	80.7	104.0
	3	49.0	60.0	64.7	85.7	80.4	96.4

Thrust along the grain (Tables 19-22)

Table 19.—*Thrust when boring along the grain with a spur machine bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Pounds</i>					
DRY							
0.50							
	1	37.8	51.6	41.9	63.7	58.2	75.4
	2	39.9	54.2	45.9	67.4	60.2	84.9
1.00	3	45.3	54.7	49.8	66.7	60.9	91.8
	1	108.0	152.1	105.6	167.7	116.4	160.0
	2	101.7	150.9	106.1	142.3	116.6	153.3
1.25	3	95.7	141.8	101.1	128.1	113.3	145.6
	1	129.7	209.4	155.0	234.4	158.9	267.8
	2	130.3	212.2	155.6	240.6	159.4	263.9
	3	122.6	186.7	147.2	198.3	146.7	208.3
	WET						
	0.50						
1		28.2	36.2	26.9	37.2	35.4	45.2
2		30.7	40.3	36.7	42.6	48.4	56.0
1.00	3	30.0	49.6	57.9	60.0	68.7	80.8
	1	66.3	85.0	85.4	76.1	71.7	90.6
	2	66.8	82.2	80.8	74.6	70.0	89.4
1.25	3	61.7	73.0	76.1	65.2	61.7	74.4
	1	106.0	136.9	115.6	148.9	110.6	140.6
	2	104.8	136.7	110.6	146.7	106.7	142.2
	3	96.4	121.4	99.4	123.9	95.0	103.9

Table 20.—*Thrust when boring along the grain with a double-spur, double-twist bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Pounds</i>					
DRY							
0.50							
	1	51.0	63.3	39.0	53.4	48.8	71.7
	2	52.2	69.7	42.8	54.4	51.4	62.0
	3	55.0	71.0	42.6	55.4	53.7	59.7
1.00							
	1	95.2	154.1	104.4	147.2	122.2	158.3
	2	94.0	152.7	106.7	146.7	122.2	160.6
	3	89.1	141.2	102.8	132.8	117.2	144.4
1.25							
	1	124.4	186.7	158.3	225.0	144.4	215.0
	2	126.1	183.3	153.3	222.8	146.1	221.1
	3	120.0	152.8	138.3	201.1	137.8	189.4
WET							
0.50							
	1	31.3	44.1	32.6	44.7	34.9	44.7
	2	29.7	44.6	31.8	44.9	34.6	46.0
	3	26.8	50.6	24.1	41.0	35.6	40.8
1.00							
	1	80.7	104.2	86.2	115.6	93.3	122.2
	2	77.2	106.6	85.2	115.6	88.3	122.2
	3	75.7	103.0	75.7	96.1	77.2	93.3
1.25							
	1	98.3	136.1	117.8	158.9	108.3	137.2
	2	96.1	135.0	118.9	153.3	98.3	133.9
	3	87.2	121.1	100.0	127.2	80.0	100.0

Table 21.—*Thrust when boring along the grain with a flat-cut, double-twist bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Pounds</i>					
DRY							
0.50							
	1	22.3	35.9	27.1	40.9	26.1	52.1
	2	22.7	41.1	31.0	45.2	31.7	59.8
	3	22.9	55.7	38.6	56.9	34.4	61.4
1.00							
	1	44.1	61.4	48.1	78.4	45.6	66.1
	2	46.3	61.4	49.6	75.6	42.8	61.1
	3	40.4	53.0	42.1	58.2	36.7	45.6
1.25							
	1	47.8	58.2	54.1	68.6	36.3	56.7
	2	44.9	55.8	50.8	70.9	35.2	52.8
	3	43.8	51.7	44.7	55.8	29.2	40.0
WET							
0.50							
	1	14.7	22.9	21.1	30.4	23.6	15.1
	2	14.7	26.2	27.4	31.9	25.1	20.0
	3	15.8	26.4	40.0	32.6	39.8	24.6
1.00							
	1	42.6	38.1	49.8	44.4	41.7	35.0
	2	39.1	37.8	46.2	44.7	35.0	31.7
	3	34.2	32.1	36.4	39.8	23.9	17.8
1.25							
	1	37.2	47.2	36.6	48.2	30.1	28.3
	2	37.3	44.4	31.1	41.6	29.1	23.9
	3	30.1	34.0	20.9	23.8	19.1	18.3

Table 22.—*Thrust when boring along the grain with a double-spur, single-twist, solid-center bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Pounds</i>					
DRY							
0.50							
	1	45.3	95.9	64.3	81.9	68.6	107.8
	2	46.7	94.1	64.8	82.0	68.3	110.2
1.00	3	46.9	75.0	69.6	78.3	67.3	102.1
	1	89.7	130.0	106.1	177.8	133.4	157.8
	2	88.9	126.4	105.6	173.3	133.3	160.0
1.25	3	85.9	115.3	100.0	161.1	130.9	150.0
	1	109.7	169.7	136.1	189.4	138.9	199.6
	2	105.3	162.9	136.1	188.9	140.0	201.1
	3	95.6	143.3	129.4	188.3	128.3	172.2
	WET						
	0.50						
1		46.2	61.9	46.6	70.4	60.8	89.1
2		39.3	59.1	47.0	63.3	58.2	90.1
1.00	3	35.9	57.3	43.4	60.0	52.4	86.4
	1	84.1	114.7	91.1	113.9	86.7	105.6
	2	80.7	114.6	83.3	112.2	79.4	101.0
1.25	3	87.4	101.4	72.2	97.2	68.3	87.0
	1	103.4	135.0	102.4	146.2	106.7	133.3
	2	100.2	140.0	99.4	144.1	97.8	130.6
	3	91.1	117.8	85.4	115.8	85.0	94.4

Torque across the grain (Tables 23—26)

Table 23.—Torque when boring across the grain with a spur machine bit

Diameter and depth of hole	0.010-inch chips		0.020-inch chips		0.030-inch chips	
	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>	<i>Inch-pounds</i>					
DRY						
0.50						
1	6.9	9.0	9.0	11.2	12.6	15.3
2	7.6	9.6	10.3	13.3	14.1	17.2
3	9.5	13.1	14.6	20.6	18.5	26.9
1.00						
1	22.3	28.8	30.8	38.7	43.3	48.2
2	22.4	29.0	30.5	37.8	37.3	45.8
3	22.3	28.4	29.6	37.8	37.3	43.6
1.25						
1	35.3	41.4	51.7	63.7	62.6	79.6
2	34.7	42.6	51.5	63.3	62.3	78.9
3	34.2	40.4	54.0	65.1	62.3	77.9
WET						
0.50						
1	8.2	7.4	8.8	11.5	12.2	15.9
2	11.1	8.7	14.5	19.2	20.2	26.3
3	15.6	12.8	21.3	26.9	25.1	36.5
1.00						
1	17.5	20.2	23.0	29.3	31.8	35.9
2	18.1	19.4	24.1	31.3	32.7	37.9
3	19.3	20.4	26.7	34.3	36.0	42.1
1.25						
1	30.1	35.8	44.0	53.0	53.8	67.0
2	31.5	37.7	46.8	54.9	57.2	71.4
3	33.1	37.9	50.8	58.2	62.0	76.0

Table 24.—*Torque when boring across the grain with a double-spur, double-twist bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Inch-pounds</i>					
DRY							
0.50							
	1	7.3	9.5	10.1	14.3	13.3	15.6
	2	11.2	16.6	18.1	24.8	20.6	27.9
	3	18.8	35.7	29.2	39.3	31.4	46.6
1.00							
	1	29.8	35.1	36.7	44.2	42.7	56.0
	2	28.5	33.3	34.3	41.1	41.8	52.2
	3	27.8	33.6	31.0	37.8	41.1	54.5
1.25							
	1	34.7	43.4	46.4	56.0	57.7	69.8
	2	34.8	42.2	46.1	56.8	55.8	68.1
	3	34.5	40.9	44.4	55.6	55.5	67.3
WET							
0.50							
	1	6.4	7.3	8.0	10.2	9.9	11.8
	2	12.8	15.4	12.1	19.8	15.3	21.3
	3	19.4	23.9	19.8	30.0	24.2	37.0
1.00							
	1	31.2	33.6	33.0	38.7	36.2	45.4
	2	29.5	33.1	34.1	37.1	36.0	45.4
	3	27.1	32.4	31.9	34.5	36.7	44.2
1.25							
	1	29.3	33.4	37.1	44.4	43.2	54.1
	2	28.6	34.0	37.7	45.1	45.0	53.9
	3	28.2	33.0	37.8	42.8	45.3	53.0

Table 25.—Torque when boring across the grain with a flat-cut, double-twist bit

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Inch-pounds</i>					
DRY							
0.50	1	8.2	9.5	10.7	12.6	14.0	16.7
	2	13.6	18.2	13.0	20.2	16.5	21.9
	3	17.6	30.2	19.0	33.8	20.9	34.3
1.00	1	16.8	21.3	26.5	33.4	33.2	41.4
	2	16.3	20.4	25.2	32.5	33.0	40.0
	3	14.8	18.8	23.7	31.8	31.9	36.9
1.25	1	26.0	30.7	33.7	41.1	43.8	48.5
	2	24.7	29.2	32.0	39.1	41.4	48.8
	3	23.6	28.8	30.2	38.0	40.0	45.8
WET							
0.50	1	9.2	11.0	14.9	15.1	16.8	20.1
	2	13.1	15.2	18.7	19.1	21.4	24.6
	3	16.5	18.3	22.2	23.2	24.7	28.1
1.00	1	20.7	23.1	27.4	34.0	33.4	41.3
	2	22.4	24.9	28.5	34.7	35.4	43.0
	3	21.8	25.7	27.9	34.4	35.4	42.5
1.25	1	25.9	29.7	33.8	40.7	43.2	48.7
	2	26.4	28.8	34.6	41.1	42.9	49.8
	3	25.4	28.6	33.1	39.8	42.4	46.9

Table 26.—*Torque when boring across the grain with double-spur, single-twist, solid-center bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>inch-pounds</i>					
DRY							
0.50							
	1	7.7	9.0	10.7	12.8	12.7	14.7
	2	10.0	11.8	12.3	15.2	14.0	17.8
	3	10.8	18.0	15.4	19.5	16.9	25.0
1.00							
	1	22.6	29.7	34.0	42.4	40.5	51.2
	2	21.7	29.1	33.2	42.5	41.1	50.0
	3	22.6	30.7	31.2	42.5	38.7	47.9
1.25							
	1	37.3	42.0	48.8	61.6	57.1	71.4
	2	37.5	41.3	47.4	59.8	57.0	70.4
	3	35.5	40.5	47.7	56.3	55.3	69.7
WET							
0.50							
	1	7.0	7.5	9.9	11.2	11.4	12.9
	2	6.8	7.4	10.1	11.5	13.2	15.0
	3	6.4	7.6	9.7	11.4	13.8	16.8
1.00							
	1	21.0	23.4	28.6	36.8	32.7	39.2
	2	20.6	23.9	28.8	36.1	34.0	38.9
	3	20.5	24.1	27.5	35.3	32.1	38.1
1.25							
	1	30.1	34.7	37.8	47.0	46.5	55.2
	2	29.0	34.8	38.4	45.0	46.6	52.7
	3	28.2	35.2	37.9	44.3	46.2	52.1

Thrust across the grain (Tables 27-30)

Table 27.—Thrust when boring across the grain with a spur machine bit

		0.010-inch chips		0.020-inch chips		0.030-inch chips	
Diameter and depth of hole		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Pounds</i>					
DRY							
0.50	1	49.8	77.2	63.0	99.8	71.8	108.2
	2	51.8	73.7	61.3	86.6	68.1	110.3
	3	57.1	81.1	71.1	113.9	86.7	119.6
1.00	1	111.8	171.3	128.7	189.7	161.9	231.4
	2	109.6	176.1	126.6	182.5	149.2	203.9
	3	105.9	171.7	120.2	176.7	142.5	184.4
1.25	1	147.4	199.3	202.2	288.6	221.4	322.5
	2	142.1	201.1	194.7	276.1	207.2	301.1
	3	133.5	178.2	190.3	258.6	198.9	268.3
WET							
0.50	1	39.7	46.1	40.7	62.5	46.8	69.6
	2	43.5	46.0	53.0	81.4	59.6	91.6
	3	55.0	58.2	72.8	102.6	78.2	127.9
1.00	1	76.5	99.3	79.1	113.3	102.8	134.9
	2	70.8	89.7	76.8	113.3	95.3	135.1
	3	68.7	77.1	72.5	109.2	91.9	127.6
1.25	1	99.9	131.8	124.2	171.9	137.5	207.5
	2	91.2	130.9	118.8	162.7	127.8	195.3
	3	86.0	113.2	112.4	159.2	119.4	179.2

Table 28.—*Thrust when boring across the grain with a double-spur, double-twist bit*

Diameter and depth of hole	0.06-inch chips		0.020-inch chips		0.030-inch chips	
	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>	<i>Pounds</i>					
DRY						
0.50						
1	55.1	83.3	70.9	102.1	87.7	115.7
2	74.1	112.9	106.9	150.4	107.5	161.7
3	108.4	160.3	139.7	199.7	156.8	230.3
1.00						
1	110.1	160.3	138.6	223.6	179.7	266.1
2	107.0	166.6	135.3	209.2	176.3	237.8
3	97.8	152.2	125.0	202.5	155.6	215.0
1.25						
1	150.3	216.9	189.2	260.1	230.8	313.1
2	143.6	209.1	181.1	266.1	206.4	307.2
3	111.7	190.3	169.1	250.3	207.8	301.4
WET						
0.50						
1	37.8	50.2	42.3	61.3	46.7	68.3
2	51.3	82.6	55.1	98.9	58.0	102.1
3	85.6	95.8	77.2	145.8	78.7	116.7
1.00						
1	76.6	101.5	88.2	112.3	106.6	150.2
2	76.1	91.8	82.7	128.5	95.8	151.8
3	72.1	87.7	85.2	115.6	95.2	137.6
1.25						
1	97.8	127.2	113.6	163.3	131.2	190.3
2	88.6	122.5	107.8	156.1	132.5	176.9
3	80.8	117.2	108.6	141.2	126.7	157.2

Table 29.—*Thrust when boring across the grain with a flat-cut, double-twist bit*

Diameter and depth of hole	0.010-inch chips		0.020-inch chips		0.030-inch chips	
	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>	<i>Pounds</i>					
DRY						
0.50						
1	36.9	50.7	45.2	56.2	43.1	74.6
2	57.9	87.1	45.1	77.3	51.9	80.2
3	74.2	134.0	69.4	133.2	57.7	118.0
1.00						
1	48.1	64.1	72.2	98.4	88.1	122.5
2	40.2	61.4	69.4	95.4	80.0	111.6
3	35.6	58.6	62.1	85.2	80.8	97.7
1.25						
1	47.8	70.1	65.7	94.9	86.8	113.1
2	45.1	62.7	60.3	85.3	72.8	101.4
3	37.6	57.6	52.7	76.7	62.6	90.7
WET						
0.50						
1	18.1	28.4	27.3	34.2	28.2	46.1
2	28.4	39.9	30.2	43.7	31.7	44.6
3	44.3	61.2	46.2	68.7	37.0	65.9
1.00						
1	34.6	37.3	34.3	52.5	41.1	66.7
2	32.8	45.7	33.8	49.1	42.5	70.3
3	32.0	49.4	30.9	42.4	40.8	55.6
1.25						
1	28.4	42.4	44.7	67.0	44.6	59.7
2	27.4	43.0	38.2	61.6	40.8	57.5
3	24.3	33.4	32.1	48.2	33.2	46.4

Table 30.—*Thrust when boring across the grain with a double-spur, single-twist, solid-center bit*

Diameter and depth of hole		0.010-inch chips		0.020-inch chips		0.030-inch chips	
		Low specific gravity	High specific gravity	Low specific gravity	High specific gravity	Low specific gravity	High specific gravity
<i>Inches</i>		<i>Pounds</i>					
DRY							
0.50							
	1	55.4	77.8	75.8	103.9	90.8	122.2
	2	68.8	82.5	77.6	109.0	78.1	126.7
	3	67.4	100.8	82.7	126.2	89.4	139.1
1.00							
	1	101.4	150.5	148.9	224.4	153.8	230.1
	2	89.6	140.9	140.3	218.3	142.9	218.2
	3	89.2	140.1	123.6	210.8	130.9	201.7
1.25							
	1	148.8	191.6	180.2	261.7	205.0	300.8
	2	151.1	187.2	177.7	248.1	195.2	281.9
	3	142.3	175.0	171.8	229.8	186.5	265.8
WET							
0.50							
	1	35.9	50.1	45.4	66.8	56.3	78.4
	2	34.7	45.4	42.1	62.9	56.7	79.0
	3	34.3	42.1	40.9	56.9	52.4	76.1
1.00							
	1	70.5	95.9	96.9	141.6	90.9	138.0
	2	63.7	89.9	91.7	138.1	88.5	135.7
	3	59.8	86.9	85.0	131.9	81.2	121.5
1.25							
	1	91.9	125.6	110.9	155.8	129.4	172.8
	2	89.3	123.4	106.6	146.0	123.3	158.3
	3	83.1	112.3	102.2	132.2	114.4	157.5

END