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In Situ Comparison of Radial and Point-Attack Bits

By L. S. Sundae and T. A. Myren

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	MPa	megapascal
deg	degree	MN	meganewton
in	inch	N	newton
lbf	pound (force)	pct	percent

IN SITU COMPARISON OF RADIAL AND POINT-ATTACK BITS

By L. S. Sundae[1] and T. A. Myren[2]

ABSTRACT

The Bureau of Mines conducted a series of tests to compare the cutting forces required by radial and point-attack bits when making similar cuts. Three radial and four point-attack bits were tested in two coal mines using the Bureau's in-seam tester to measure coal-cutting forces in situ. Tests were also conducted to investigate the effects of weathering and cleating.

The test results show that in each case, at a specific clearance angle, the radial bits required less tangential and much less normal force than the point-attack bits. The resultant of the cutting forces for some types of cut was 50 pct less at mine 1 for radial cuts compared to cuts with the best point-attack bit, and 40 pct less at mine 2. There was some difference between three types of radial bits, but it was not as significant as the difference between each type of point-attack bit.

Cutting coal perpendicular to the cleat planes required less cutting and normal force than the same type of cuts parallel to the cleat planes. Test results showed no effect due to weathering on cutting force data. Cutting parallel increased forces only because cuts were made in the rock band.

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INTRODUCTION

Prior research by the Bureau in a coal mine (1)[3] and laboratory tests (2) suggested that radial bits required less tangential and much less normal force than point-attack bits to make the same types of cuts. To verify this in situ, the Bureau conducted tests in different types of coal to determine whether or not the radial bits consistently required less cutting force than other types of bits.

The objective was to compare the performance of several types of commercially available radial and point-attack bits at different depths of cut and bit spacings. The effects of cleat planes and weathering would be incorporated in the experimental design.

LITERATURE REVIEW

Historically, radial bits have been used in European coal mines, while point-attack bits have been used in North American coal mines. The marketing forces have promoted determination of bit usage based on the assumed rotation of conical bits, without first comparing their performance against that of radial types.

No serious efforts have been made by U.S. research establishments to compare the performance of radial and point-attack bits, except for work done by the Bureau (1-2). Evans (3) put forth his theory of coal cutting in 1956. He wrote two papers in 1984 (4-5) to relate the effects of radial and point-attack bits to his coal-cutting theory without presenting experimental data, stating in effect, that for deep cuts, both bits have the same effectiveness. He further stated that "...point attack bits have a reputation for ruggedness and hard wear, but also a propensity for making excessive dust at small penetration and for frictional sparking."

Furthermore, up until 1978 when the Bureau of Mines designed and fabricated a new device for measuring coal-cutting forces underground (6), no instrumentation was available to directly compare the performance of these bit types in situ. Therefore, until that date, no reliable comparisons could be made in the field.

Past researchers working with radial bits have evaluated the effects of rake and clearance angles on test results. However, the majority of investigators working with point-attack bits have reported their test results by merely using attack angle as a single independent test parameter. This approach fails to isolate and quantify the individual effects of rake or clearance angles on cutting forces for conical bits. Rake, attack, clearance angles, and other technical terms used in the report are illustrated in figure 1.

Theoretically, it is well established that the optimum back clearance angle is between 5° and 6° (7-8). Insufficient back clearance angle will increase friction between the bit and the coal contact area, and then increase the cutting forces and premature bit wear (7). Increase in this angle beyond 8° will reduce bit strength without any beneficial effect (7).

Coal-cutting theory suggests, however, that an increase in rake angles works differently (7). In this case, reactive force or the normal force needed to hold the bit in the coal is reduced drastically with increased rake angle (7-8). Many investigators have used +40° rake angles, but theoretically rake angles beyond +10° to +15° would have no beneficial effect on normal force.

Coal seams contain joints and fracture planes running in all directions. When these planes are aligned parallel or perpendicular to the pillar face, rib, or butts, they are referred to as face, rib, or butt cleats (9). The literature search revealed no test data on the effect of cleating on cutting forces. Therefore, efforts were made to use test

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

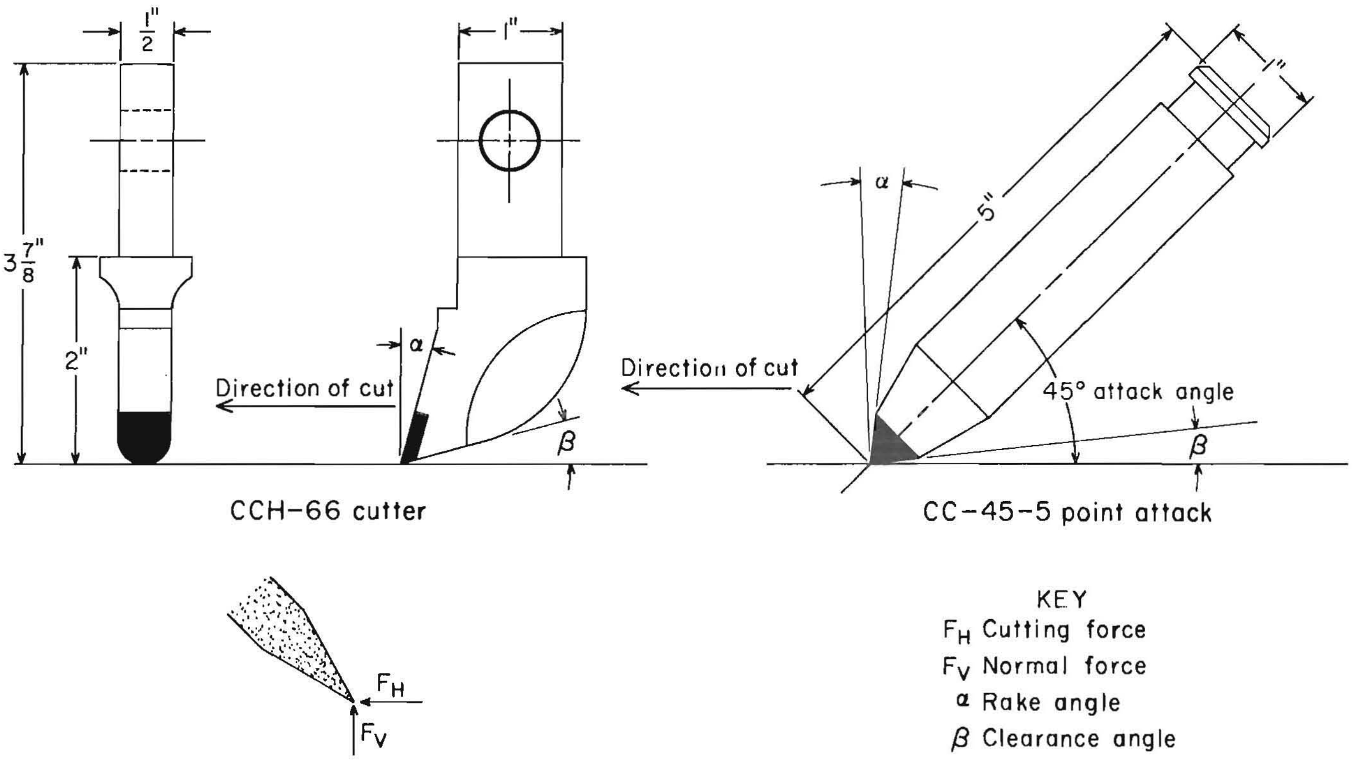

FIGURE 1.—Illustration of technical terms used in this report.

faces parallel and perpendicular to cleat planes to quantify the effect of cleats on cutting forces. All test cuts were made in each face perpendicular to the bedding planes of the seam.

TEST METHOD AND EXPERIMENTAL DESIGN

All field tests were conducted by using the Bureau's in-seam tester to measure coal-cutting forces in situ. The mechanical functions of this devise have been fully described (1-6). The data acquisition has been updated. A schematic of the IST and its components is shown in figure 2.

A two-axis strain gauge force dynamometer outputs signals proportional to cutting and normal bit force. The data aquisition system is triggered after the tool has entered the coal, and force data are collected in digital form at 1,200 samples per second and stored in histogram format. The full range of 3,200 lbf for each channel is divided into 32 class intervals of 100 lbf each and stored as a time-at-level histogram in battery-powered solid state memory. The memory can be interrogated by a battery-powered terminal for readout or storage in ASCII code for subsequent printing or computer analysis.

The calibration curves of cutting and normal forces for the strain gage assembly or dynamometer are shown in figure 3. From the figures for cutting and normal forces, it may be seen that hysteresis and cross-talk between axes are minimal.

Mine 1 is near Berry, Fayette County, AL, where coal is mined from the 54-in-thick Pratt Seam. Test sites 1 through 5 were located in a room-and-pillar area, and sites 6 through 8 were located on an active longwall panel. Mine 2 is located in the Emery Seam, Emery County, UT. At present, this mine is inactive, owing to the low demand for coal. The seam thickness ranges from 25 to 30 ft without any impurities in the coal seam. The overburden is approximately 110 ft in the area of the test sites. All tests were

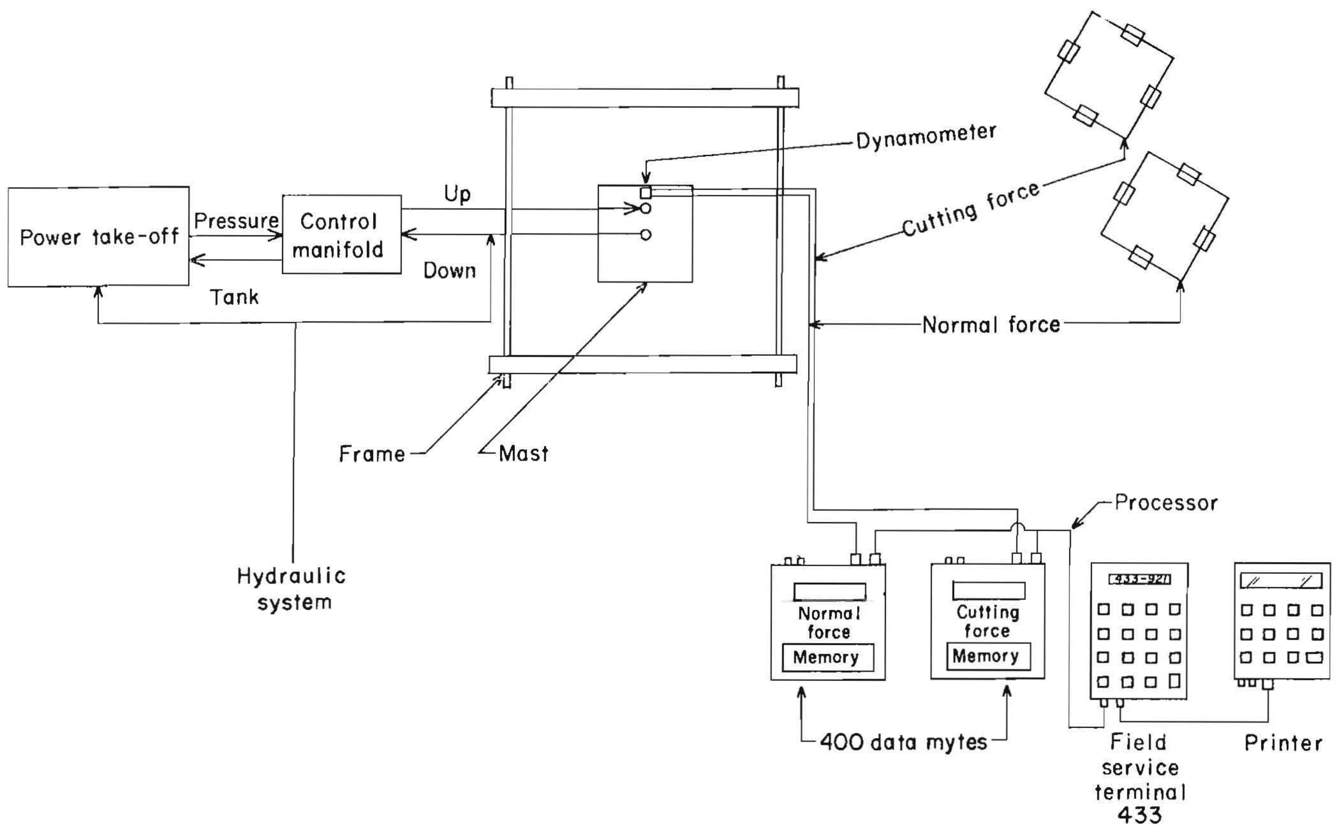

FIGURE 2.—In-seam tester schematics.

conducted on a pillar as the room-and-pillar mining method has been utilized to win coal.

Uniaxial compression tests conducted in a Bureau laboratory on coal from mines 1 and 2 are reported in table 1. The mean compressive strength of coal from mines 1 and 2 is 9.93 and 27.37 MPa respectively.

A summary of all the tests conducted is presented below to help the reader identify areas of specific interest.

TABLE 1. - Uniaxial compressive strength of coal from mines 1 and 2

Sample No.[1]	Height, cm	Diameter, cm	Compressive strength, MPa	Sample No.[1]	Height, cm	Diameter, cm	Compressive strength, MPa
		MINE 1				MINE 2	
1....	5.11	2.56	12.31	1....	5.06	2.55	16.36
2....	5.14	2.56	15.40	2....	5.06	2.55	27.14
3....	4.16	2.53	5.61	3....	5.06	2.55	26.35
4....	5.15	2.57	8.21	4....	5.06	2.55	23.45
5....	4.52	2.54	7.47	5....	5.03	2.55	26.61
6....	4.79	2.56	6.35	6....	4.33	2.54	24.26
7....	5.20	2.54	7.55	7....	4.04	2.55	32.81
8....	5.01	2.53	9.89	8....	4.70	2.55	37.14
9....	4.45	2.54	15.16	9....	4.72	2.55	31.38
10....	5.08	2.55	11.32	10....	3.70	2.55	25.59
Mean.	NAp	NAp	9.93± 3.51 = 1,425 psi	11....	4.33	2.55	24.84
				12....	3.99	2.55	32.46
				Mean.	NAp	NAp	27.37± 4.99 = 3,970 psi

NAp Not applicable. [1]All samples were cylindrical.

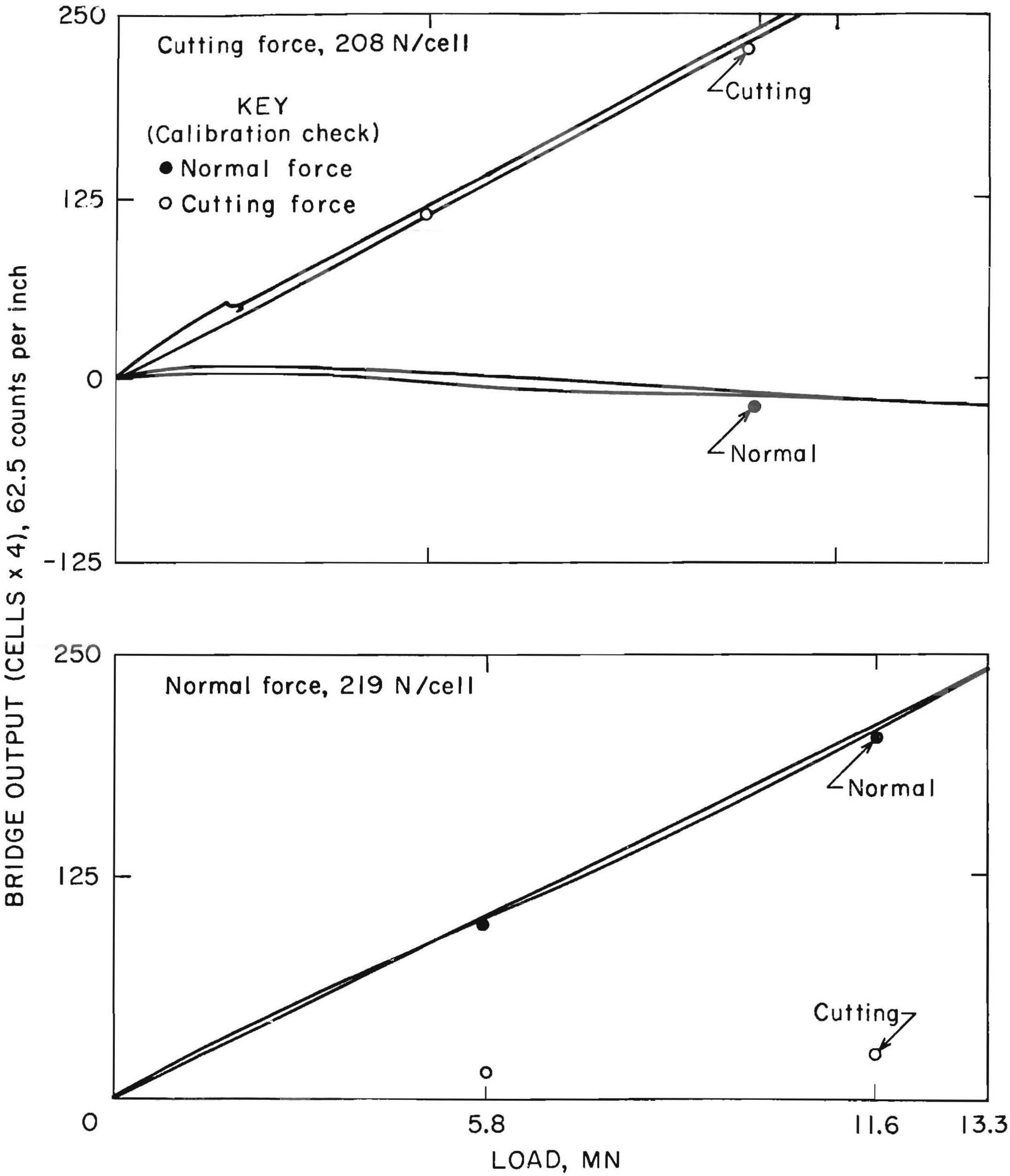

FIGURE 3.—Calibration curves for cutting and normal forces made just prior to field testing.

Bit Comparison tests were conducted within each mine at several sites. In mine 1 the point-attack bits were run with 5.08-cm spacing, and the radial bits were run with 5.08- and 7.62-cm spacing; all cuts were at a depth of 2.54 cm. In mine 2, the point-attack bits were run with 2.54-cm spacing, and the radial bits were run with 2.54- and 5.08-cm spacing; all cuts were at a depth of 1.27 cm. The test made are summarized in tables 2 and 3. The data are presented in tables 4 and 5.

DOC and spacing tests were conducted at both mines with a 75° plumb-bob bit using the following conditions: 2.54-cm depth by 7.62-, 5.08-, and 2.54-cm spacing; and 1.27-cm depth by 7.62-, 5.08-, and 2.54-cm spacing.

Weathering effects tests were conducted at three sites in mine 1 using a 75° plumb bob. Depth was 2.54 cm, and spacing was 5.08 cm. Results are presented in table 7.

Cleating effect tests were conducted at four sites. The same test procedures are used for "Weathering Effects" were used on a rib 90° from the previous test site. The data are presented in tables 4 and 5.

FIELD TESTS AT MINES 1 AND 2

Figure 4 shows the test bits used at mines 1 and 2. Three different radial bits, and three plumb-bob point-attack bits (70°, 75°, and 90°) two cigar point-attack bits (80° and 90°) were tested at mine 1. The round-nose radial bit identified as radial bit C in figure 4 was damaged during field testing at mine 1. Since no replacement was available, this bit was not tested at mine 2. At mine 2, the 70° plumb bob was replaced with a 60° plumb bob to provide greater range in bit tip angles being tested.

The test procedures used with the in-seam tester have been described previously in detail (1). Tables 2 and 3 identify the interactive tests conducted at each mine. A total of 28 independent

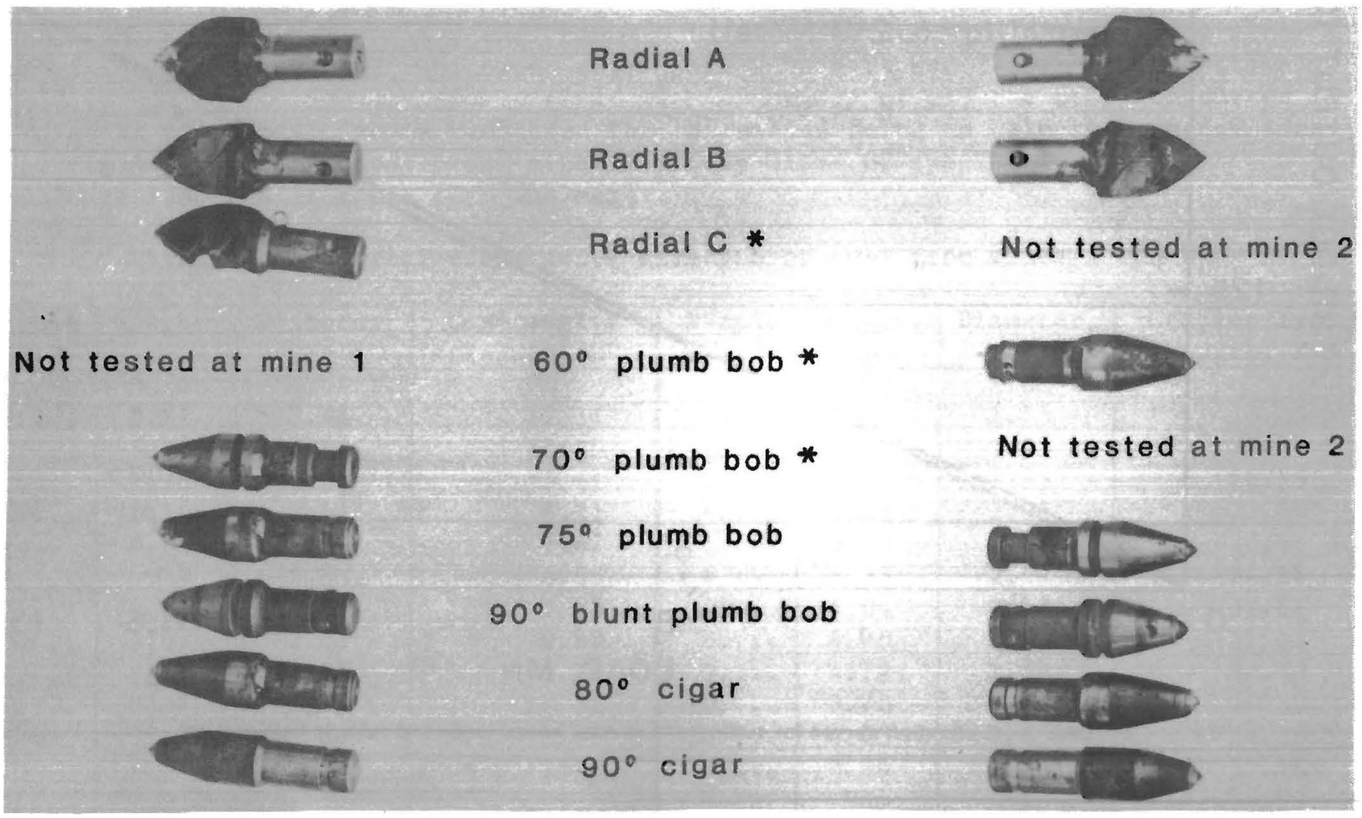

FIGURE 4.—Test bits used at mines 1 and 2. *Indicates that data were not used for bit comparison since bits were used at only one mine.

TABLE 2. - Interacting cuts made with radial and point-attack bits with 45° attack angle and 2.54-cm depth at mine 1

Bit type	Spacing, cm	Parallel		Perpendicular	
		Test site	Test cuts	Test site	Test cuts
Radial:					
A............	5.08	6	8	8	9
	7.62	3,4	12	-	-
B............	5.08	6	7	8	9
	7.62	3,4	11	-	-
C............	5.08	-	-	8	6
	7.62	3	6	-	-
Plumb bob:					
70°..........	5.08	3,4,5	25	-	-
75°..........	5.08	1,2,5,6	126	7	56
90° blunt....	5.08	3,4	19	8	9
Cigar:					
80°..........	5.08	3,4	19	8	9
90°..........	5.08	3,4	19	8	9

TABLE 3. - Interacting cuts made with radial and point-attack bits with 40° to 50° attack angles and 1.27-cm depth at mine 2

Bit type	Spacing, cm	Attack angle, deg	Parallel		Perpendicular	
			Test site	Test cuts	Test site	Test cuts
Radial:						
A..........	2.54	45	2,3	34	5	17
	5.08	45	2,3	16	5	8
B..........	2.54	45	2,3,4	51	5,6	36
	2.54	40	4	17	5	18
	2.54	50	4	17	5	18
	5.08	45	3	8	6	8
Plumb bob:						
60°........	2.54	45	2,3	34	6	18
75°........	2.54	45	2,3,4	51	5,6,7	51
	2.54	40	4	17	5	18
	2.54	50	4	17	5	18
90° blunt..	2.54	45	2,3	34	6	18
Cigar:						
80°........	2.54	45	2,3	34	6	18
90°........	2.54	45	2,3	34	6	18

cuts were taken at each mine to determine the peak cutting forces with each class of bit for each coal type. Altogether, more than 1,000 tests perpendicular to the bedding planes were conducted.

At mine 1,130 tests were conducted to compare the performance of bits and determine the effects of moisture and of cleating on coal-cutting forces. Mine 2 had been closed over a year, and the coal in the mine face had reached moisture equilibrium with the mine environment. Therefore, no tests for moisture effect were possible at mine 2. However, 116 tests were conducted at 0° and 90° to the major cleat to compare forces on test bits with various depths of cut and spacing for any cleating effect.

TEST RESULTS

COMPARISON OF RADIAL AND POINT-ATTACK

The cutting force can be resolved into two components: normal and horizontal (tangential). The normal component is primarily thrust required to hold the bit against coal or rock. Thus, the energy utilized in overcoming friction, temperature rise at the bit-rock contact area, and other losses are provided by the normal component. The horizontal component primarily acts to split and break the coal or rock.

Figures 5 and 6 depict the test results for two radial and four point-attack bits for cuts from mines 1 and 2. Figures 5 and 6 do not include test results for radial bit C, the 70° plumb bob, and the 60° plumb bob because these bits were not tested in both mines. Test results from both mines clearly show that radial bits require less cutting and much less normal force than do point-attack bits. The same conclusion is also reached by examining the peak forces obtained from these cuts in tables 4 and 5. Test results also show that the 90° cigar bit required higher cutting and normal force than the 90° blunt plumb-bob bit. The opposite was expected, because at shallow depths of cuts the 90° cigar bit has less body surface area in contact with the coal being cut.

Owing to their geometry, radial bits make wider cuts and remove more coal per cut than point-attack bits. To determine the effect of wider spacings, further

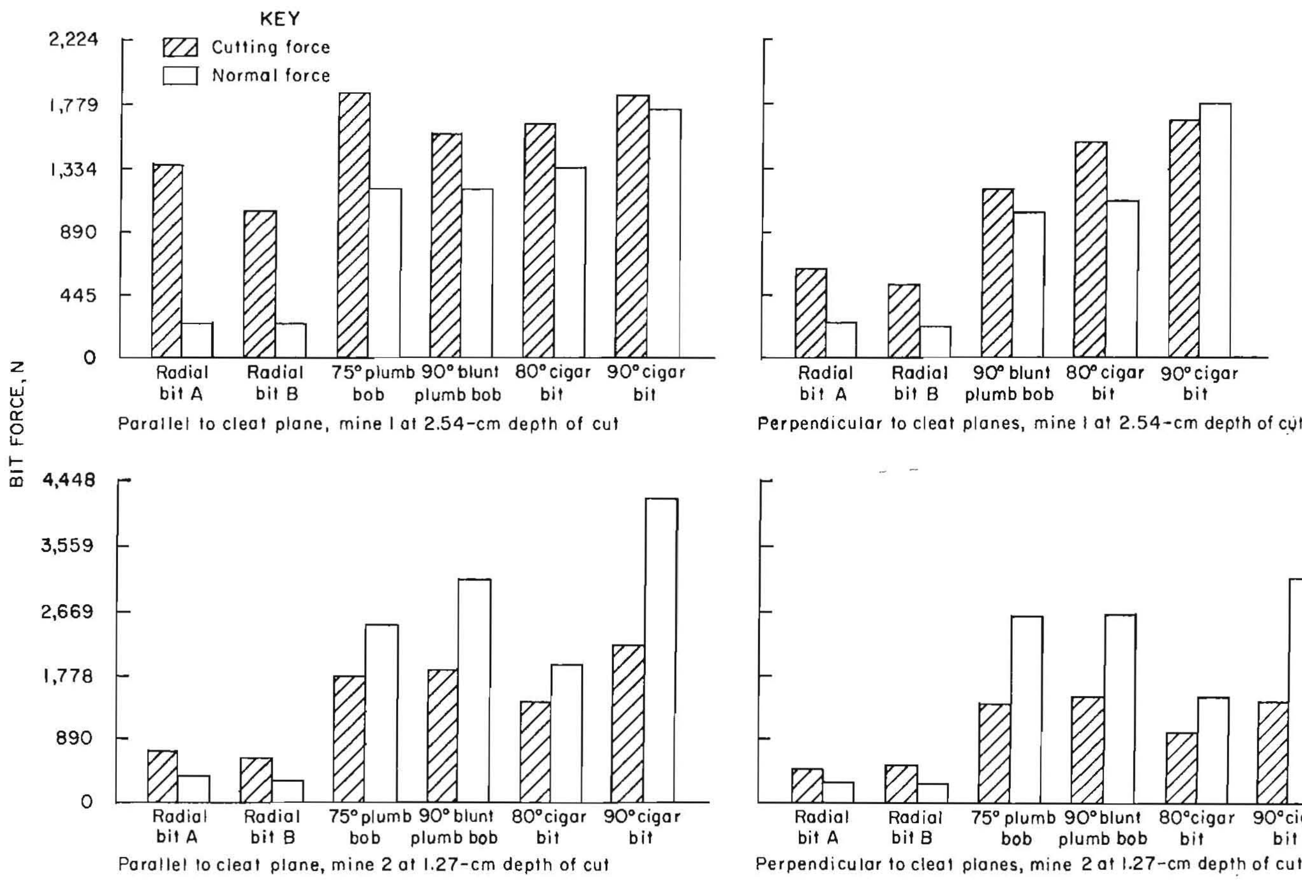

FIGURE 5.—Histograms of mean bit forces for interacting cuts parallel and perpendicular to the major cleat plane at mines 1 and 2.

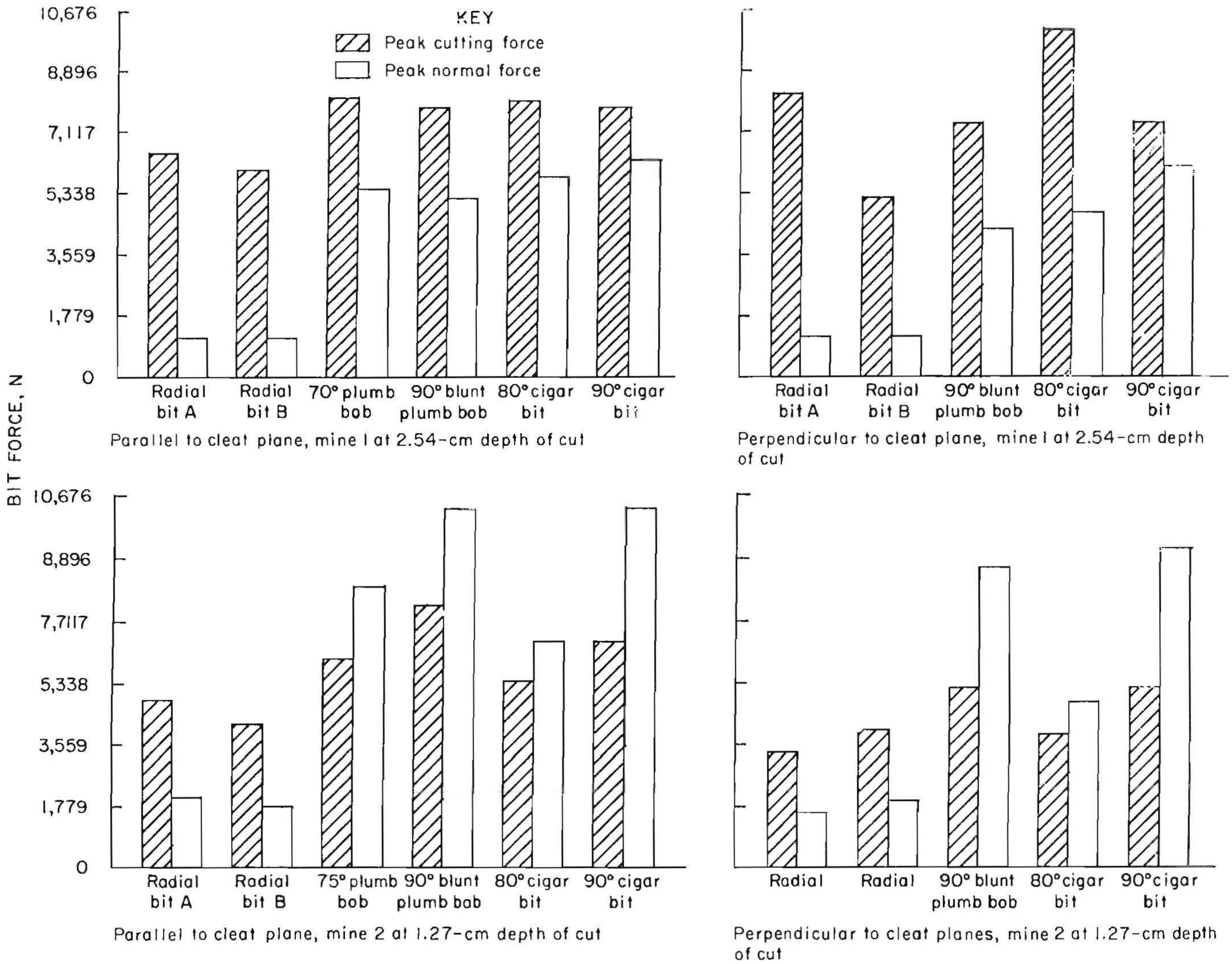

FIGURE 6.—Histograms of mean peak bit forces for interacting cuts parallel and perpendicular to the major cleat plane at mines 1 and 2.

tests were conducted with radial bits at 7.62-cm spacing for 2.54-cm deep cuts and 5.08-cm spacing for 1.27-cm-deep cuts. Despite the greater ratio of spacing to depth of cut (S/D ratio) and despite a larger amount of coal removal per cut, the test results in tables 4 and 5 suggest that the radial bits still required much lower normal force than point-attack bits cutting with narrower spacing.

To further evaluate this point, independent cuts were made for each test series. Test results shown in tables 4 and 5 for the independent cuts suggest the radial bit requires lower cutting and much lower normal force in all but one case. In this report, cuts placed 60 cm apart are called independent cuts; all other cuts were placed from 2.54 to 7.62 cm apart and are called interacting cuts.

The peak forces for independent and interacting cuts are also reported in tables 4 and 5. Generally the peak cutting and normal forces for independent cuts were up to twice as high as those for interacting cuts. Similar results were also noticed for the mean forces in the two classes of cuts.

Test results in figures 5 and 6 show that in making cuts through the hard coal in mine 2, the normal forces for the point-attack bits became greater than the cutting force in both directions to the cleating. With the radial bits, the normal force component remained smaller than the cutting force. The rake and

TABLE 4. - Mean and peak forces for independent and interacting cuts with radial bits and point-attack bits with 45° attack angle and 2.54-cm depth at mine 1[1]

Bit type	Spacing, cm	Test cuts	Direction	Av force, N		Av peak force, N	
				Cutting	Normal	Cutting	Normal
Radial:							
A........	5.08	8	=	1,343	249	6,450	1,112
		9	+	632	245	8,230	1,112
	7.62	12	=	1,219	262	7,785	1,557
		0	+	NA	NA	NA	NA
	60.00	2	=	2,433	463	8,821	2,149
		2	+	1,708	423	10,009	2,002
B........	5.08	7	=	1,019	240	6,005	1,112
		9	+	512	222	5,116	1,112
	7.62	11	=	1,237	289	7,785	1,779
		0	+	NA	NA	NA	NA
	60.00	2	=	2,011	405	7,785	1,704
		2	+	1,277	294	3,781	1,112
C........	5.08	0	=	NA	NA	NA	NA
		6	+	783	343	6,005	2,002
	7.62	6	=	1,410	427	6,895	2,002
		0	+	NA	NA	NA	NA
	60.00	2	=	2,015	587	7,340	2,002
		2	+	988	503	6,005	2,002
Plumb bob:							
75°......	5.08	25	=	1,842	1,179	8,083	5,414
		0	+	NA	NA	NA	NA
	60.00	2	=	3,252	2,598	10,454	7,340
			+	NA	NA	NA	NA
90° blunt	5.08	19	=	1,548	1,143	7,785	5,116
		9	+	1,170	1,005	7,340	4,226
	60.00	2	=	5,240	4,715	11,566	8,892
		2	+	2,375	1,940	5,560	4,671
Cigar:							
80°......	5.08	19	=	1,628	1,326	8,007	5,783
		9	+	1,504	1,099	10,009	4,691
	60.00	2	=	4,382	3,665	11,566	8,452
		2	+	1,619	1,308	4,226	3,336
90°......	5.08	19	=	1,810	1,695	7,785	6,228
		9	+	1,633	1,753	7,340	6,005
	60.00	2	=	3,488	3,772	8,674	7,785
		2	+	1,942	1,842	5,560	5,116

= Parallel to cleat planes.
+ Perpendicular to cleat planes.
NA Not available.
[1]60 cm is independent spacing; all others are interactive.

clearance angles with this bit design appear to split the coal in tension.

Test results from mines 1 and 2 also show that the 90° blunt plumb-bob bit required less cutting force than the 90° cigar bit. A similar anomaly was also noticed in comparing the 75° plumb-bob and 80° cigar bit. Although the inconsistency is smaller, it cannot be explained by coal-cutting theory or the Bureau's past experience under similar test conditions.

TABLE 5. - Mean and peak forces for independent and interacting cuts with radial bits and point-attack bits with 45° attack angle and 1.27-cm depth at mine 2[1]

Bit type	Spacing, cm	Test cuts	Direction	Av force, N		Av peak force, N	
				Cutting	Normal	Cutting	Normal
Radial:							
A.......	2.54	34	=	676	311	4,671	2,002
		17	+	485	307	3,336	1,557
	5.08	16	=	1,036	472	6,228	2,669
		8	+	609	320	4,671	1,557
	60.00	4	=	1,379	592	6,339	2,891
		2	+	1,593	698	8,452	3,114
B.......	2.54	51	=	529	262	4,079	1,704
		36	+	503	285	4,004	2,002
	5.08	8	=	956	409	5,116	2,002
		8	+	645	325	5,560	2,447
	60.00	3	=	1,401	507	5,859	2,593
		3	+	1,873	721	8,674	4,079
Plumb bob:							
60°.....	2.54	34	=	1,468	1,748	6,005	7,785
		13	+	983	1,268	4,671	5,116
	60.00	1	=	3,096	3,577	6,895	9,119
		1	+	4,675	5,578	10,009	10,454
70°.....	2.54	51	=	1,677	2,415	6,005	8,083
		51	+	1,370	2,451	5,414	8,230
	60.00	3	=	3,203	3,999	7,931	9,862
90°.....	2.54	34	=	1,784	3,003	7,562	10,231
		18	+	1,495	2,562	5,116	8,674
	60.00	2	+	3,906	4,577	9,564	11,121
		1	+	4,008	4,853	11,788	10,899
Cigar:							
80°.....	2.54	34	=	1,339	1,833	5,338	6,450
		18	+	961	1,579	3,781	4,671
	60.00	2	=	3,096	3,194	8,674	9,564
		1	+	3,470	4,386	7,785	9,119
90°.....	2.54	34	=	2,073	4,110	6,450	10,231
		18	+	1,406	3,123	5,116	9,119
	60.00	2	=	3,670	5,529	8,452	11,121
		1	+	3,901	7,829	10,009	12,233

= Parallel to cleat planes.
+ Perpendicular to cleat planes.
[1]60 cm independent spacing; all others are interactive.

Higher normal forces are an indication of greater dust production and inefficient cutting due to worn-out bits, negative clearance angles, or poor bit design. Under these conditions, excessive thrust is required to hold the bit at the depth of cut. The radial bits used in this investigation had 10°, 5°, and 8° clearance angles and 5°, 10°, and 12° rake angles respectively. Therefore, less friction was encountered when making test cuts with these bits. The greater rake angles also appear to help the coal fracture in the tensile mode of failure.

Higher cutting forces are an indication of higher coal strength, greater primary dust generation, improper bit design and/or lacing, worn bits, and low or negative rake and clearance angles. In these situations, normal force and friction will also increase.

The majority of the radial bits can be classified as half-point-attack bits. By their design, the radial bits have a distinct advantage over point-attack bits by providing larger rake angles. The radial bits make wider cuts and appear to cause rock failure by splitting it in tension. The point-attack bits appear to initiate failure in a more complex shear-tensile mode. As the tensile strength of the coal being cut is approximately one-tenth the compressive strength, any bits that exploit this weakness may be expected to exhibit lower cutting and normal forces.

Visual observation at the test sites suggested that the radial bits produced a larger product size than the point-attack bits. There was less streaking, or a smaller slicken surface, along the length of cut with the radial bits than with the point-attack bits. The increase in the normal component of the cutting force for the conical bits also suggests that excessive force is being utilized in the crushing of coal under the bit tip, causing size reduction in the broken coal by the conical point-attack bits.

Radial bits appear to take advantage of tensile failure rather than the complex Mohr failure criterion (10). Tensile failure of minerals will reduce the cutting and normal forces and hence the dust generation.

Hurt and Laidlaw (11), working with Darley Dale sandstone using a 76° plumb-bob bit and V-shaped and round nose radial bits, reported that considerable differences between the mean cutting force requirements of three rock cutting tools were found. But the presence of relief and effect of blunting reduced or eliminated these differences, particularly at the smaller depths of cut.

However, it should be pointed out that at the shallower depths of cuts, the shape of blunt radial bits approximates or reaches the shapes of point-attack bit tips. Therefore, no difference in tangential or normal forces can be envisioned. At shallow depths of cut, the difference in the magnitude of cutting forces for different types of bits is quite small and within the scatter in the test results. Therefore it is difficult to measure these differences.

Demou (12), working with the same types of bits as Hurt and Laidlaw (11) in three different rock types, found that radial bits performed better and required much less specific energy than point-attack bits.

EFFECT OF CLEATING ON CUTTING FORCES

To determine the effect of cleat planes on cutting forces, 13 tests consisting of 117 cuts were made in mine 1 at test site 3, 4, 6, and 8. These involved two types of radial bits, 80° and 90° cigar bits, and a 90° blunt plumb bob, all at 2.54-cm depth of cut and 5.08-cm spacing. At mine 2, 24 tests with 414 cuts were made at test sites 2, 3, 5, 6, and 7 using two radial bits, 60°, 75°, and 90° plumb bob bits, and 80° and 90° cigar bits; all used 1.27-cm depth of cut and 2.54-cm spacing. Seventy-two test cuts parallel to major cleat planes and 45 cuts perpendicular to major cleat planes were made at mine 1, and 238 cuts parallel to cleat planes and 176 cuts perpendicular to cleat planes were made at mine 2.

Visual observations of the broken coal indicated a larger byproduct size while cutting perpendicular versus parallel to cleat planes, resulting in lower average and peak cutting forces for both independent and interacting cuts. Cleating test results may be found in tables 4, 5, and 6.

RELATIONSHIP BETWEEN DEPTH OF CUT, BIT SPACING, AND CUTTING FORCE

Mine 1

To determine the effects of depth of cut, 1.27-, 2.54-, and 5.09-cm deep test cuts were planned. However, during the initial field testing, it was determined that it is not possible to make 5.08-cm-deep cuts in the Pratt Seam with the in-seam tester. For 1.27- and 2.54-cm-deep cuts made with a 75° plumb bob, the peak cutting force increased from 4,448 and 5,560 N respectively to 5,783 and 8,007 N.

TABLE 6. - Effect of depth of cut and bit spacing for 75° plumb-bob cutting and normal forces for test data from mines 1 and 2.

Test cuts	Coal layer removed	Depth of cut, cm	Spacing, cm	Av force, N		Av Peak force, N	
				Cutting	Normal	Cutting	Normal
MINE 1 (TEST SITES 2 and 6), PARALLEL TO CLEAT PLANES							
37	1	1.27	2.54	876	1,041	4,448	4,671
18	2	1.27	5.08	1,259	1,517	5,338	5,783
10	3	1.27	7.62	1,432	1,668	5,560	5,338
37	4	2.54	2.54	1,259	1,335	5,783	5,116
18	5	2.54	5.08	1,744	1,753	6,895	7,117
10	6	2.54	7.62	2,424	2,349	8,007	7,117
MINE 2 (TEST SITE 1), PARALLEL TO CLEAT PLANES							
16	1	1.27	2.54	1,010	1,014	5,116	5,116
8	2	1.27	5.08	1,481	1,472	5,560	5,560
5	3	1.27	7.62	1,971	2,024	6,450	7,340
16	4	2.54	2.54	1,895	1,980	7,785	8,674
7	5	2.54	5.08	2,705	3,114	9,119	9,119
4	6	2.54	7.62	2,678	3,746	7,785	11,343
MINE 2 (TEST SITE 7), PERPENDICULAR TO CLEAT PLANES							
16	1	1.27	1.27	756	1,045	3,336	3,781
8	2	1.27	5.08	988	1,219	4,226	5,560
6	3	1.27	7.62	1,455	1,824	5,560	6,005
17	4	2.54	2.54	1,152	2,278	5,116	7,340
8	5	2.54	5.08	2,069	2,767	8,230	9,119
5	6	2.54	7.62	2,469	2,722	9,119	8,230

To obtain the effects of bit spacing, test cuts were placed 2.54, 5.08, and 7.62 cm apart. In addition to this, independent (unrelieved) cuts were also made for 2.54-cm depth of cut with each bit type. Table 6 shows results from 1.27- and 2.54-cm-deep cuts for test sites 2 and 6 placed 2.54 and 5.08, and 7.62 cm apart. For a 75° plumb bob at 1.27-cm depth of cut, the cutting forces were 876, 1,259, and 1,432 N, respectively, for each spacing. Similar increases may also be noticed in normal forces. For 2.54-cm-deep cuts made with a 75° plumb bob, the cutting forces were 1,259, 1,744, and 2,424 N, respectively, for each spacing.

Mine 2

To verify the test results from mine 1 on the effects of depth of cut and spacing on cutting forces, the experimental design used at mine 1 was repeated at mine 2. The coal in mine 2 had a compressive strength of 27.37 MPa, and most of the time it was not possible to make 2.54- or 5.08-cm-deep cuts. However, in a few instances when it was possible to make 2.54-cm-deep cuts with the 75° plumb bob, the mean cutting forces increased from 1,010 N for 1.27-cm depth to 2,705 N for a 2.54-cm-deep cut. Test results for independent cuts and interacting cuts spaced at 2.54 and 5.08 cm spacing are shown in table 5.

From these tests, it can be concluded that generally the cutting and normal forces increased with the depth of cut and bit spacing. Visual observation showed that at an S/D ratio of 2, coal was being left between the cuts. Therefore, in the Pratt and Emery Seams, the S/D ratio necessary for interactive cutting is closer to 1.75 than to 2.

EFFECT OF WEATHERING ON CUTTING FORCES

To evaluate the effect of mine environment on the pillar, face, and rib, 18 tests were conducted at 3 different test sites in mine 1 by cutting a series of

TABLE 7. - Results of weathering tests for 75° plumb bob at mine 1 (2.54-cm depth of cut and 5.08-cm-spacing)

Test cuts	Coal layer removed	Av force, N		Av Peak force, N	
		Cutting	Normal	Cutting	Normal
TEST SITE 1, PARALLEL TO CLEAT PLANES					
7	1	NA	2,269	NA	6,895
10	2	NA	2,900	NA	10,009
11	3	2,598	3,327	9,119	10,454
7	4	2,349	3,158	9,119	9,564
10	5	2,553	3,528	10,899	10,454
9	6	2,398	3,674	10,009	10,454
TEST SITE 5, PARALLEL TO CLEAT PLANES					
9	1	2,656	2,540	9,119	8,674
9	2	2,740	2,295	7,785	7,340
9	3	2,527	2,060	8,230	6,450
9	4	2,553	2,153	8,674	7,340
9	5	2,469	1,984	8,230	8,230
9	6	1,931	1,312	10,454	6,005
TEST SITE 7, PERPENDICULAR TO CLEAT PLANES					
10	1	1,940	1,317	7,785	6,005
10	2	1,766	1,041	6,450	4,226
9	3	1,268	734	6,450	3,781
9	4	1,077	667	6,005	4,226
9	5	1,499	1,232	6,895	6,895
9	6	1,668	1,397	6,450	6,005

NA Not available.

layers at each test site. Mine 2 had been shut down for more than a year. During this period, the moisture level in the mine air had remained constant, and coal up to the depth of 30 cm had reached moisture equilibrium. Therefore, it was concluded that it would not be useful to conduct tests at this location for evaluation of moisture effects on fragmentation forces.

The assumption was made that if there is no change in the moisture content of coal from one point to another, its mechanical property from point to point would remain unaffected by the moisture. The hypothesis was that weathering reduces strength, and that therefore each layer removed would present a stronger fresh face. The assumption was then made that forces will increase with depth of the test layer in the series. The hypothesis and assumption were not confirmed: Test results shown in table 7 show no statistical significance due to weathering.

CONCLUSIONS

The trend in the data shown in tables 4 and 5 and figures 5 and 6 clearly indicate that the radial bits tested required lower cutting and much lower normal forces than the point-attack bits tested in the same types of cuts.

The lower forces for radial bits appear to be caused by better orientation of the cutter tip with the bedding direction. Radial cutting appears to facilitate coal splitting in the tensile mode, while the point-attack bits appear to fragment the coal with a more complex mode of failure.

It should be also pointed out that these findings are well supported by the metal-cutting theory. This theory in part states that the higher the rake angle, the lower the magnitude of cutting force. The majority of 75° or greater than 75° tip plumb bobs by their inherent design are unable to provide rake and clearance angles greater than 7.5°, while radial bits are designed to provide 5° clearance with 15° to 35° rake angles. Ideal radial bit tips approximate half a point-attack bit in the direction of cut.

Comparison of test results in figures 5 and 6 shows that making cuts through hard coal requires much greater normal forces. This is to be expected since the reactive force on the bit increases as the strength of the material being cut increases. This means it requires greater force to hold a bit in hard coal at a predetermined depth of cut. The difference in the magnitude of cutting forces is not as great, however, because the tensile strength of the two types of coals is similar.

Cutting coal perpendicular to cleat planes requires less cutting and normal force than making the same types of cuts parallel to cleat planes. This substantiates the mining industry practice of cutting perpendicular to cleat planes whenever possible, especially during room-and-pillar operations.

These test results further suggest that the rake and clearance angles have more influence on the magnitude of cutting forces than previously thought.

REFERENCES

1. Sundae, L. S. Measurement of Coal-Cutting Forces Underground With the In-Seam Tester. BuMines RI 9033, 1986, 16 pp.
2. Roepke, W. W., and J. I. Voltz. Coal-Cutting Forces and Primary Dust Generation Using Radial Gage Cutters. BuMines RI 8800, 1983, 24 pp.
3. Evans, I. (ed.). Theoretical Aspects of Coal Ploughing (Conf. on Non-Metallic Brittle Materials). Butterworth, 1958, 451 pp.
4. ______. Basic Mechanics of the Point Attack Pick. Colliery Guardian, May 1984, pp. 189-191.
5. ______. A Theory of the Cutting Force for Point Attack Picks. Int. J. Min. Eng., v. 2, No. 1, 1984, pp. 63-71.
6. Banerjee, B. R., and J. N. Wisner (Ingersoll-Rand Research Inc.). In-Seam Tester for Underground Mines. Ongoing BuMines contract H0282030; for inf., contact W. W. Roepke, Twin Cities Research Center, Minneapolis, MN.
7. Finnie, I., R. Strait, and L. Foote. Relationship of Coal Properties and Machine Parameters to Continuous Mining Machine Cutting. On going BuMines contract J0155084; for inf. contact B. D. Hanson, TPO, Twin Cities Research Center, Minneapolis, MN.
8. Melloy, M. Mechanics of Cutting and Boring. CRREL Rep. 77-7, Apr. 1977, 96 pp.
9. McCullogh, C. M., M. Deul, and P. W. Jeran. Cleat in Bituminous Coalbeds. BuMines RI 7910, 1974, 25 pp.
10. Goodman, R. E. Introduction to Rock Mechanics. Wiley, 1980, pp. 50-85.
11. Hurt, K. G., and D. D. Laidlaw. Laboratory Comparison of Three Rock Cutting Tools. Tunnels and Tunneling (London), v. 11, No. 4, May 1979, pp. 13-16.
12. Demou, S. G., R. C. Olson, and C. F. Wingquist. Determination of Bit Forces Encountered in Hard Rock Cutting for Application to Continuous Miner Design. BuMines RI 8748, 1983, 24 pp.

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