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Cutting Parameters Affecting the Ignition Potential of Conical Bits

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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°C	degree Celsius	ips	inch per second
fpm	foot per minute	lb	pound
ft	foot	pct	percent
gpm	gallon per minute	rpm	revolution per minute
in	inch		

CUTTING PARAMETERS AFFECTING THE IGNITION POTENTIAL OF CONICAL BITS

By Bruce D. Hanson[1]

ABSTRACT

The Bureau of Mines conducted a series of ignition tests with two types of conical bits (plumb bob and pencil) used on continuous mining machines, to determine their ignition potential at various bit speeds, cut depths, and wear conditions. The tests were conducted using single bits mounted on a 34-in-diam drum in a Bureau ignition test facility. The bits impacted blocks of Berea sandstone in a 6.5 pct methane atmosphere at various bit speeds and cut depths. In a new condition, the plumb bob bits were considerably more incendive than the pencil bits, causing ignitions in 32 of 35 tests at 60 rpm, compared with ignitions in 2 of 22 tests for the pencil bits. The results from new bit testing also show that reduction of bit tip velocity to 180 fpm does not eliminate ignition potential. When subjected to progressive wear, bits of both types were more incendive when they were locked in place, unable to rotate, than when they were free to rotate.

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INTRODUCTION

In 1979, a total of 87 methane ignitions caused by continuous mining machines or longwall wearers was reported. These ignitions provide a source for disastrous coal dust explosions. As part of its program to help ensure safer working conditions for miners, the Bureau of Mines is studying the mechanisms of these ignitions. Considerable prior research has been done in this area by the Bureau and others.

Blickensderfer (1),[2] using high-speed photography, found the source of ignitions caused by tangential impacts to be a hot streak on the rock. Coward and Ramsey (2), in a review paper, identified quartzitic sandstone as the coal measure rock that most readily causes ignitions when struck by mining picks. Ramsey (6) reported that ignitions can be caused by hot surfaces having a temperature of 600° to 700° C. Where the hot surface is exposed to convection ventilation, the minimum temperature needed for ignition exceeds 1,000° C.

M'Combe (5) established the importance of the peripheral speed of the mining tool. He found that at tool speeds of 300 to 360 fpm no ignitions occurred, while at 500 fpm frequent ignitions occurred. This is consistent with the work of Blickensderfer (1), which was carried out with samples of various tool materials.

Larson (4) conducted preliminary ignition tests with two types of conical bits at shallow advances (0.0015 in per impact) during fabrication of the ignition test facility at the Bureau's Twin Cities (Minn.) Research Center. Ignitions occurred at a bit tip velocity of 188 fpm with new bits. Tests were also conducted on bits with machined flats, simulating the worst wear conditions. These bits showed an ignition frequency 3 to 5 times greater than that of new bits for all speeds tested.

The purpose of the research reported here was to verify the effect of bit tip velocity and rotation at much deeper cut depths (up to 0.25 in) under cutting conditions more closely resembling those found underground. Commercially obtained bits were tested at various bit tip velocities, cut depths, and rotation modes.

ACKNOWLEDGMENTS

The author thanks Carl F. Wingquist, physicist, Twin Cities Research Center, for designing the electronic control system for the ignition test facility, and V. William Dellorfano, mining engineer technician, Twin Cities, for his assistance in conducting the test program and installing mechanical modifications to the facility.

EXPERIMENTAL PROCEDURES

EQUIPMENT

The test chamber (fig. 1) is 3 by 4-1/2 by 6 ft and is constructed of 1/8-in-thick steel plate. The front side of the chamber is open. A 21- by 27-in opening on the back provides access for equipment maintenance. The cutting drum is powered by four hydraulic motors driven by a 130-gpm pump. The drum can deliver a maximum force of 5,200 lb, and the rotational speed can be varied from 0 to 100 rpm. The maximum bit tip circle diam is 34 in.

The rock sample is mounted on a powered table that can either be translated across the drum or advanced into the drum. Translating across the drum produces constant-depth, constant-arc-length cuts similar to those produced by a

[2] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

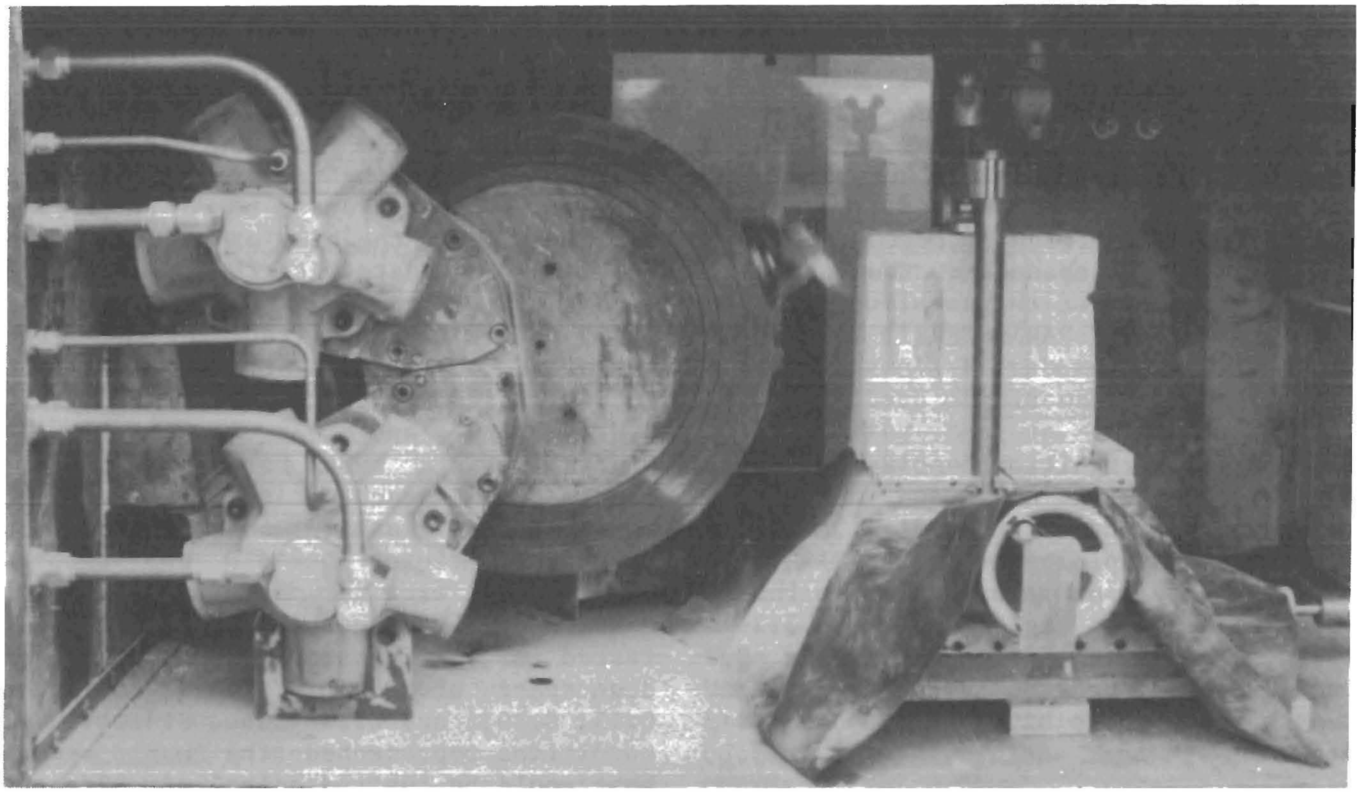

FIGURE 1. - Ignition test chamber, showing drum with test bit during cutting of sample.

mining machine sumping into coal seam parallel to the roof. Advancing into the drum produces cuts with increasing arc lengths in the same kerf. The table is driven by two dc stepping motors that are programmable and remotely controlled. The table can be translated past the drum at a speed between 0 and 3/4 ips and advanced toward the drum at a speed between 0 and 3/8 ips.

The open side of the chamber is sealed with 2-mil polyethylene sheet. Flaps are positioned to vent the explosion to the outside. Natural gas (89 pct methane) is introduced into the chamber through a solenoid valve controlled in the instrumentation room. A 6.5 pct methane-air mixture is used for all ignition tests. An electric spark is used to explode the air-methane mixture if test conditions do not produce an ignition.

During all methane ignition tests, the cutting (tangential) force, work performed per impact, and percent methane in the test chamber are recorded on a multichannel strip chart recorder.

Cutting force is recorded from a differential pressure transducer connected across the hydraulic motors that drive the cutterhead. The pressure drop across the motors is related to the torque output at the cutterhead. This relationship was established by calibration with a load cell.

Work performed, or energy absorbed per impact, is determined by electronically recording the time integral of the cutting force signal and multiplying this result by the cutting radius and angular velocity of the cutter head.

Angular velocity, or revolutions per minute, is monitored by a magnetic gear tooth sensor near a drive gear. The pulse output of the sensor drives a frequency-to-voltage converter, which in turn drives a revolution-per-minute-scaled meter.

Methane concentration is monitored continuously by a methanometer in the test chamber. This sensor is a Wheatstone bridge in which the temperature and, therefore, the resistance of one of the arms depends on the concentration of methane in the atmosphere. The bridge signal is amplified to drive a meter movement and one channel of the recorder.

TEST PARAMETERS

New Bits

Two types of ignition testing were performed, trenching cuts and transverse cuts, on two types of conical bits, a pencil and a plumb bob (fig. 2). The carbide insert on the pencil bit has a 70° included tip angle and a 0.312-in diam. The plumb bob insert has a 90° included tip angle and a 0.356-in diam. The shanks of both bits have 30° included angles. The end of the pencil bit shank has a 0.375-in diam, and the end of the plumb bob shank has a 0.563-in diam.

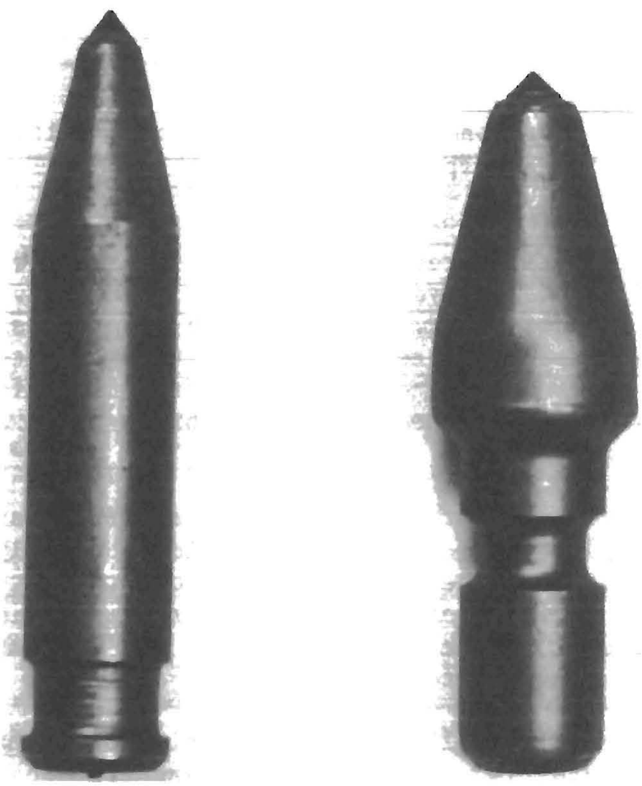

FIGURE 2. - Bit types tested, pencil (left) and plumb bob. The pencil bit is approximately 5 in long.

Since the system was being modified during the testing program, the test parameters were selected based on system capabilities at the time of testing. The trenching cut tests with the pencil bits were run at 60 rpm and an advance rate of 0.005 in per impact. Trenching cuts with the plumb bob were run at drum speeds of 20, 40, and 60 rpm[3] and advance rates of 0.015, 0.020, and 0.025 in per impact. Generally, six tests were run on one face, two at each of the drum speeds. Advance rate was held constant on each face.

The pencil-type bit was initially tested in the transverse mode using a drum speed of 60 rpm with cut depths of 0.15, 0.20, and 0.25 in. Since these conditions represented the most severe that could be run and only 2 of 22 tests produced ignitions, no further pencil bit testing was conducted. Preliminary tests (data shown in table A-4 in the appendix) with the plumb bob bit were conducted at a drum speed of 60 rpm and cut depths of 0.05, 0.10, and 0.15 in. The results were used to develop a more sophisticated experimental design. A three-factor design was chosen, with cut depth (0.05, 0.10, and 0.15 in), drum speed (20, 40, and 60 rpm) and final kerf length (4.5, 6.4, and 7.8 in) as the three variables. Final kerf length was chosen as a variable to minimize the number of sandstone blocks necessary for the test series. A block confounding scheme (3) was used to systematically control any differences in the test results due to variations in the sandstone samples. The experimental configuration is shown in table 1, where it can be seen that three different sets of conditions were run on each face of the sandstone sample.

[3] 20, 40, and 60 rpm are equivalent to 180, 360, and 540 fpm, respectively.

TABLE 1. - Experimental design for transverse plumb bob tests

Cut depth, in	Kerf length, in	Face designation at drum speed of--		
		20 rpm	40 rpm	60 rpm
0.05.....	4.5	1	4	7
	6.4	2	5	8
	7.8	3	6	9
0.10.....	4.5	5	8	2
	6.4	6	9	3
	7.8	4	7	1
0.15.....	4.5	9	3	6
	6.4	7	1	4
	7.8	8	2	5

Prior to each test, an initial smooth circular cut was made across the entire face. The length of this initial cut depended on the cut depth and final kerf length of the test condition. The transverse motion of the sandstone was stopped immediately upon ignition. If the ignition occurred in seven or fewer impacts, the bit was replaced and the test was repeated, starting at the opposite edge of the face. Individual cuts on each test were spaced 1/2 in apart. A test was one pass across the face, usually consisting of 22 to 23 cuts or impacts. Since the experimental design was repeated twice, each test condition had two to four replications.

Worn Bits

The worn bit portion of this work looked at the ignition characteristics of six bit types and rotational modes under progressive wear. The plumb-bob and pencil bits were tested both in a locked (unable to rotate) mode and a free mode. Two other bits were tested, a plumb bob with a double-angled carbide tip and a "mushroom"-tip bit, which were developed at the Bureau's Pittsburgh (Pa.) Research Center. Both of these bits were free to rotate during testing. Each individual test consisted of two phases: the bit was first subjected to a predetermined amount of cutting, and then an ignition test was performed. The wear phase consisted of 10 transverse passes (16 impacts per pass) at a 0.05-in cut depth. This produced 940 in of lineal cutting. Methane was then introduced into the chamber, and an ignition test was conducted. The ignition test was run at a cut depth of 0.10 in. Three transverse passes constituted the ignition test. This testing procedure was repeated up to eight times using the same bit. Each combination of bit type and rotational mode was replicated twice.

DISCUSSION OF RESULTS

The two types of ignition testing that were used on the new bits, trenching and transverse, have several differences that make direct comparison of results difficult. The trenching cuts were made starting with a flat face. As the test progressed, the cut's kerf length increased. The transverse cuts had a constant kerf length. The shallow advance rates used in the trenching cuts did not produce any "breakout" of the rock past the sides of the bit, as did the deeper cuts of the transverse tests. Consequently, in trenching, after the kerf reached a certain depth the sides of the bit began to rub against the side of the kerf. As the kerf deepened, the contact area between the bit and the sandstone increased. Transverse cuts had a constant contact area.

Results for the pencil-type bit are shown in tables 2 and 3. The trench cuts resulted in ignitions in approximately half the tests. Most of the ignitions occurred after 100 or more impacts, where contact between the sides of the bit shank and the sandstone kerf may have been a factor. Tests in the transverse mode produced only 2 ignitions in 22 tests, both of which occurred at the 0.25-in cut depth.

TABLE 2. - Summary of pencil-trench cut tests

Number of impacts to ignition	Number of tests
0-50..................	1
51-100................	3
101-150...............	4
151-200...............	6
201-250...............	2
No ignition...........	17

NOTE.--Tests were run at 60 rpm and an advance rate of 0.005 in per impact.

TABLE 3. - Summary of pencil-transverse cut tests

(Drum speed, 60 rpm)

Cut depth, in	Spacing, in	Number of tests	Number of ingitions
0.250.....	0.75	8	2
0.200.....	.60	6	0
0.150.....	.50	3	0
	.45	5	0
Total..	NAp	22	2

NAp Not applicable.

The plumb bob-trench cut tests (table 4) show little or no difference in ignition potential due to the variables of speed and advance rate. All test conditions, except 20 rpm at a 0.020-in-per-impact advance rate, resulted in a high percentage of ignitions. The only change that was noted was in the tests run at an advance rate of 0.015 in per impact, where the number of impacts required for ignition increased as drum speed decreased. This is shown graphically in figure 3. The average number of impacts to ignition rose from 5.8 at 60 rpm to 8.2 at 40 rpm and 22.1 at 20 rpm.

TABLE 4. - Summary of plumb bob-trench cut tests

Drum speed, rpm	Advance rate, in per impact	Number of tests	Number of ignitions
60.........	0.025	6	6
	.020	7	7
	.015	17	17
40.........	.025	6	4
	.020	7	7
	.015	16	16
20.........	.025	6	5
	.020	7	2
	.015	16	13

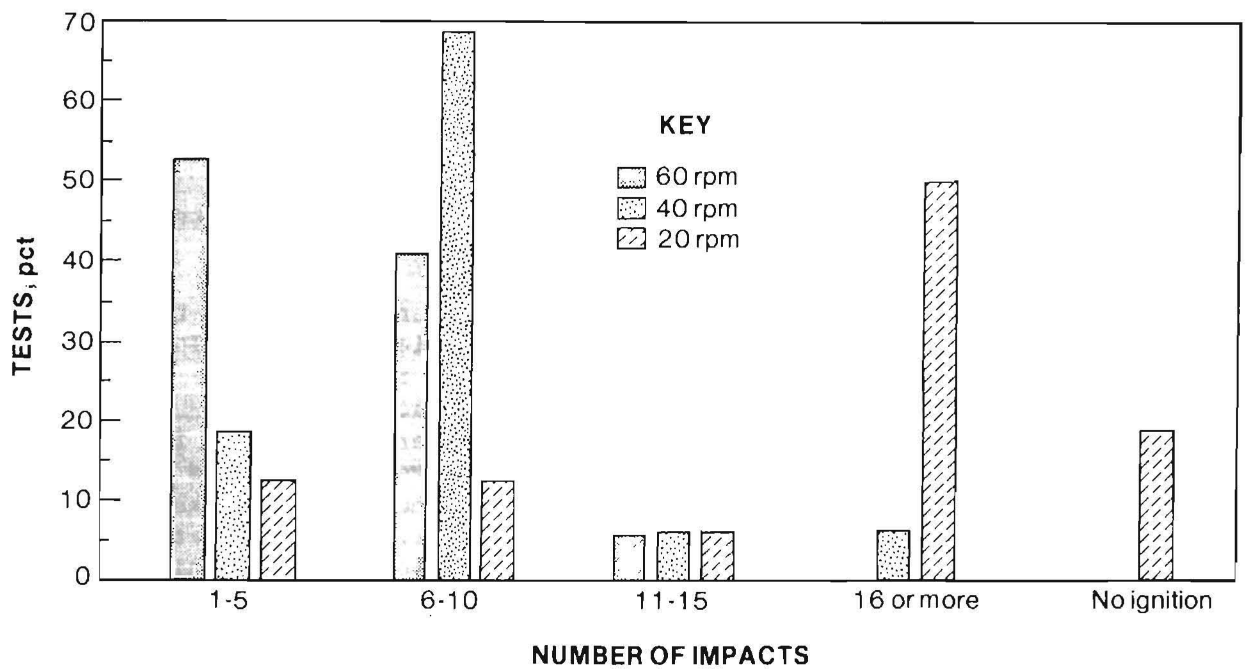

FIGURE 3. - Distribution of number of impacts to ignition for new plumb bobs tested in trenching mode at 0.015-in advance per impact.

The results from the plumb bob-transverse cut test series are shown in table 5. Drum speed was the most important factor affecting ignition potential. At 20 rpm only 10 of 23 tests resulted in ignitions, while at 40 and 60 rpm the proportion was much higher (25 of 32 and 32 of 35). The number of impacts required to produce an ignition also increased as the drum speed decreased. The largest difference was between 40 and 20 rpm, as shown graphically in figure 4. Cut depth also appeared to affect ignition potential, although not to the same extent as drum speed. At a cut depth of 0.05 in, 62 pct (16 of 26) of the tests resulted in ignitions, while at 0.10 and 0.15 in, 85 pct (28 of 33) and 74 pct (23 of 31) of the tests resulted in ignitions.

The influence of normal force on ignition potential could not be determined directly, since normal force measurements were not made. The average tangential cutting force was measured and can be used to indirectly assess the effect of normal force, since the two forces should vary proportionally. The data were searched for pairs of tests that were run on the same face at the same cut depth, drum speed, and final kerf length, where one test produced an ignition and the other did not. Six pairs meeting those criteria were found and are listed in table 6. In three of these pairs, the average cutting force for the ingition-producing and the nonignition tests were approximately the same. In the remaining three pairs, the average cutting force for the ingition-producing test was approximately twice that of the nonignition-producing test.

The results for the worn bit study are shown in table 7. Of the bits tested in the free mode, the mushroom and double-angled bits showed slightly better ignition characteristics. For the two bit types tested in both the locked and free modes, the locked bits produced ignitions sooner than those that were free to rotate. The locked plumb bob and locked pencil types did show different behavior once the first igntion occurred. Once a pencil bit caused an ignition, it continued to cause ignitions, but the plumb bob bit did not always exhibit this behavior.

Analysis of cutting forces revealed no relationship between the amount of wear and the cutting forces.

TABLE 5. - Summary of plumb bob-transverse cuts

Drum speed, rpm	Cut depth, in	Number of ignitions	Number of tests	Number of ignitions to number of tests at final kerf length of--		
				4.5 in	6.4 in	7.8 in
60................	0.15	11	12	4/4	3/4	4/4
	.10	11	12	4/4	4/4	3/4
	.05	10	11	2/3	4/4	4/4
40................	.15	10	12	2/4	4/4	4/4
	.10	11	12	3/4	4/4	4/4
	.05	4	8	0/2	2/3	2/3
20................	.15	2	7	0/2	2/3	0/2
	.10	6	9	1/2	3/4	2/3
	.05	2	7	0/2	2/3	0/2

NOTE.--All tests run at a spacing of 0.50 in.

TABLE 6. - Comparison of average cutting force for ignition-producing and nonignition tests

Speed, rpm	Cut depth, in	Final kerf length, in	Average cutting force, lb	
			Ignition	No ignition
60.........	0.10	7.8	960	512
	.15	6.4	1,040	456
40.........	.15	4.5	600	792
	.15	4.5	1,024	1,160
	.10	4.5	1,144	464
20.........	.10	6.4	1,168	1,072

TABLE 7. - Test results for worn bit study, impacts to ignition

Test	Plumb bob				Pencil				Mushroom		Double-angled	
	Locked		Free		Locked		Free		1	2	1	2
	1	2	1	2	1	2	1	2				
1...............	39N	39N	41N	45N	46N	31	46N	48N	45N	48N	47N	48N
2...............	43N	45N	44N	42N	47N	25	45N	49N	48N	48N	46N	45N
3...............	43N	48N	35N	42N	48N	31	48N	48N	45N	44N	46N	45N
4...............	8	41N	34N	42N	48N	13	48N	48N	48N	39N	42N	43N
5...............	20	6	39N	45N	1	NR	48N	48N	47N	39N	46N	46N
6...............	40N	46N	5	40N	27	NR	48N	6	47N	31	43N	45N
7...............	15	44N	1	43N	11	NR	45N	15	45N	45N	43N	45N
8...............	17	43N	NR	NR	24	NR	45N	48N	43N	45N	43N	45N

N No ignition.
NR Test not run.

NOTE.--Each test had 2 replications, designated 1 and 2 in the table headings.

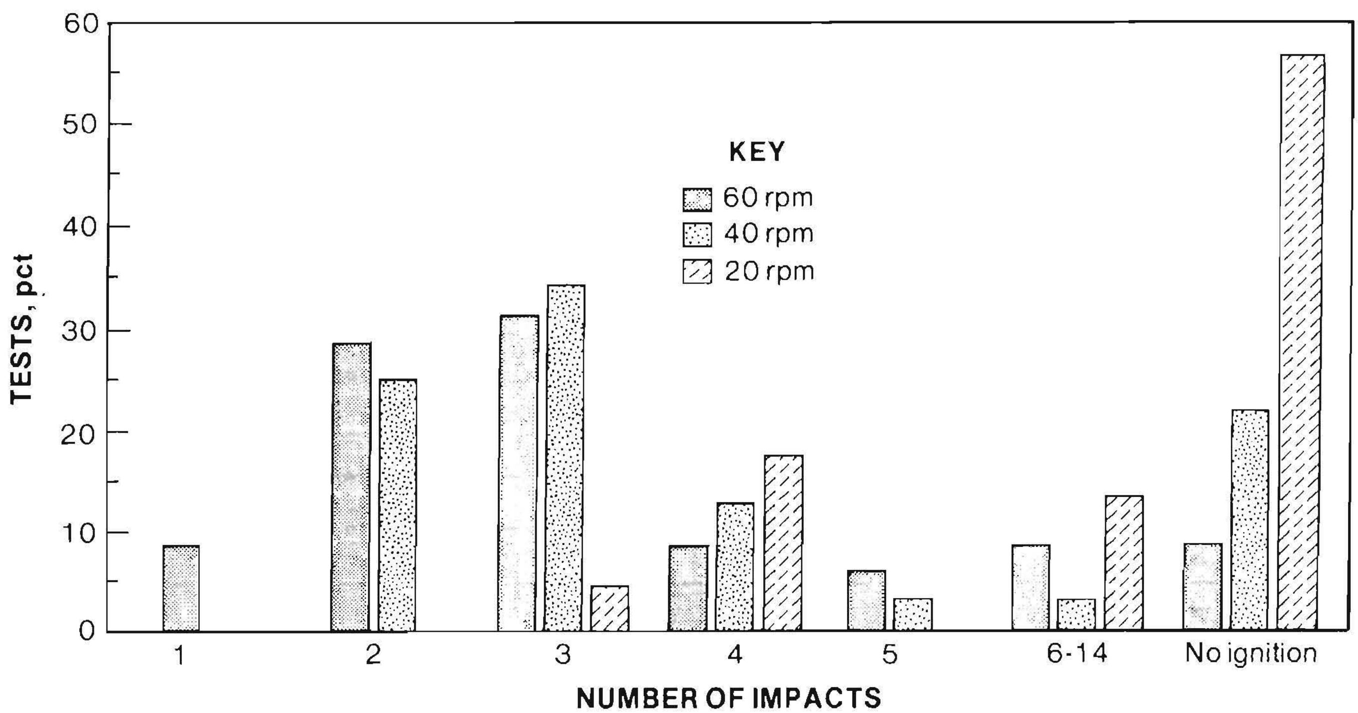

FIGURE 4. - Distribution of number of impacts to ignition for new plumb bobs in transverse testing mode.

SUMMARY AND CONCLUSIONS

The three most important findings of this work are (1) reducing the bit tip velocity did not totally eliminate the potential for an ignition, (2) the geometry of bit tip area (carbide tip and the immediate shank) was an important factor in the ignition potential of new bits, and (3) conical bits that are able to rotate during cutting can be subjected to more wear before becoming incendive than can bits that are locked in. Tests conducted with the plumb bobs produced ignitions at a bit velocity of only 180 fpm (20 rpm on a 34-in-diam drum). The importance of the bit tip area geometry is illustrated by the marked difference in ignition potential between the pencil and plumb bob bits. The pencil bit, which produced very few ignitions, has a tip geometry such that the carbide insert cuts clearance for the steel shank. The plumb bob used in this study, which produced a very high percentage of ignitions, has a tip geometry such that the carbide insert did not totally cut clearance for the steel shank. The contact between the sandstone and steel shank can be corrected in one of two ways: through design of the bit and good quality control during manufacturing to insure the carbide tip is properly centered, and by increasing the attack angle so that clearance between the sandstone and the bit shank is obtained.

REFERENCES

1. Blickensderfer, R., D. K. Deardorff, and J. E. Kelley. Incendivity of Some Coal-Cutter Materials by Impact-Abrasion in Air-Methane. BuMines RI 7930, 1974, 20 pp.

2. Coward, H. F., and H. T. Ramsey. Ignition of Firedamp by Means Other Than Electricity and Explosives: A Review. SMRE Res. Rept. 231, October 1965, 64 pp.

3. Hicks, C. R. Fundamental Concepts in the Design of Experiments. Holt, Rinehart, and Winston, Inc., New York, 1964, 293 pp.

4. Larson, D. A., V. W. Dellorfano, C. F. Wingquist, and W. W. Roepke. Preliminary Evaluation of Bit Impact Ignitions of Methane Using a Drum-Type Cutting Head. BuMines RI 8755, 1983, 23 pp.

5. M'Combe, J. Sparking of Coal-Cutter Pick Tool Steel in Explosive Firedamp Mixtures. J. Royal Tech. Coll., Glasgow, 1933, v. 3, p. 173.

6. Ramsey, H. T. Ignition by Impact and Friction. Sec. 3 of A Summary Account of the Manner and the Frequency of Ignition of Firedamp in British Coal Mines. Min. Eng. (London), v. 60, September 1965, p. 732.

APPENDIX.--TEST DATA

TABLE A-1. - Results of pencil-trench cut tests

Number of impacts to ignition	Number of impacts without ignition
31	180
64	189
78	193
93	200
104	200
120	201
137	201
143	202
156	203
163	203
164	205
182	205
196	206
198	209
214	222
219	223
	236

NOTE.--Tests were run at 60 rpm and an advance rate of 0.005 in per impact.

TABLE A-2. - Results of pencil-transverse cut tests

(Drum speed, 60 rpm)

Spacing, in	Number of impacts to ignition	Average force, lb
0.25-IN CUT DEPTH		
0.75.........	7	664.0
	13N	632.0
	2	700.0
	15N	496.0
	19N	568.0
	18N	504.0
	15N	410.7
	14N	394.7
0.20-IN CUT DEPTH		
0.60.........	16N	336.0
	16N	448.0
	19N	400.0
	18N	304.0
	18N	352.0
	18N	560.0
0.15-IN CUT DEPTH		
0.50.........	20N	279.6
	23N	314.8
	22N	338.2
0.45.........	23N	312.0
	22N	416.0
	23N	376.0
	25N	640.0
	24N	480.0

N No ignition.

TABLE A-3. - Results of plumb bob-trench cut tests, number of impacts to ignition

Advance rate, in per impact	60-rpm drum speed	40-rpm drum speed	20-rpm drum speed
0.025............	14	49N	8
	2	2	6
	4	3	3
	5	3	41N
	3	42N	5
	3	3	5
0.020............	6	3	4
	6	3	51N
	14	6	41N
	3	4	47N
	12	7	7
	4	40	50N
	6	6	42N
0.015............	4	6	21
	5	5	40
	7	9	19
	4	10	23
	6	7	24
	3	6	5
	4	5	48
	4	8	12
	8	6	7
	3	11	18
	6	6	65N
	3	8	61N
	15	26	56
	6	4	5
	4	7	68N
	8	7	9
	5		

N No ignition.

TABLE A-4. - Results of preliminary plumb bob-transverse cut tests

(Drum speed, 60 rpm)

Spacing, in	Number of impacts to ignition	Average force, lb
0.100-IN CUT DEPTH		
0.50.........	3	616.0
	3	728.0
	2	544.0
	10	820.0
	23N	636.0
	16N	392.0
	3	732.0
0.075-IN CUT DEPTH		
0.75.........	7	556.0
	3	492.0
0.50.........	21N	484.7
	6	272.0
	4	659.0
	9	407.0
	4	570.0
	23N	388.0
	1	420.0
0.050-IN CUT DEPTH		
0.50.........	22N	140.0
	21N	264.0
	23N	204.0

N No ignition.

TABLE A-5. - Results of plumb bob-transverse cut tests, at 60-rpm drum speed

Final kerf length, in	Number of impacts to ignition	Average force, lb
0.15-IN CUT DEPTH		
7.8..........	7	800.0
	3	680.0
	3	1,080.0
	10	976.0
6.4..........	3	1,040.0
	18N	456.0
	4	984.0
	4	864.0
4.5..........	3	912.0
	2	1,016.0
	2	1,240.0
	13	1,224.0
0.10-IN CUT DEPTH		
7.8..........	3	728.0
	2	536.0
	3	960.0
	14N	512.0
6.4..........	2	1,032.0
	3	968.0
	3	776.0
	2	1,000.0
4.5..........	2	860.0
	4	1,088.0
	3	1,064.0
	3	1,224.0
0.05-IN CUT DEPTH		
7.8..........	1	500.0
	1	356.0
	5	392.0
	2	480.0
6.4..........	1	408.0
	2	476.0
	5	412.0
	2	540.0
4.5..........	3	468.0
	2	568.0
	22N	328.0

N No ignition.

TABLE A-6. - Results of plumb bob-transverse cut tests, at 40-rpm drum speed

Final kerf length, in	Number of impacts to ignition	Average force, lb
0.15-IN CUT DEPTH		
7.8..........	6	1,024.0
	5	784.0
	3	984.0
	4	1,032.0
6.4..........	4	1,024.0
	3	976.0
	3	1,008.0
	2	1,240.0
4.5..........	3	1,024.0
	17N	1,160.0
	2	600.0
	19N	792.0
0.10-IN CUT DEPTH		
7.8..........	2	624.0
	3	1,056.0
	3	944.0
	4	952.0
6.4..........	4	768.0
	2	872.0
	3	0.0
	3	1,000.0
4.5..........	3	1,144.0
	19N	464.0
	2	1,120.0
	3	744.0
0.05-IN CUT DEPTH		
7.8..........	2	300.0
	2	280.0
	21N	516.0
6.4..........	23N	340.0
	2	520.0
	3	572.0
4.5..........	22N	328.0
	22N	208.0

N No ignition.

TABLE A-7. - Results of plumb bob-transverse cut tests, at 20-rpm drum speed

Final kerf length, in	Number of impacts to ignition	Average force, lb	Final kerf length, in	Number of impacts to ignition	Average force, lb
0.15-IN CUT DEPTH			0.05-IN CUT DEPTH		
7.8..........	23N	1,048.0	7.8..........	22N	436.0
	21N	912.0		21N	408.0
6.4..........	3	960.0	6.4..........	5	692.0
	2	624.0		4	528.0
	20N	1,264.0		22N	396.0
4.5..........	22N	896.0	4.5..........	20N	412.0
	22N	1,080.0		22N	640.0
0.10-IN CUT DEPTH					
7.8..........	23N	648.0			
	7	984.0			
	4	536.0			
6.4..........	4	1,168.0			
	5	880.0			
	4	1,168.0			
	16N	1,072.0			
4.5..........	23N	784.0			
	14	1,016.0			

N No ignition.

TABLE A-8. - Results of worn bit tests

Test	Replication 1: Number of impacts to ignition	Replication 1: Average force	Replication 2: Number of impacts to ignition	Replication 2: Average force
PLUMB BOB--LOCKED				
1	39N	914	39N	944
2	43N	959	45N	1,016
3	43N	895	48N	808
4	8	809	41N	760
5	20	903	6	1,312
6	40N	766	46N	936
7	15	1,071	44N	904
8	17	1,088	43N	864
PLUMB BOB--FREE				
1	41N	656	45N	760
2	44N	696	42N	728
3	35N	1,056	42N	856
4	34N	1,112	42N	912
5	39N	1,024	45N	1,048
6	5	1,088	40N	720
7	1	896	43N	704
PENCIL--LOCKED				
1	46N	473	31	864
2	47N	598	25	904
3	48N	576	31	784
4	48N	569	13	824
5	1	720		
6	27	591		
7	11	819		
8	24	729		

Test	Replication 1: Number of impacts to ignition	Replication 1: Average force	Replication 2: Number of impacts to ignition	Replication 2: Average force
PENCIL--FREE				
1	46N	648	48N	620
2	45N	668	49N	496
3	48N	640	48N	392
4	48N	544	48N	576
5	48N	712	48N	584
6	48N	636	6	824
7	45N	608	15	672
8	45N	684	48N	616
MUSHROOM				
1	45N	728	48N	600
2	48N	704	48N	764
3	45N	680	44N	782
4	48N	592	39N	783
5	47N	688	39N	778
6	47N	704	31	734
7	45N	608	45N	867
8	43N	672	45N	697
DOUBLE-ANGLED				
1	47N	536	48N	758
2	46N	560	45N	677
3	46N	592	45N	629
4	42N	592	43N	627
5	46N	584	46N	559
6	43N	664	45N	701
7	43N	636	45N	612
8	43N	628	45N	569

N No ignition.

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