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Measurement of Coal-Cutting Forces Underground With the In-Seam Tester

By Laxman S. Sundae

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

in	inch	MPa	megapascal
cm	centimeter	N	newton
gpm	gallon per minute	pct	percent
MN	meganewton	psi	pound per square inch

OTHER ABBREVIATIONS USED IN THIS REPORT

DOC	depth of cut	PB	plumb bob
IST	in-seam tester	S/D	ratio, spacing to depth of cut (DOC)
MTK	Mettiki		

MEASUREMENT OF COAL-CUTTING FORCES UNDERGROUND WITH THE IN-SEAM TESTER

By Laxman S. Sundae[1]

ABSTRACT

The Bureau of Mines designed, fabricated, and is using an in-seam tester (IST) for in situ determination of coal cutting forces. This report describes the results of field tests conducted in the Pocahontas No. 3 and Upper Freeport seams to obtain peak and mean cutting forces during coal cutting with several bit geometries, including radial and point attack bits currently used on drum-type machines. Comparisons were also made between new and worn bits, and using data obtained from a Bureau-modified chisel bit. The test results show that longwall plough cutting (horizontal cuts) in bony coal bands (shale) requires >3 times the cutting force for the same cuts in a vertical direction. When no bony coal is present, the cutting forces required to make horizontal and vertical cuts are equal. Worn bits require 4 to 5 times more cutting and normal force than new or undamaged bits. Normal force increased drastically for the worn chisel bit. Peak force encountered in making independent cuts was found to be ≈3 times higher than that required to make interactive cuts using a spacing-to-depth-of-cut ratio of 2. Both rake and clearance angles were found to have a significant effect on normal and cutting force.

[1]Mining engineer, Twin Cities Research Center, Bureau of Mines, Minneapolis, Mn.

INTRODUCTION

The Bureau of Mines has been actively engaged in coal cutting research since the enactment of the Federal Coal Mining Health and Safety Act of 1969. This research has been directed to the reduction of respirable dust and energy required for coal cutting. As a part of this research, an extensive evaluation of different types of commercially available bits has been performed at the coal cutting research laboratory of the Bureau's Twin Cities (MN) Research Center. The laboratory tests were extended to underground coal mines.

The Bureau designed and fabricated, through a research contract with Ingersoll-Rand Research Inc. (IRRI), an in situ testing machine (the in-seam tester) for direct measurement of cutting forces in underground coal mines using standard, commercially available cutting tools. The machine designed to accomplish this goal is now being used to build a data bank of information on cutting forces affecting primary dust generation and cutting energy from major coal seams in the United States.

This report describes the results of tests made in the Pocahontas No. 3 seam and Upper Freeport seam during 1983. The objectives of the testing were--

1. To obtain in situ data on cutting and normal force with a variety of cutting tools for manufacturers and mine operators.
2. To compare the performance of a variety of bit types.
3. To confirm previous data from the Bureau's coal cutting laboratory and establish correlation with in situ field test results.

ACKNOWLEDGMENTS

The author appreciates the help of Mr. Carl F. Wingquist, physicist, Twin Cities Research Center, for his assistance with the systems instrumentation and Theodore A. Myren, mining engineering technician, Twin Cities Research Center, who assisted in conducting field tests under trying conditions. Messrs. Joseph Subrick, Director of Equipment and Maintenance, U.S. Steel Mining Co., Inc., and Om Magoon and Craig Mamose, mining engineers, Mettiki Coal Corp., provided access to their respective mines and helped with the Bureau's on-site research.

LITERATURE SURVEY

Werblow (14)[2] examined the effects of coal plough blade angles and found a decrease in specific energy and an increase in mean peak force with the increasing depth of cut (DOC) for blade angles 30°, 45°, 55°, and 65°. Roepke (9, 12) working with point attack bits, and Hurt (5, 7) working with chisel bits, have also reported that deeper cuts require less specific energy and produce less specific dust. Roxborough and Pedroncelli (13) verified Roepke and Hanson's (8, 11), Hurt's (5, 6), and Whittaker's (15) findings by field test comparison of point attack and radial bits on continous miner in hard, compact, and relatively cleat-free coal. Roepke (10) further investigated the effect of bit angles in point attack bits. His test results support Werblow's conclusions for blade angles on coal ploughs.

Hanson (4), investigating the effects of 35°, 45°, and 55° attack angles using a plumb bob with a 90° tip, reported that attack angles only affected average cutting force.

Demou (3) determined cutting and normal forces using similar coal cutting bits (radial bits, cigar bits) for rock cutting. His test data show 1.27 cm DOC with the radial bit required 69, 63, and 56 pct of the cutting force needed for the cigar bit in marble, limestone, and trona, respectively. Similarly, for the

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

same depth of cut in marble, the cigar bit required a normal force almost 2-1/2 times higher than the cutting force. For each depth of cut, the radial bit required less mean peak force and energy than the 75° tip cigar bit. Although this work was done in hard rock, the results are considered pertinent to these bit comparison tests, since hard inclusive materials are found in coal.

The literature survey did not specifically address rake angle or clearance angle in comparing different types of bits. No information was available in the literature to signify the importance of bony coal either on bit life or on forces encountered in cutting bony inclusions.[3]

All of the above investigations were limited to laboratory tests with unconfined specimens without considering the effects of cracks, flaws or cleat planes, or inclusive materials found in coal. Therefore, the test values reported in the literature may be different than those to be expected with field testing.

EXPERIMENTAL SYSTEM

The in-seam tester (IST) is shown in figure 1, and its assembly schematic is shown in figure 2. Major components of the IST system are (a) anchor (roof) bolts, (b) frame, (c) mast, (d) hydraulics, (e) dynamometer, and (f) data acquisition system. These components have been fully described by Ingersoll-Rand personnel (1, 8) and are described in detail by the Bureau in RI 8925 (2). A brief description of major components follows.

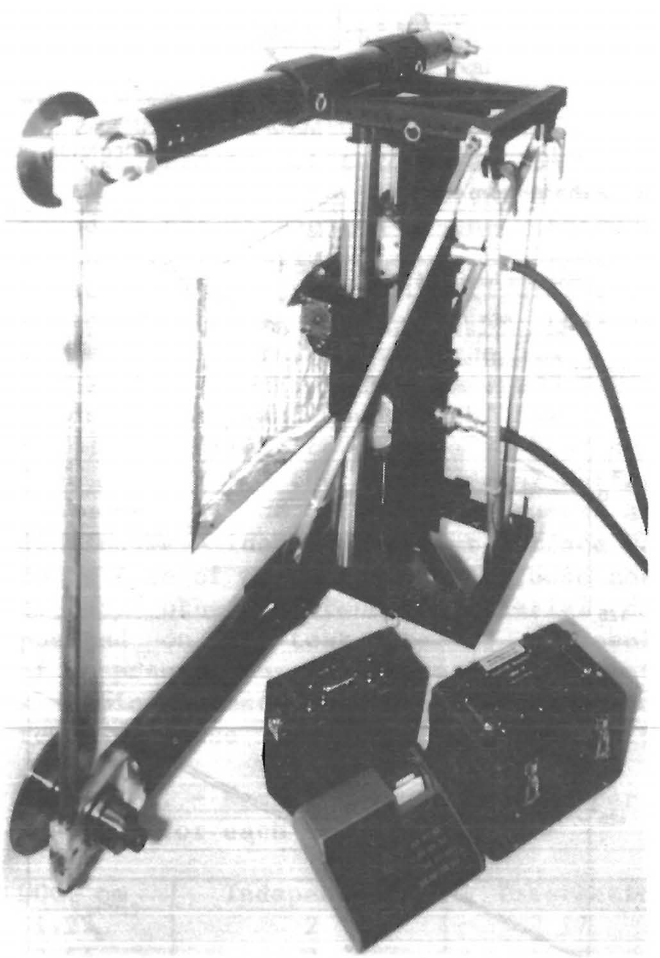

FIGURE 1.—The in-seam tester.

ROOF BOLTS

Four roof bolts (91.4 cm in length) were used to fasten the IST frame to the mine face or rib. These bolts must be installed in the square pattern dictated by the IST frame. There is no allowance for departure from this pattern in the operation of the IST mast system, so great care is required in setting up the mounting system.

FRAME

The frame that supports the mast consists of two traverse rods, six struts, (including two side tubes), and upper and lower weldments, as shown in figures 1 and 2. These components are assembled and mounted on the mine face or rib after the roof bolts are in proper position.

[3]Bony coal in this report is defined as a layer or layers of hard impure coal, shale, pyrites or other impurities found in partings between layers of relatively uniform coal seams.

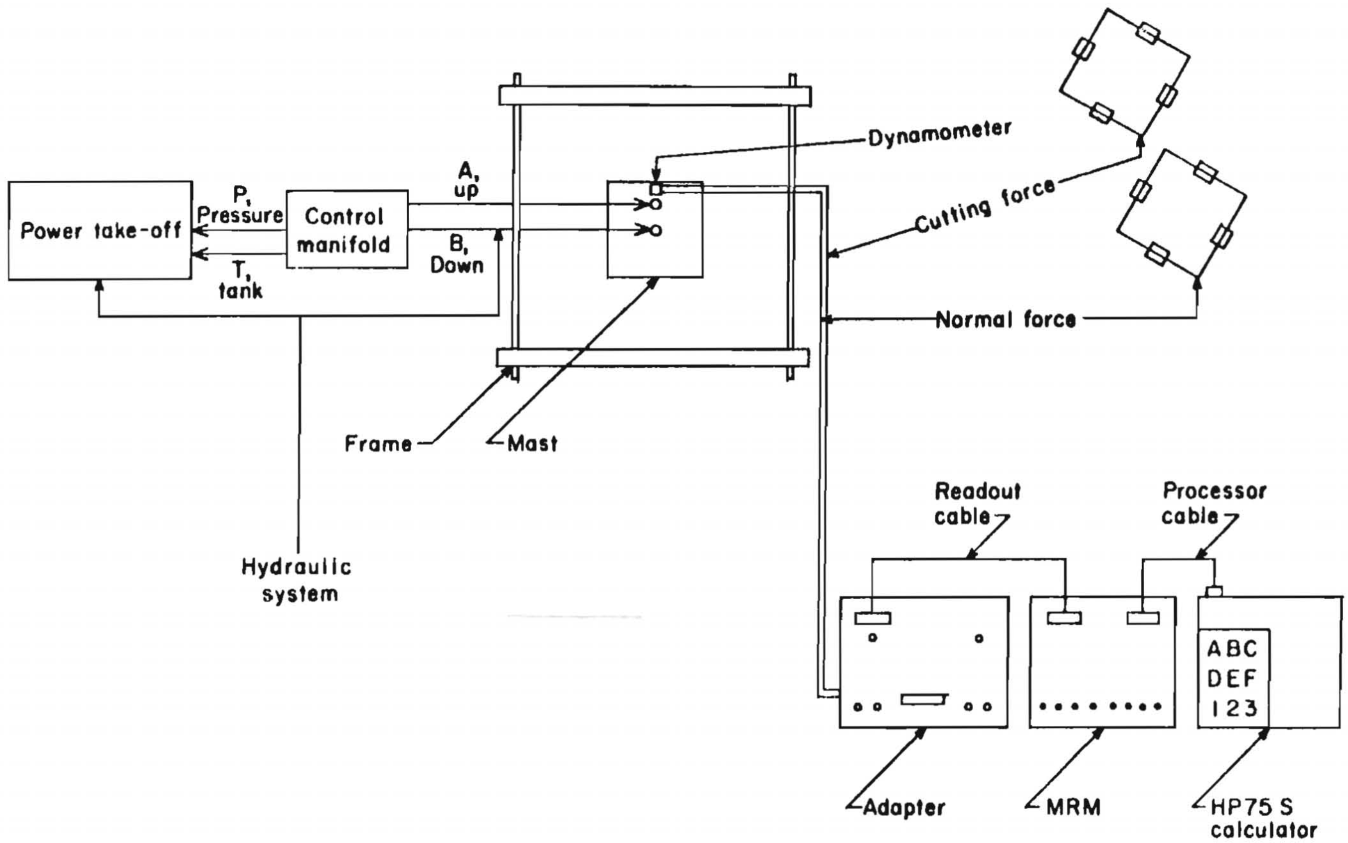

FIGURE 2.—Assembly schematic for the in-seam tester.

MAST

The mast is used to transport the cutter-dynamometer assembly up and down or back and forth across a seam area; i.e., it can be manually traversed in any direction, depending on the mounting orientation of the frame. The mast assembly, which is mounted in the frame, consists of the bit and dynamometer with supporting track, the hydraulic cylinder, and a chain.

HYDRAULICS

The IST was designed to operate from the hydraulic power take-off of existing mining machinery such as a roof bolter, transport buggy, continous miner, or any other source of hydraulic power that can provide 1,500 psi at a minimum 5 gpm.

DYNAMOMETER

The dynamometer serves as a load path between the cutting bit, the bit holder,

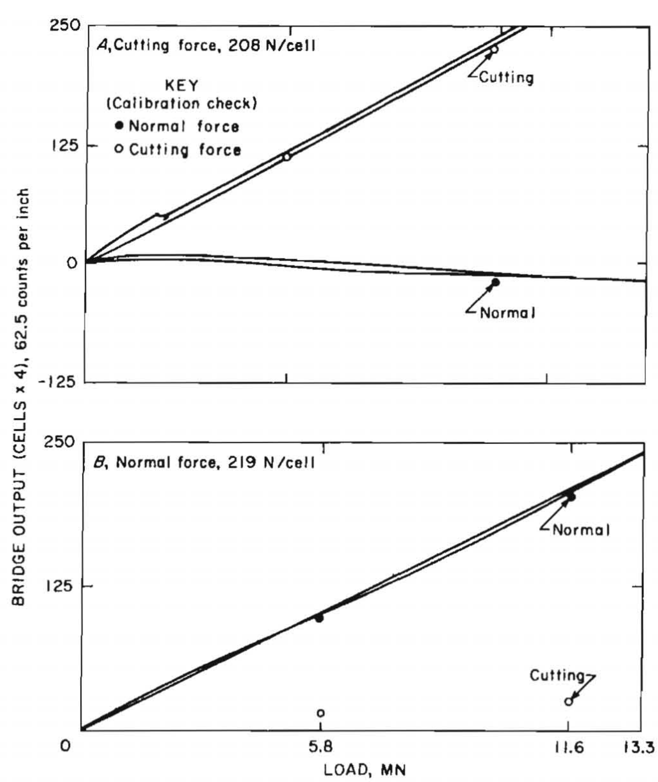

FIGURE 3.—Calibration curves for cutting and normal forces.

and the supporting structure. A custom-designed torsional dynamometer for measuring cutting and normal forces supports the bit holder. The ends of the dynamometer are splined to match splined collars mounted on the supporting mast. This design feature makes it free from interaction to side load torque. To accurately measure orthogonal forces directly, strain gauges are used in a full-bridge design (fig. 2). Calibration curves (fig. 3) of the applied load (0 to 13.3 MN) versus readout values are plotted for each axis of the dynamometer. The dynamometer is calibrated to verify accuracy before each field test series.

DATA RECOVERY

The data acquisition system is composed of a memory module that interfaces with a microcomputer for data processing. Cutting and normal forces exerted on the bit holder are converted into two separate electrical signals by the dynamometer and stored in the memory as cumulative cutting and normal forces. Bit forces are sampled and stored in memory 10,000 times per second for each channel.

EXPERIMENTAL DESIGN

The number of test cuts per bit type is shown in table 1. The 75° and 90° plumb bobs and 80° cigar bits were tested at both mine A and mine B. Additional tests were conducted at mine A with the 3.17-cm-width new and worn chisels and with a 2.19-cm radial bit. At mine B tests were also conducted with a MTK plumb bob, which is a custom-made point attack bit designed to cut through a 15- to 20-cm-thick layer of hard shale, such as are found in the midsection of the Pittsburgh coal seam. Relative shapes and sizes of these bits are shown in figure 4, and various technical terms used in this report are illustrated in figure 5.

The first constraint on in situ testing after assembly and mounting of the IST on the coal seam was to prepare a test surface similar to the fresh coal surface encountered by the longwall shearers and continuous miners. The test surface had to be free of weathered and/or loose coal or any other extraneous material deposited on the test site as a result of exposure to the mine environment. A typical test sequence consisted of removing loose coal from the test site

TABLE 1. - Number of cuts planned per test for each bit type

DOC, cm	Independent	Interacting
1.27	2	17
2.54	2	8
5.08	2	4

NOTE.--For 35°, 45°, and 55° attack angles.

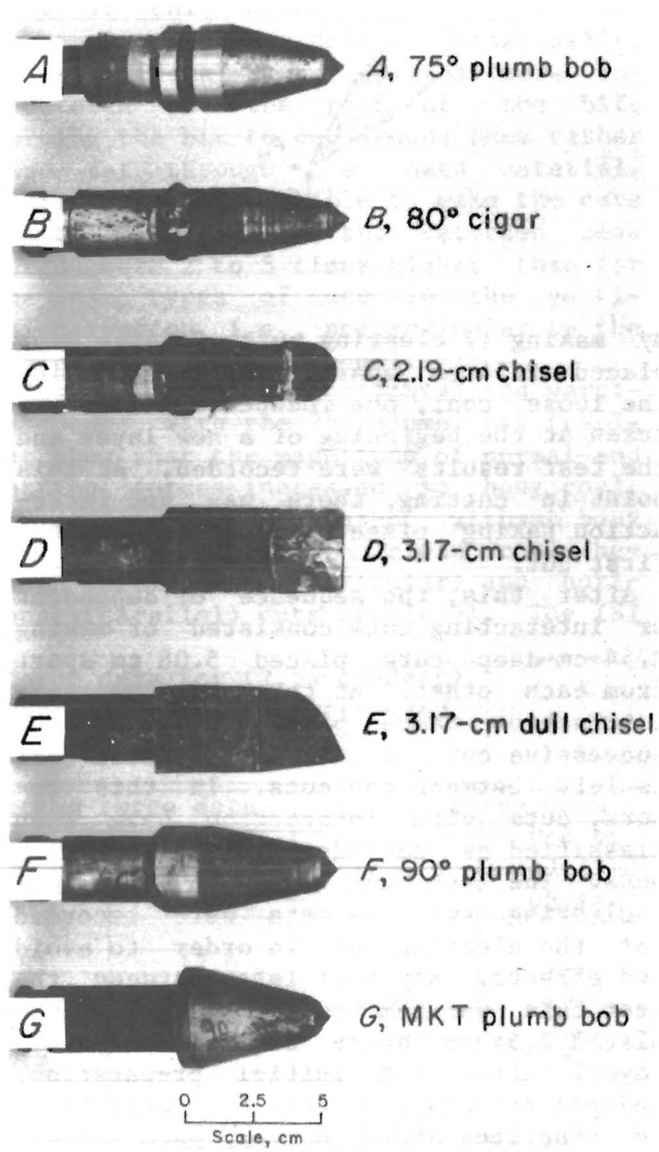

FIGURE 4.—Test bits used in this investigation.

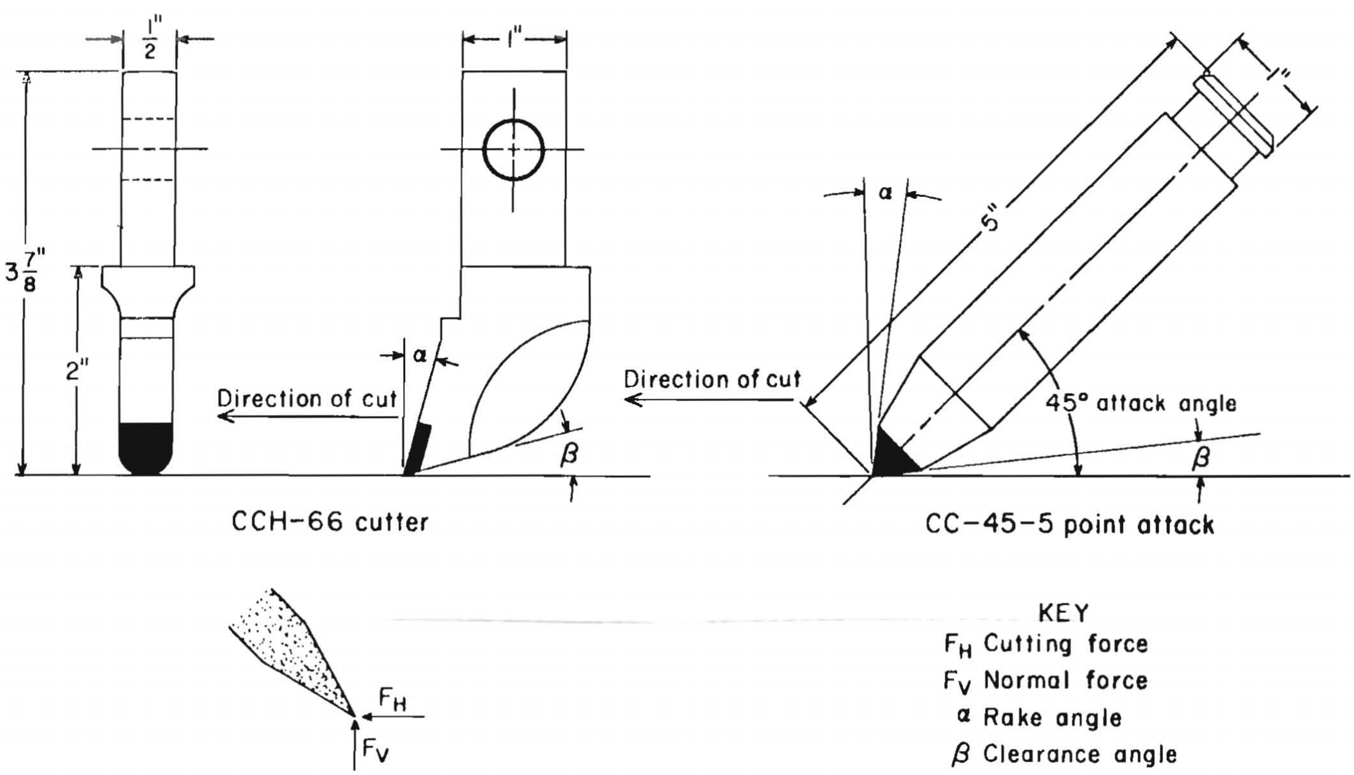

FIGURE 5.—Illustration of technical terms.

by making 17 clearing cuts 2.54 cm deep placed 2.54 cm apart. After removing the loose coal, one independent cut was taken at the beginning of a new layer and the test results were recorded. At this point in cutting, there was not interaction taking place, since this was the first cut.

After this, the sequence of dependent or interacting cuts consisted of making 2.54-cm-deep cuts placed 5.08 cm apart from each other. At this spacing, some interaction takes place between each successive cut, so that very little coal is left between the cuts. In this report, cuts with interaction have been classified as dependent or interacting cuts. The last cut in each layer was a clearing cut. No data were recorded for the clearing cut, in order to avoid end effects. Any coal left between the test cuts was removed by clearing cuts placed 2.54 cm apart across the entire layer. After the initial preparation, independent and dependent cuts were taken as described above during each successive layer. The entire test sequence is graphically illustrated by Roepke (11).

The initial experimental design anticipated a total of 36 tests (210 individual test cuts) at each mine site. Only 138 test cuts could be run at mine A, because the coal would break into large chunks when using the 3.17-cm-wide chisel bit. A total of 284 test cuts were run at mine B, because the space was available to conduct the extra tests. The final experimental design for each bit with each depth of cut and angle of attack used two independent cuts and four or more dependent or interacting cuts.

Peak and mean cutting force and peak and mean normal force were computed for each test. The length of cut for all tests was set at 28 cm. For dependent cutting tests, 17 cuts were made at 1.27-cm DOC, 8 cuts at 2.54 cm DOC, and 4 cuts at 5.08 cm DOC. For each dependent cut the S/D ratio was set at 2. Clearing cuts were made at each end of the test face to eliminate end effects. All of the independent clearing cuts were placed 68.6 cm apart. The independent cuts were made on rough surfaces; the depth of these cuts varied along the length of the cut according to the surface roughness, but the values were nominally 1.27 cm, 2.54 cm, and 5.08 cm, as shown in table 1.

MINE A

A total of 138 test cuts were conducted at six sites in Pocahontas No. 3 seam in an underground coal mine located near Filbert, McDowell County, WV. The first and second test sites were located in the rib of the last developed pillar. There was no additional plain surface available at this test site, so the remaining tests were conducted at two different locations in the immediate vicinity of this pillar. Site 1 contained one large layer of bony coal ranging in thickness from 10.16 to 16.5 cm. At the second test site this layer was split into two parts by a thin layer of coal interveining through it. Test sites 3-6 were located on two different pillars. Though all of these sites contained bony coal, it did not pass through the portion of test cuts at which measurements were made. Although no compression tests were made on coal from site 3, visual observations of the coal at this site indicated that it is very soft. At sites 4-6, the coal was fairly uniform and appeared quite strong, with a large number of fractures running through the test material in random directions.

Table 2 shows peak forces for the independent cuts made by the test bits used in mine A. The 75° plumb bob, cigar bit, 90° plumb bob, 2.19-cm radial bit, and 3.17-cm chisel bit required 16, 30, 47, 79, and 73 pct, respectively, of the peak normal force required to make the same depth of cut that was made using the 3.17-cm modified chisel bit. A piece of bony coal, approximately 2.54 cm, was encountered by the radial bit while making the second test cut. Therefore, the test results using the radial bit for the cutting and normal force are higher than they would have been without the presence of bony coal.

Seven tests were also conducted in horizontal direction to determine the peak forces encountered by coal ploughs. It was difficult to make sufficient test cuts in this direction, owing to the presence of bony coal. Occasionally, lances of shale and pyrites were encountered in the path of the bit, forcing the bit to cut around them rather than cut through the hard material. Wherever it was possible to make the cuts in the bony coal, the recorded peak forces were 2 to 3 times higher than for the same types of cuts in the vertical direction, i.e., perpendicular to the shale parting or bony coal.

Test results from horizontal and vertical cuts, with the 75° plumb bob (table 3), show that the magnitude of normal and cutting forces increased in bony coal. No difference was apparent without bony coal present; i.e., in clean coal, between vertical (perpendicular) and horizonal (parallel) cuts (table 3). The IST

TABLE 2. - Peak cutting and normal force data for (2.54-cm-deep) independently spaced cuts (at 55° attack angle) for bits used at test mine A

Bit type	Test cuts	Spacing, cm	Cutting force data		Normal force data	
			Force, N	Pct of modified chisel	Force, N	Pct of modified chisel
Plumb bob:						
75°............	3	12.70	1,481	17.0	2,015	15.5
90°............	2	12.70	4,773	54.9	6,085	46.7
80° cigar........	2	25.40	4,221	48.6	3,936	30.2
Radial, 2.19 cm..	2	12.70	6,112	70.3	10,226	78.5
Chisel, 3.17 cm:						
Standard.......	2	12.70	6,254	72.0	9,523	73.1
Modified.......	2	12.70	8,691	100.0	13,019	100.0

was not able to make cuts in the horizontal direction in partings with the radial bit. In each of three attempts the anchoring bolts bent.

This finding suggests that ploughs making horizontal cuts will be subjected to substantially higher forces than drums making vertical cuts in longwall or room and pillar mining if the bit(s) must cut a large amount of partings with the coal.

At this test location, 101 interacting vertical cuts were made to evaluate the effect of attack angle and depth of cut on performance of the 75° and 90° plumb bobs and the 80° cigar bit and a 2.19-cm radial bit. All tests were made with a S/D ratio of 2 at 1.27, 2.54, and 5.08 cm DOC.

Table 3. - Test results for horizontal and vertical cuts using a 75° plumb bob bit with indefinite spacing[1]

DOC, cm	Force, N	
	Cutting	Normal
Horizontal:		
2.54............	14,213	5,940
	14,212	5,910
	7,445	4,319
5.08............	1,331.40	552.98
	1,079.76	645.05
	1,730.54	1,730.54
	1,074.69	645.07
Vertical:		
2.54............	13,085	6,364
5.08............	1,137	1,256

[1]Attack angle is 45°.

Test results in table 4 show that less force was required by the 75° plumb bob at a 45° attack angle. With a 45° attack angle, this bit had +7.5° rake and clearance angles. Several attempts were made to determine optimum attack angles for other bit types. These efforts were unsuccessful because the coal broke into large chunks along the existing macroscopic cracks, and because flaws were found at each test site. Further rest results show that the cutting forces increased with the increased depth of cut, up to maximum 5.08 cm, DOC used.

At all locations in this mine the wide chisel bit broke the coal into large chunks, thus rendering the test sites unusable for conducting further bit comparison tests.

MINE B

A total of 284 test cuts were conducted in an underground mine located in the Upper Freeport coal seam, located in Garrett County, MD. The main purpose of testing at this location was to determine the cutting efficiency of the 75° and 90° plumb bobs, the cigar bits, and the MTK

TABLE 4. - Test results for 35°, 45°, and 55° attack angles from test mine A

Bit type and attack angle	Test cuts	DOC, cm	Spacing, cm	Force, N	
				Cutting	Normal
80° cigar:					
35°......................	9	2.54	5.08	1,788	1,695
	3	5.08	10.16	2,657	3,892
75° plumb bob:					
35°......................	9	2.54	5.08	1,227	1,112
45°......................	14	1.27	2.54	160	569
	9	2.54	5.08	831	768
	4	5.08	10.16	2,316	2,159
55°......................	19	1.27	2.54	981	1,932
	9	2.54	5.08	1,644	2,342
	4	5.08	10.16	3,031	4,546
90° plumb bob:					
35°......................	9	2.54	5.08	1,459	1,636
55°......................	19	1.27	2.54	509	618
	4	2.54	5.08	948	1,041
	4	5.08	10.16	5,414	3,182

plumb bob bits. Test results from mine B are shown in table 5. The structure of the coal varied from one test site to another. The shale partings or bony coal interveining the first test site ranged in thickness from 5.08 to 11.43 cm and ran through sites 2-4. There was no bony coal present in test site 5. Absence or presence of bony coal (shale) is borne out by large scatter in both test results and the uniaxial compressive strength.

Figures 6 and 7 show that the lines drawn through the mean points for cutting and normal forces for different types of bits overlap each other. Therefore, numerical values for mean peak forces for the same cuts were also plotted to compare bit performance. Figures 8 and 9 show that the average peak forces for different types of bits were found to be 3 to 5 times greater than the average mean forces. The difference in the magnitude of peak forces is also much greater and permits comparison of test bits. Therefore, it can be concluded that for the same S/D ratio, the MTK plumb bob and 90° plumb bob required higher cutting and normal forces than either the 75° plumb bob or the cigar bit. Although both the MTK and the 90° plumb bob bits have a 90° tip angle, the body of the MTK plumb bob is much wider than that of the 90° plumb bob; therefore, the higher values for cutting and normal forces were anticipated for MTK plumb bob.

Figure 8 shows the relationship between the depth of cut and mean cutting and normal forces for the 75° and 90° plumb bobs, the cigar bit, and the MTK plumb bob for a 45° attack angle. Similar data for a 55° attack angle are depicted in figure 9.

The test results for independent cuts are very much analogous to those for dependent cuts, except that these cuts require 3 to 5 times higher cutting and normal forces than the interactive cuts.

The data in figures 8 and 9 show that a 55° attack angle requires higher cutting and normal forces for the same depth of cut and S/D ratio than does a 45° attack angle, with one exception. Test data show that the MTK plumb bob required lower forces at a 55° attack angle than at a 45° angle. This inconsistency may be related to absence of shale parting or bony coal at test sites 4 and 5, where the 55° attack angle tests were performed. Presence of shale partings at test sites 4 and 5 would have required higher cutting forces, so the effect of the 55° attack angle would have been more significant.

A 90° plumb bob at a 45° attack angle provides 0° rake and clearance angles. With any other attack angles, either the rake or clearance angle will become

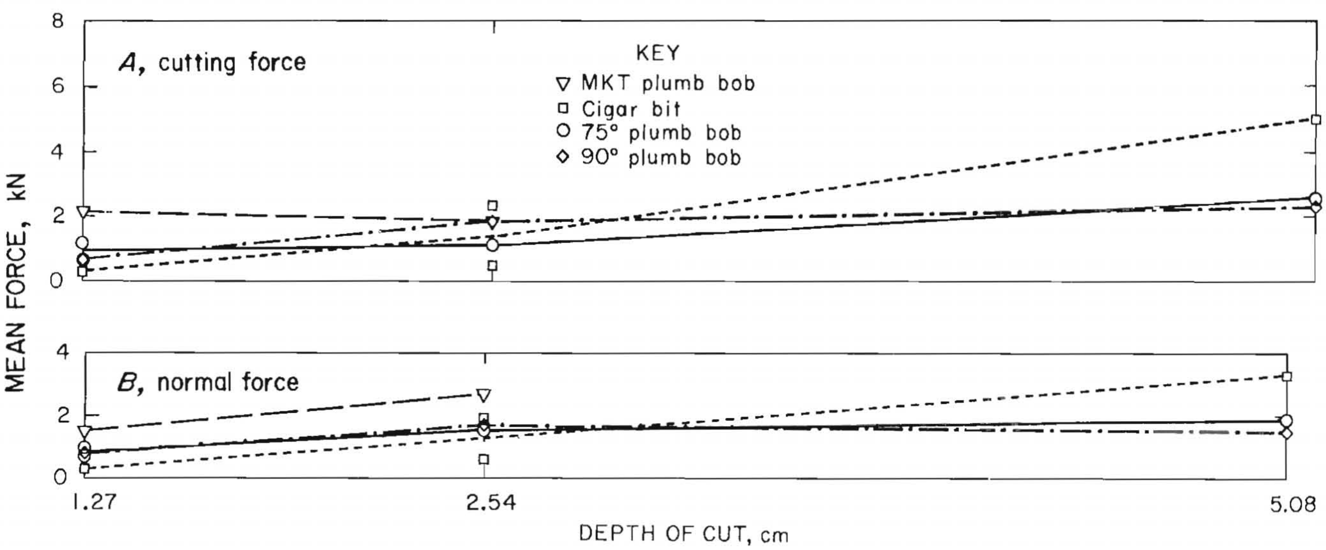

FIGURE 6.—Mean cutting and normal force versus depth of cut with 45° attack angle at mine B.

TABLE 5. - Field test data for different types of bits from test mine B

Bit type and attack angle	Test cuts	DOC, cm	Spacing, cm	Peak force, N		Mean force, N	
				Cutting	Normal	Cutting	Normal
75° plumb bob:							
45°.........................	1	1.27	Ind	304.32	255.50	43.03	43.87
	1	2.54	Ind	507.20	357.70	159.60	141.45
	1	2.54	Ind	557.92	408.80	132.45	164.74
	1	5.08	Ind	760.80	255.50	363.92	136.69
	17	1.27	2.54	557.92	306.60	64.29	67.48
	17	1.27	2.54	1,065.12	511.00	121.06	81.93
	8	2.54	5.08	862.24	664.30	113.55	142.73
	4	5.08	10.16	1,217.28	459.90	252.85	192.94
55°.........................	1	1.27	Ind	456.48	255.50	88.75	43.67
	1	1.27	Ind	1,014.40	306.60	152.46	128.04
	1	2.54	Ind	2,028.80	664.30	335.18	195.84
	19	1.27	2.54	1,369.44	613.20	89.20	121.60
	18	1.27	2.54	1,217.28	664.30	68.94	92.85
	7	2.54	5.08	1,927.36	817.60	186.73	154.27
80° cigar:							
45°.........................	1	1.27	Ind	456.48	255.50	119.98	76.15
	1	1.27	Ind	862.24	209.36	273.08	209.36
	1	2.54	Ind	260.41	182.21		
	1	2.54	Ind	1,724.48	1,022.00	528.22	328.56
	1	5.08	Ind	2,840.32	1,022.00	907.11	543.54
	1	5.08	Ind	557.92	919.80	176.01	370.88
	17	1.27	2.54	202.88	306.60	27.96	28.73
	8	2.54	5.08	1,166.56	664.30	235.88	192.90
	7	2.54	5.08	304.32	357.70	53.91	61.47
	4	5.08	10.16	1,724.48	868.70	506.55	331.93
55°.........................	1	1.27	Ind	710.00	408.80	196.64	108.79
	1	2.54	Ind	456.48	204.40	155.12	96.20
	1	5.08	Ind	1,369.44	613.20	255.94	131.17
	17	1.27	2.54	710.08	306.60	71.17	43.14
	8	2.54	5.08	1,420.16	664.30	209.94	115.05
	4	5.08	10.16	2,688.16	1,124.20	629.09	403.48
90° plumb bob:							
45°.........................	1	1.27	Ind				
	1	2.54	Ind	710.08	613.20	109.17	112.89
	1	5.08	Ind	1,825.92	1,277.50	761.34	441.15
	17	1.27	2.54	456.48	408.80	62.34	83.15
	8	2.54	5.08	862.24	613.20	193.71	164.34
	4	5.08	10.16	1,065.12	715.40	238.11	154.68
55°.........................	1	1.27	Ind	1,724.48	1,226.40	401.87	397.04
	1	2.54	Ind	2,028.80	664.30	335.18	195.84
	17	1.27	2.54	1,217.28	1,022.00	117.73	175.14
	8	2.54	5.08	2,180.96	1,533.00	329.44	313.45
MTK plumb bob:							
45°.........................	1	1.27	Ind	862.24	562.10	190.67	225.59
	1	2.54	Ind				
	1	5.08	Ind	710.08	715.40	246.27	208.62
	17	1.27	2.54	963.68	664.30	219.24	157.62
	8	2.54	5.08	1,470.88	1,073.10	188.60	264.03
55°.........................	1	1.27	Ind	1,166.56	613.20	231.37	306.89
	1	2.54	Ind	2,485.28	1,686.30	554.60	571.60
	17	1.27	2.54	912.96	970.90	41.21	194.12
	7	2.54	5.08	1,775.20	1,328.60	264.56	268.80

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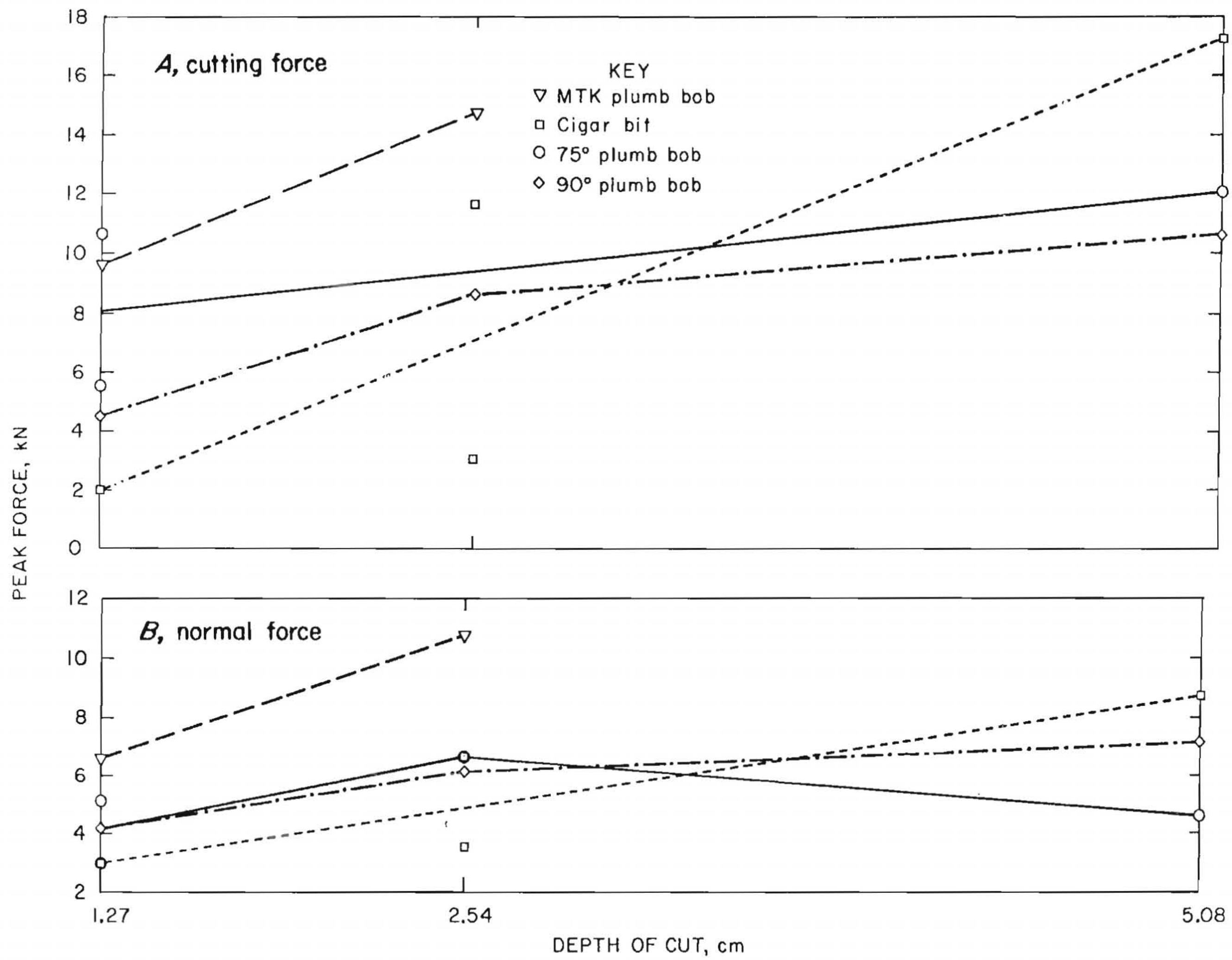

FIGURE 7.—Peak cutting and normal force versus depth of cut with 45° attack angle at mine B.

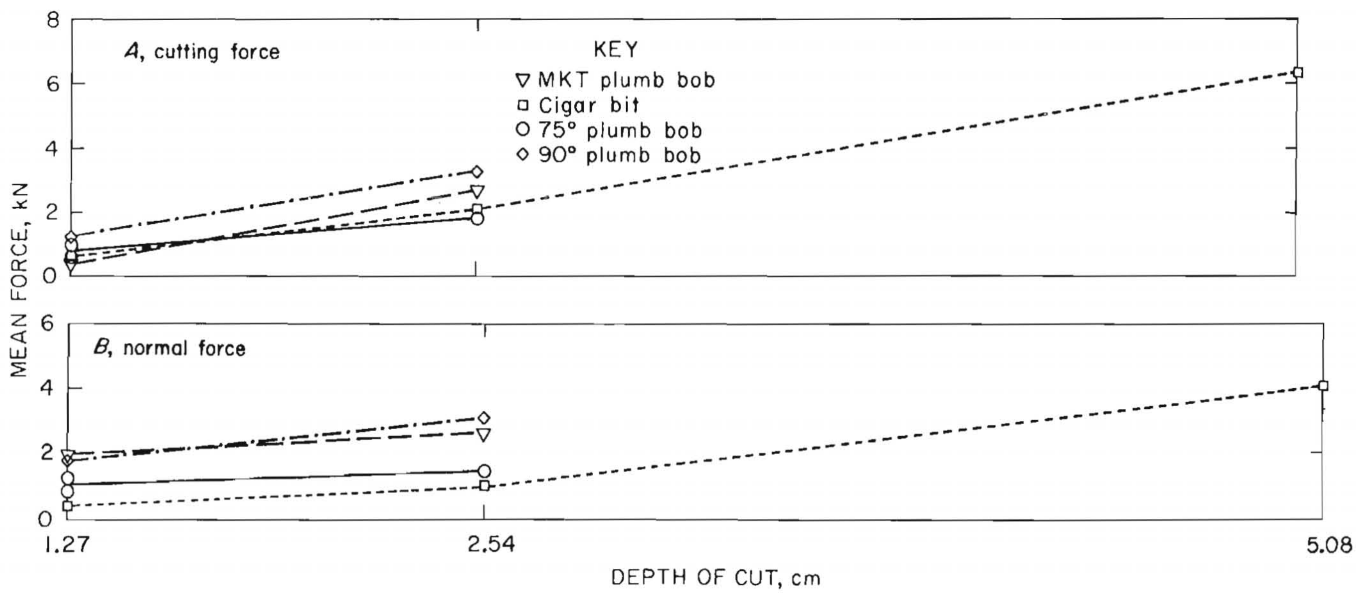

FIGURE 8.—Mean cutting and normal force versus depth of cut with 55° attack angle at mine B.

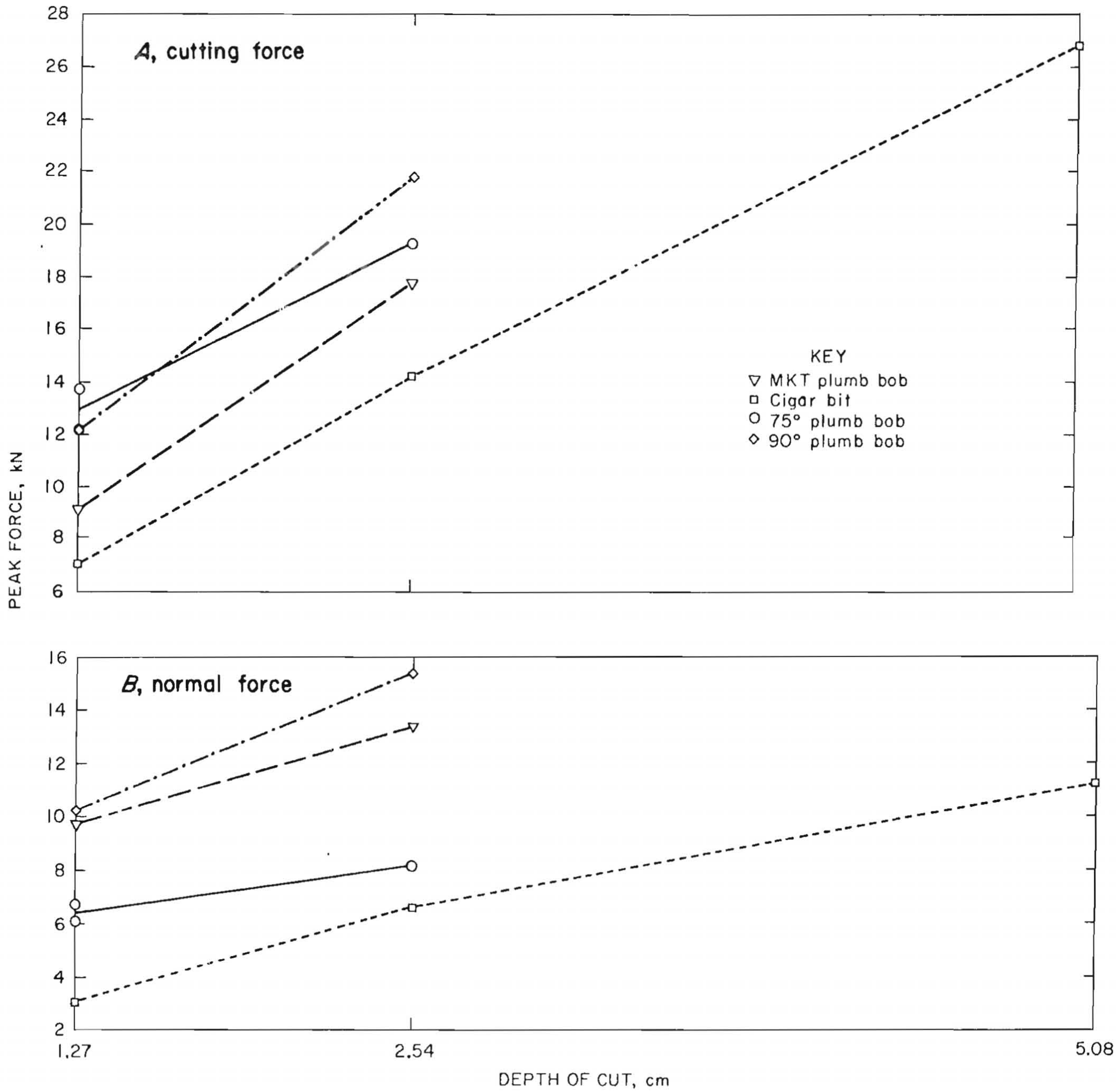

FIGURE 9.—Peak cutting and normal force versus depth of cut with 55° attack angle at mine B.

negative. This appears to be the only possible explanation for the higher cutting and normal forces obtained by using this bit. Independent cuts made for each test series show that peak and mean forces are usually twice those required for interactive cuts.

COMPARISON WITH LABORATORY TESTS

As mentioned in the Introduction, the Bureau has conducted extensive research on the effects of bit geometry on the dust generation and methane ignition in coal cutting. This data bank was screened, and pertinent data were reanalyzed to supplement the in situ field test results.

Hanson and Roepke (3) have shown that a 45° attack angle has lower average cutting force than 35° and 55° attack angles in four different coal types for conical bits tested.

Roepke and Voltz's (11) work shows that radial bits require less cutting force than a 90° plumb bob, but about the same force as a 75° plumb bob. Roepke (10) compared the cutting efficiencies of two types of cigar bits and a 90° plumb bob bit in Illinois No. 6 coal and Pittsburgh coal. His results show that cigar bits required less mean force than the 90° plumb bob bit for each S/D ratio. The two cigar bits required roughly the same magnitude of force. The differences in the mean cutting forces are analogous to the test results from both test mines A and B.

The order of difference shown in table 2 was further confirmed by an additional test series at the Bureau's coal cutting laboratory. Tests conducted in simulated coal (table 6) using the test procedure described by Roepke (10) showed that, while the radial bit required 57 pct less average cutting force than the chisel bit and 62 pct less average cutting force than the 90° plumb bob bit, it produced 15 and 22 pct more coal, respectively. A second laboratory test series was

TABLE 6. - Laboratory comparison test with bits used at mine A on simulated coal using test method[1]

Bit type	Cutting force, N		Normal force, N		Weight of cut, g
	Peak	Av	Peak	Av	
2.19-cm radial	5,614	2,095	2,487	1,099	134.2
	6,103	440	658	133	312.8
	5,026	689	1,192	262	136.0
	5,858	894	1,277	414	157.0
	3,229	480	360	147	98.2
	3,857	351	374	116	232.3
	2,424	512	489	165	84.9
Mean	4,587	780	977	334	165.1
90° plumb bob	5,044	1,886	2,740	1,134	154.8
	5,187	1,730	2,384	1,188	145.0
	5,863	1,766	2,598	1,165	133.1
	5,538	1,931	2,758	1,010	119.8
	6,468	1,544	2,620	832	132.6
	5,574	1,793	2,165	947	128.1
Mean	5,612	1,775	2,544	1,046	135.7
3.17-cm chisel	5,289	1,980	3,301	1,521	131.5
	4,938	1,339	3,358	1,041	205.6
	4,920	1,650	3,425	1,343	169.9
	5,000	1,726	3,390	1,415	120.9
	7,299	1,103	2,309	712	157.8
	4,026	1,116	2,006	698	160.8
	4,639	992	1,984	583	166.9
Mean	5,158	1,404	2,844	1,044	159.0
3.17-cm chisel, dull	9,030	4,346	7,371	3,812	164.7
	10,378	6,032	8,460	5,258	110.5
	11,423	5,369	9,097	4,648	156.9
Mean	10,277	5,249	8,309	4,573	144.0

Test parameters: 1.27-cm DOC, 19-cm cut length, 5.8-cm cut-to-cut spacing, and 45° attack angle.

[1] From Roepke (10).

conducted on simulated coal using the IST. The results (table 7) showed that the radial bit required 47 pct less cutting force than the 90° plumb bob bit and 53 pct less than the 3.17-cm dull chisel bit. The dull (completely worn) chisel bit required 4 to 8 times higher cutting forces than the other test bits.

All three chisel bits used in this investigation were 0.63 cm wider than the radial bit. Therefore, higher forces were anticipated from these bits. The cutting portion of a radial bit is similar in geometry to a point attack bit split along its axis with an additional face area inserted. The radial bit used had design modifications (1) to increase the rake angle by 35° and (2) to alter the attack angle to split the coal in tension along the direction of cut better than a point attack bit does.

As the tensile strength of the material being cut is approximately one-tenth the compressive strength, one may assume that any bit which exploits this weakness will exhibit lower cutting and normal forces. Results of the modification to the radial bit are consistent with this assumption.

TABLE 7. - Laboratory comparison of bits used at test mine A with the aid of IST[1] on simulated coal

Bit type	Force, N	
	Cutting	Normal
Radial...............	749.88	326.19
90° plumb bob........	1,587.07	870.29
3.17-cm chisel:		
Normal.............	1,413.46	1,160.09
Dull:		
1st test.........	4,805.17	4,690.05
2nd test.........	6,082.87	5,754.06

[1]1.27-cm DOC with 2.54-cm spacing and 45° attack angle.

SOURCE OF SCATTER IN THE TEST RESULTS

The coal being mined at test mines A and B was found to be very heterogeneous. At each site, the coal ranged from very soft to very hard in every possible direction. Sometimes the coal was observed to have a blocky structure, while in other areas no structure pattern was apparent. At both mines the shale partings varied widely for each test site. The thickness of shale parting ranged from 0.64 to 16.5 cm. Occasionally, the shale parting was also intertwined with coal and pyrite impurities. At test mine A, there was no obvious cleating, while at test mine A the cleat was 45° to the cutting face. At both mines, there were cracks and flaws running in all directions at random. On a few occasions, while running the tests, large pieces of coal broke along planes of weakness, destroying the usefulness of the test site.

Therefore, it was decided to conduct uniaxial compression tests to determine the extent of scatter in the compressive strength and its relevancy to scatter in test results. Since the test site contained a shale parting running through, it was decided to run tests on coal as well as on shale partings to determine the difference in the strength values for coal and shale partings.

Test results in table 8 show that the compressive strength of coal ranged from 3.6 to 7.1 MPa, and that of shale, from 10.1 to 13.9 MPa. This illustrates that both the coal and shale partings are the contributing causes of scatter in the test results, with a greater contribution being made by the coal itself. Therefore, it can be concluded that the sources of scatter in the test results are due to the hetergeneity of coal itself, to the presence of shale and pyrite, and to cracks and flaws. It has been concluded that the scatter found in the field tests is an inherent coal property and must be accepted as the norm for the two mines.

TABLE 8. - Uniaxial compressive strength of coal and shale partings form test mine B

Sample	Height, cm	Width, cm	Compressive strength, MPa
Coal:			
2321 (1).............	4.042	5.27	6.337
2322 (2).............	3.972	5.65	3.571
2323 (3).............	3.939	5.11	7.123
2324 (4).............	4.959	5.19	5.235
2325 (5).............	4.030	5.977	6.103
2326 (6).............	3.908	5.03	5.415
2327 (7).............	4.006	5.21	5.637
Mean.............	NAp	NAp	5.63±1.11
Shale partings:			
2328 (8).............	4.016	1.999	12.478
2329 (9).............	4.034	1.977	10.119
2330 (10).............	4.019	1.994	11.249
2331 (11).............	3.879	1.998	13.927
Mean.............	NAp	NAp	11.94+1.6

NAp Not applicable.

CONCLUSIONS

The IST proved to be a viable piece of equipment for in situ determination of cutting forces. For each week of testing with the IST, a crew of three employees was needed to conduct about 20 complete test sets (up to 300 test cuts of 28-cm length each). The IST can be used in a mine by mounting it on a pillar face, rib, roof, or floor. It can be used to make cuts in any direction, but it was found to be most effective in making vertical cuts on a pillar face or rib.

The 2.19-cm radial bit cut more coal and required less cutting and much less normal force than the 3.17-cm chisel bit and 90° plumb bob bit.

For interactive cuts, cutting and normal forces, as expected, increased with depth of cut and increasing bit tip angles. When cutting force increased, there was an increase in normal force, but the reverse is not true. An increase in normal force may result in a decrease or no change in cutting force, depending on clearance angle or degree of tool wear.

The width and shape of radial bits were also found to have profound effects on cutting and normal forces. The test results show that both the worn and the new 3.17-cm chisel bits required much higher cutting and normal forces than other shapes of radial bits having 2.54-cm width.

Worn bits required 4 to 5 times higher cutting and normal forces than those required for new or undamaged bits. Normal force increased significantly for the worn chisel bit. Peak force encountered in making independent cuts was found to be ≈3 times higher than that required to make interactive cuts, using a S/D ratio of 2.

Cutting forces increased with the presence of pyrite and pyrites disseminated in shale. The scatter in test results was influenced by cracks and flaws and by the presence of shales, pyrites, and other impurities. Horizontal cuts in bony coal bands (shale) required >3 times the cutting force for the same cuts in a vertical direction. When no bony coal is present, the cutting forces required to make horizontal and vertical cuts were the same for the seams tested. Both rake and clearance angles appear to affect normal and cutting forces.

The field tests verified the previous laboratory tests. The IST has been shown to be a useful tool for in situ measurement of coal cutting forces. Test results indicate that the radial bits perform much better than the point attack bits. Although there is nothing in the literature to support this conclusion, previous unpublished results of tests at the Twin Cities Research Center (TCRC) with British longwall bits gave similar results. Additional field tests will be required to refute or support this finding. Specifications, prints, parts lists, and other details for manufacturing the IST system are available from the Bureau on request.

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