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BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft/min	foot per minute	mm	millimeter
gal/min	gallon per minute	pct	percent
Hz	hertz	psi	pound (force) per square inch
in	inch	psig	pound (force) per square inch, gauge
lbf	pound (force)		

EVALUATION OF MODERATELY HIGH-PRESSURE WATER-JET ASSIST APPLIED TO SINGLE DRAG BIT TOOLS

By J. L. Thompson,[1] E. D. Thimons,[2] and R. J. Timko[3]

ABSTRACT

The U.S. Bureau of Mines conducted a water-jet-studies program using a single-bit, in-seam test unit to determine effects of a moderately high-pressure (up to 10,000 psi) water-jet-assisted cutting system on rock weakening. The in-seam test unit was used to obtain cutting force data in tangential, normal, and side force directions.

Conical continuous miner and radial longwall miner bits were used to penetrate test samples of coalcrete, Berea sandstone, and Indiana limestone with unconfined compressive strengths of 4,600, 8,000 and 10,000 psi, respectively. Depth of cut in the coalcrete tests was 1 in, with 2-in cut spacing (2:1 ratio). Because of cutting equipment and instrumentation limitations, the Berea sandstone and Indiana limestone were cut using a 0.5-in depth of cut and 2-in spacing (4:1 ratio). Bit velocity was maintained at 25 ft/min for both bits. Each specimen and bit type was tested using 0.3-, 0.6-, 0.8-, and 1.0-mm-diam nozzles and water-jet pressures of 2,500, 5,000, 7,500, and 10,000 psig.

Water-jet-assisted cutting decreased average resultant conical and radial longwall bit cutting forces 6.4 and 8.4 pct in coalcrete, 5.5 and 1.4 pct in Berea sandstone, and 2.0 and 5.5 pct in Indiana limestone. Slight reductions of power requirements resulting from water-jet assist were ascertained during these experiments.

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INTRODUCTION

The objective of the Bureau's water-jet-studies using a single-bit in-seam test unit is to determine the effect of a moderately high-pressure water-jet-assisted cutting system on rock weakening, as manifest by average and peak tool bit forces and mechanical power requirements.

The research used moderately high pressure (up to 10,000 psi) solid water streams, directed close to the cutting bit tip. This technique was considered a possible method to decrease average and peak cutting forces generated by drag bits used for coal and coal measure rocks. The bits used were the two most frequently used in coal mining–the conical plumb bob bit, used on continuous room-and-pillar mining machines, and the radial attack bit, used on longwall shearers. Testing was performed at the Bureau's Mining Equipment Test Facility (METF) at Bruceton, PA.

The coalcrete (a cast-in-place mixture of coal, cement, and fly ash), Berea sandstone, and Indiana limestone test samples were subjected to 72 cuts each with the conical bit and the radial attack longwall bit, using all combinations of 0.3-, 0.6-, 0.8-, and 1.0-mm-diam nozzles and jet pressures of 250, 2,500, 5,000, 7,500 and 10,000 psig.

The triaxial load cell mounted on the in-seam tester was calibrated using the calibration test fixture after each of the three test sequences (coalcrete, sandstone, and limestone). This was done to create a calibration history of the load cell in order to detect transducer degradation.

TEST APPARATUS

The apparatus used for this evaluation included an in-seam test unit; a four-pillar dynamometer; a calibration test fixture; an instrument system to measure and record cutting forces, water pressure and flow rate; and a VAX 11/780[4] computer system.

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

IN-SEAM TESTER

The in-seam tester (IST) (fig. 1) is a semiportable, hydraulically actuated, single-bit cutting machine that can move the test bit in three orthogonal directions in preparation for a vertical, upward only, cut. The following are the IST specifications.

Figure 1.—In-seam tester.

Length of stroke (max)	in	56
Cutter velocity (max)	ft/min	26
Nozzle standoff	in	3
Nozzle design		Leech and Walker (13° included angle).
Water pressure range	psig	0-10,000
Water flow rate range	gal/min	0-5
Hydraulic pressure range	psig	0-5,000
Dynamometer		Triaxial strain gauge type.

CALIBRATION TEST FIXTURE

The calibration test fixture (fig. 2) is mounted on the IST using a specially fabricated bracket to properly position the fixture next to the dynamometer. The fixture permits the user to calibrate the triaxial load cell while it is mounted on the IST by using a calibrated uniaxial load cell in series with a hydraulic cylinder that applies a force to a simulated cutting bit mounted in the bit fixture. Calibration is accomplished by applying a load-cell-identified force along each of the three axes. The force output, indicated by the microstrain levels generated by the strain-gage bridges mounted on the dynamometer, is then recorded.

FOUR-PILLAR DYNAMOMETER

The microstrain displacement of each pillar of the four-pillar dynamometer is algebraically summed to identify the

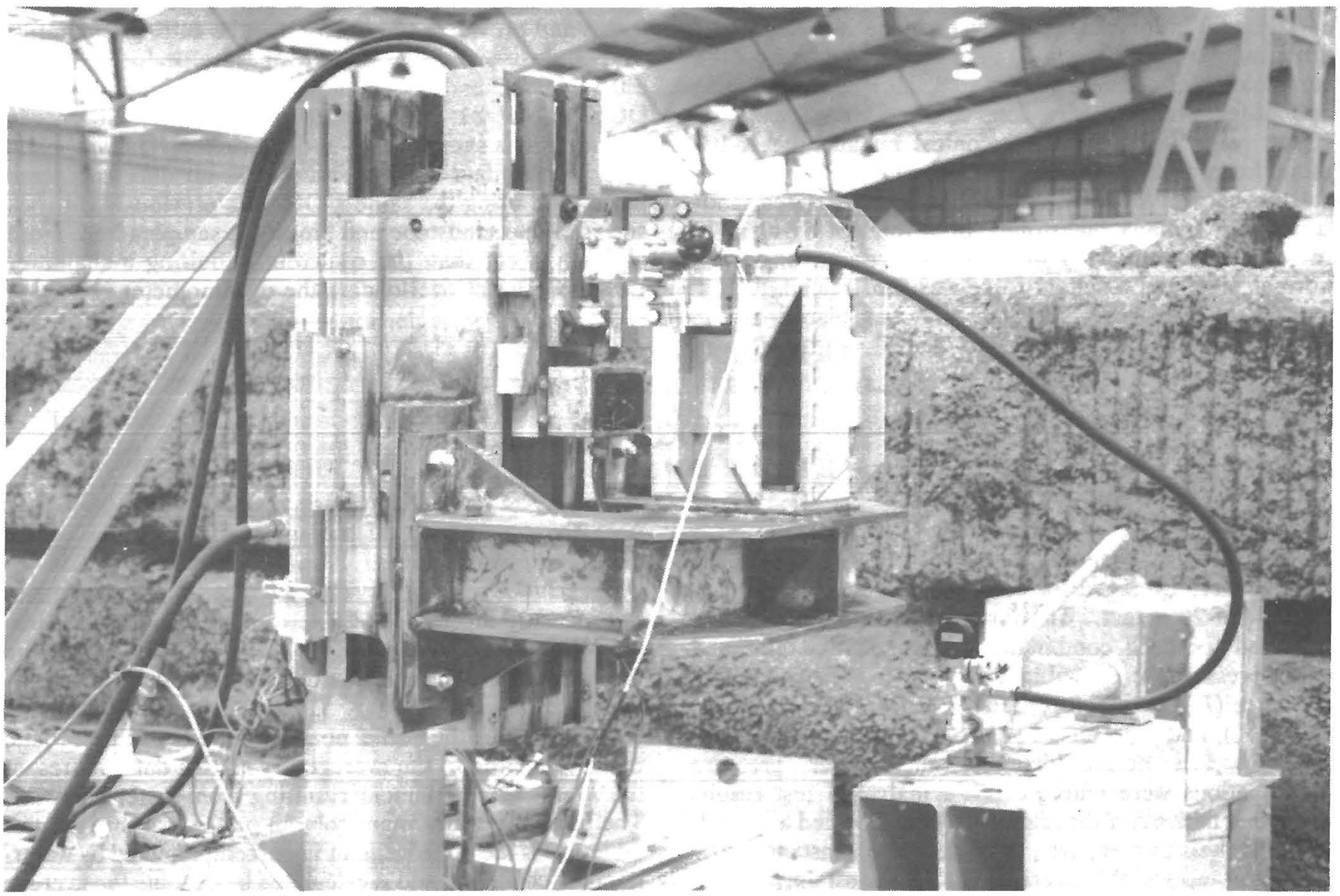

Figure 2.—Calibration test fixture mounted on in-seam tester.

tangential, normal, and side displacements generated by the cutting process during the testing. The combined microstrain is then converted to pounds (force) by a conversion factor obtained from calibrations performed on the calibration test fixture.

The following are the cutting force ranges for the dynamometer, in pounds (force).

Normal force (F_n)	0-7,500
Tangential force (F_t)	0-7,500
Side force (F_z)	±5,000

TEST PROCEDURE

The order of the tests was random for three separate passes using identical parameters. This random order eliminated the depth-effect influence of the test sample on the cutting parameters as the test cuts went deeper into the test samples on subsequent data cuts. Depth effect may occur as subsequent cuts are made deeper within the rock specimen. Because it was unknown if the results were prejudiced because of the deeper location relative to the initial rock cuts, the test series were randomly performed.

Three 20-in-long data cuts were made in each of the three samples, resulting in 60 in of recorded data for each combination of nozzle diameter (0.3, 0.6, 0.8, and 1.0 mm) and water pressure (dry, 250, 2,500, 5,000, 7,500, and 10,000 psig), using the U-70 conical bit and the K-107 radial longwall bit. This yielded a total of 2,880 in of test cuts for each of the three samples (coalcrete, Berea sandstone, and Indiana limestone), or a total of 8,640 in of recorded data cuts from which a data base of tangential, normal, side, and resultant force was constructed.

For the coalcrete tests, the IST was placed at the coalcrete block and bolted to the floor to prevent overtipping and pushback from the face resulting from the reaction of cutting forces. The coalcrete tests used a 1-in depth of cut (DOC) and a 2-in cut spacing to maintain a spacing-to-DOC ratio of 2:1. To provide an unhoneycombed cutting surface and eliminate specimen-induced inconsistencies, two 0.5-in-deep cleanup cuts were performed whenever the IST was relocated to a new position on the coalcrete block.

For the sandstone and limestone tests, the IST was welded on the rock-holding fixture to generate cutting forces and provide a stable base for the cutting apparatus. The sandstone and limestone tests were performed using a 0.5-in DOC and a 2-in cut spacing, yielding a spacing-DOC ratio of 4:1. Whenever the IST initially cut a newly mounted rock sample a 0.5-in-deep cleanup cut was made prior to the data cuts to assure that all data cuts were performed using the same DOC on a previously cut rock surface. The sandstone and limestone samples were more difficult to cut than the coalcrete, requiring a shallower DOC to prevent overloading the dynamometer.

CUTTING TESTS

AVERAGE FORCES

The test data, sampled at a rate of 10 samples per second, were averaged for each cut over a specified data window of 20 in/cut. The three 20-in data cut averages obtained for each combination of nozzle diameter and water pressure were combined to yield an average tangential force (F_t), normal force (F_n), side force (F_z), resultant force (F_r), and mechanical power (P_r). Force and power data for all nozzle diameter and water pressure combinations were entered into a matrix of test results identified tables A-1 through A-5. This provided a spreadsheet analysis to compare parameters at a constant nozzle diameter and variable pressure, or at a constant pressure and variable nozzle diameter. A family of curves, utilizing data from the matrix of test results for force, was generated to graphically identify the spread-sheet relationships. Curves representing resultant, tangential, normal, and side forces in coalcrete, sandstone, and limestone are presented in figures 3, 4, and 5, respectively.

Table A-4 gives the average resultant force calculated from the square root of the sum of the squares of the three orthogonal forces. The data obtained at 250 psi were included with the dry data averages because sprays at this pressure are more suitable for dust suppression than for water-jet-assisted cutting. The data included in the average wet force column are the average values calculated from the data in the 2,500-, 5,000-, 7,500-, and 10,000-psig columns, using the same nozzle diameter. These data, when compared to the average dry cutting data, represent the average improvement resulting from water-jet assist. The percent improvement column on the extreme right of table A-4 is the improvement in percent, effected by water-jet-assisted cutting and is calculated by dividing the average force of all wet cuts using a specific nozzle size by the average force of *all* dry and 250-psig cuts performed on the particular test specimen.

The resultant force data for each sample type were averaged for each nozzle diameter at the same pressure and are given in table 1. The percentile improvement

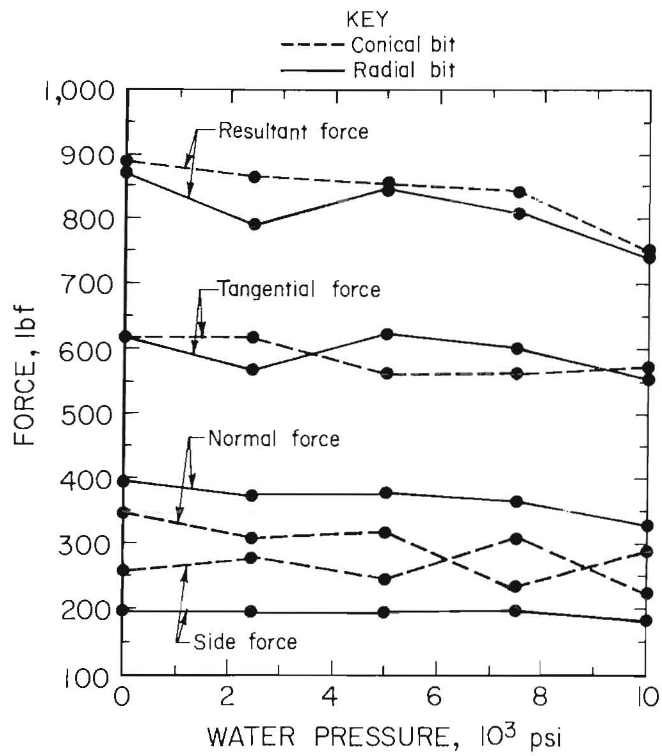

Figure 3.—Cutting forces as a function of water pressure—coalcrete.

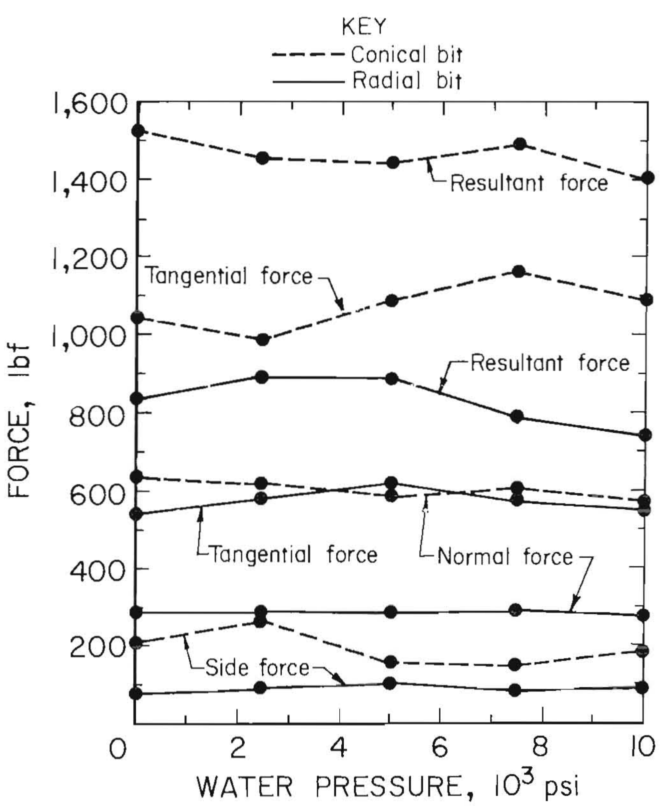

Figure 4.—Cutting forces as a function of water pressure—Berea sandstone.

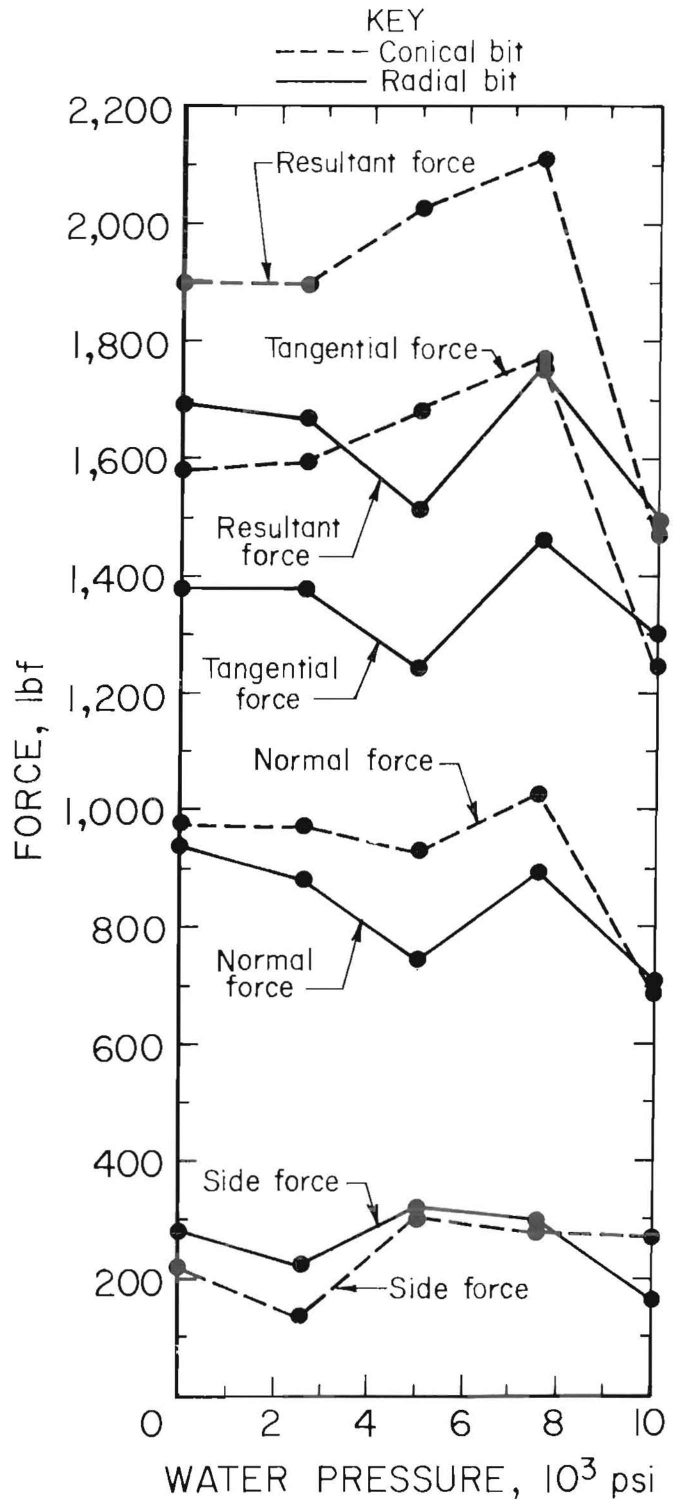

Figure 5.—Cutting forces as a function of water pressure—Indiana limestone.

Table 1.—Force results summary

		Dry	2,500[1]	5,000[1]	7,500[1]	10,000[1]	Av wet force
			CONICAL BIT				
Coalcrete:							
Force	lbf	894	869	863	848	767	837
Improvement	pct	NAp	2.8	3.5	5.1	14.2	6.4
Sandstone:							
Force	lbf	1,524	1,449	1,432	1,482	1,398	1,440
Improvement	pct	NAp	4.9	6.0	2.8	8.3	5.5
Limestone:							
Force	lbf	1,905	1,894	2,013	2,100	1,460	1,867
Improvement	pct	NAp	0.6	-5.7	-10.2	23.4	2.0
Average:							
Force	lbf	1,441	1,404	1,436	1,477	1,208	1,381
Improvement	pct	NAp	2.6	0.3	-2.5	16.2	4.2
			RADIAL BIT				
Coalcrete:							
Force	lbf	876	791	846	810	761	802
Improvement	pct	NAp	9.7	3.4	7.5	13.1	8.4
Sandstone:							
Force	lbf	837	888	887	784	741	825
Improvement	pct	NAp	-6.1	-6.0	6.3	11.5	1.4
Limestone:							
Force	lbf	1,696	1,663	1,507	1,751	1,492	1,603
Improvement	pct	NAp	1.9	11.1	-3.2	12.0	5.5
Average:							
Force	lbf	1,136	1,114	1,080	1,115	998	1,077
Improvement	pct	NAp	1.9	4.9	1.8	12.1	5.2
			BOTH BITS				
Average:							
Force	lbf	1,289	1,259	1,258	1,295	1,103	1,229
Improvement	pct	NAp	2.3	2.4	-0.5	14.4	4.7

NAp Not applicable.
[1]Water pressure, pounds (force) per square inch, gauge.

caused by water-jet assist with reference to the average dry data is also given. The data in table 1 and corresponding figures 3, 4, and 5 provide the net results of water-jet-assisted cutting on coalcrete, sandstone, and limestone.

The improvement of cutting forces (reduction of resultant force requirements) in the three samples due to water-jet assist were slight to moderate at 2,500, 5,000, and 7,500 psig; however, at 10,000 psig there was an 8- to 23-pct improvement. Table 1 gives the average resultant force at each pressure, and the average resultant force for all pressures with a specific sample and cutting bit. A grand average combining the data for each bit type in all tests using 10,000-psig water-jet assist shows a 14.4-pct reduction in resultant force requirement.

The average force data in table 1 at each test pressure, obtained by averaging all force readings at a specified pressure, regardless of nozzle size, were plotted for each orthogonal direction and the calculated resultant force for the test samples. Figures 3, 4, and 5 give the average tangential, normal, side, and resultant forces for coalcrete, Berea sandstone and Indiana limestone, respectively.

A review of these graphs indicates that reductions in cutting force are not a precise function of increased water pressure or nozzle size. Data were widely dispersed throughout the cutting tests for all samples and nozzle sizes. In figure 3 (coalcrete) there is a decreasing trend in resultant, normal, and tangential forces as water pressure is increased, while side forces remain relatively constant throughout the entire range of water-pressure application on the coalcrete block. Figure 4 (Berea sandstone) shows an almost horizontal trend for the cutting forces up to 10,000 psig where a slight decrease in force occurred. Figure 5 (Indiana limestone) shows much more fluctuation in cutting forces, however significant improvement is obtained at 10,000-psig water pressure.

The resultant forces of all wet cuts (table 1) were averaged and compared with the resultant forces of all dry cuts using the conical and radial longwall bits for each sample to obtain an overall water-jet effectiveness. When cutting the coalcrete block, water-jet assist reduced the resultant force requirements of the conical bit by 6.4 pct and the radial longwall bit by 8.4 pct. In sandstone, resultant forces were reduced 5.5 pct for the conical bit and 1.4 pct for the radial bit. In limestone, resultant forces were 2.0 pct lower with the conical bit, and 5.5 pct lower with the radial bit. Because data at the lower water-jet pressures are included in the analysis, the impact of 10,000-psig cutting on resultant forces is reduced. Looking at only 10,000 psig results, force reduction benefits of 8.3 to 23.4 pct were realized.

Subsequent studies found that water jets lacking flow straightening devices and having nozzle-to-bit-tip distances of 2.5 to 3.0 in reduce stated pressure by approximately 65 to 70 pct. This suggests that the benefits caused by 10,000-psig water-jet assist actually occur somewhere between 3,000 and 3,500 psi.

Table 2 compares the wet and dry effectiveness of the two bits tested in cutting the three samples. The bits were maintained in a new, unworn condition. The average forces required to cut the sample during dry tests and wet tests were compiled for each sample. The radial longwall bit required less force in all materials, wet or dry, than did the conical bit. However, using the conical bit, the water-jet assist was slightly more effective in reducing cutting forces at 10,000 psig.

PEAK FORCES

Reductions in peak forces are credited with extending machine and gear train service life of coal and rock mining equipment. Research was performed to identify what reductions in peak cutting forces were caused by the water-jet assist, and to determine if these peak force reductions were greater than average force reductions. Two methods of analysis were used to determine peak forces; a peak value algorithm and a statistical analysis.

Table 2.—Force comparison between cutting bits, wet and dry, pounds (force)

	Coalcrete		Sandstone		Limestone	
	Dry	Wet	Dry	Wet	Dry	Wet
Conical	894	837	1,524	1,440	1,905	1,867
Radial	876	802	837	825	1,696	1,603
Radial pct of conical	98	96	55	57	89	86

Peak Value Algorithm

The response of each strain bridge was processed on a spectrum analyzer to identify the predominant frequencies imparted to the triaxial load cell; this was to assure that the sampling rate was sufficiently high to capture the peak forces. Predominant strain frequencies caused by cutting occurred at less than 5 Hz. Peak values of normal, tangential, side, and resultant forces were derived using an algorithm that identified a peak value as a positive-to-negative change of slope that continued for a prespecified number of data points before rechanging from a negative to positive slope.

Statistical Evaluation of Peak Force

A statistical method for determining the average peak force was achieved by compiling a time-at-level histogram of all force levels sampled. From this histogram, the average peak force was obtained by adding the value of the mean cell to the standard deviation.

The statistical evaluation of average peak force is considered to be more realistic than the peak value algorithm because all data samples are included in the statistical approach. The peak algorithm must use a method of selection to determine which peaks are retained in the data and which peaks are eliminated.

The peak force, based upon the standard deviation method of analysis, was reduced by 6.5 pct when water-jet assist was used with the conical bit and 0.6-mm-diam nozzle. This value is similar to the 5.5-pct reduction in the average force when using water-jet assist. This suggests that reductions in peak forces will be reflected by reductions in average force, and will parallel them.

BETWEEN-TEST CALIBRATIONS

The accuracy and precision of the IST was maintained by calibrating it after the completion of each series of tests. The first calibration was initiated after the coalcrete tests, the second after the Berea sandstone tests, and the third after the Indiana limestone tests. The calibrations indicated that the transducer was free from appreciable drift.

Calibration was effected by applying a load through a uniaxial force transducer in all three axes and recording the output force measured by the dynamometer strain-gage bridges. The dynamometer output in each of the three orthogonal directions was compared with the output of the uniaxial force transducer by plotting them on a common graph. The load cell-dynamometer comparison in the same direction yielded a regression curve and percentage of full-scale error, while a comparison in orthogonal directions yielded crosstalk, or electronic background noise.

Test results indicated that the dynamometer behaved linearly in each of the orthogonal directions, with minimal drift. The instrumentation system and dynamometer proved to be reliable and repeatable through the parameter ranges tested.

CONCLUSIONS

The objective of this research was to determine cutting force and mechanical power changes when different water pressures were applied to a water-jet-assist cutting system. These tests were performed in a laboratory using a device designed to measure and record the various forces generated when cutting. Water pressures were 2,500, 5,000, 7,500, and 10,000 psig. Four different nozzle diameters were used, 0.3, 0.6, 0.8, and 1.0 mm. Three rock types–coalcrete (a mixture of ≤2-in coal, Portland cement, and fly ash), Berea sandstone, and Indiana limestone–were cut with conical and radial bits.

When results of tests using water-jet assist were combined and compared with results of dry tests, the resultant force was reduced an average 6.4 pct in coalcrete, 5.5 pct in sandstone, and 2.0 pct in limestone while using the conical bit. The average reduction using the radial bit was 8.4 pct in coalcrete, 1.4 pct in sandstone, and 5.5 pct in limestone. Force reductions obtained over the full range of water pressures were modest, however, significant improvements were found when results at 10,000 psig were isolated from the remainder of the data. At 10,000 psig, the average reduction in resultant force was 14.2 pct in coalcrete, 8.3 pct in sandstone, and 23.4 pct in limestone using the conical bit, while the radial bit generated resultant force reductions of 13.1 pct in coalcrete, 11.5 pct in sandstone, and 12.0 pct in limestone.

APPENDIX.–TEST RESULTS

Table A-1.—Normal force, pounds (force)

Nozzle diam, mm	Dry		250[1]		2,500[1]		5,000[1]		7,500[1]		10,000[1]	
	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad
Coalcrete:												
0.3	533	403	429	399	346	457	471	427	456	397	472	349
0.6	179	397	157	360	117	276	250	378	32	313	101	338
0.8	373	411	386	334	419	376	334	396	340	356	273	286
1.0	381	444	318	424	338	377	206	301	116	393	291	324
Sandstone:												
0.3	454	392	527	355	528	408	453	320	648	306	525	260
0.6	580	194	982	316	709	281	554	333	640	261	549	281
0.8	590	186	631	305	687	178	690	200	534	315	596	303
1.0	656	200	606	426	494	288	611	297	580	282	609	238
Limestone:												
0.3	1,085	957	834	891	1,082	895	806	740	1,121	1,026	640	888
0.6	1,008	1,096	529	782	1,052	870	1,087	830	995	867	764	656
0.8	1,155	970	1,283	1,092	745	905	955	767	945	827	714	884
1.0	949	901	939	815	995	884	897	676	1,086	854	722	460

Con Conical continuous miner bit.
Rad Radial longwall miner bit.
[1]Water pressure, pounds (force) per square inch, gauge.

Table A-2.—Tangential force, pounds (force)

Nozzle diam, mm	Dry		250[1]		2,500[1]		5,000[1]		7,500[1]		10,000[1]	
	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad
Coalcrete:												
0.3	705	605	611	681	474	662	631	661	623	685	673	587
0.6	637	582	712	552	632	433	531	601	535	461	539	584
0.8	515	595	581	536	653	581	528	646	539	572	444	486
1.0	496	637	596	715	694	583	540	569	538	668	582	555
Sandstone:												
0.3	763	712	872	585	852	766	788	667	1,038	525	1,031	516
0.6	811	427	1,428	505	1,003	578	1,009	702	1,323	552	1,129	541
0.8	957	472	1,465	470	1,200	452	1,221	477	1,231	700	1,092	645
1.0	1,038	524	1,044	635	878	521	1,317	626	1,066	512	1,084	488
Limestone:												
0.3	1,676	1,403	1,366	1,290	1,620	1,416	1,200	1,159	1,597	1,563	1,112	1,423
0.6	1,562	1,598	943	1,142	1,647	1,401	2,193	1,480	1,588	1,469	1,292	1,197
0.8	1,722	1,357	2,218	1,633	1,251	1,325	1,691	1,190	1,617	1,290	1,162	1,532
1.0	1,459	1,338	1,632	1,217	1,816	1,350	1,609	1,122	2,221	1,517	1,274	998

Con Conical continuous miner bit.
Rad Radial longwall miner bit.
[1]Water pressure, pounds (force) per square inch, gauge.

Table A-3.—Side force, pounds (force)

Nozzle diam, mm	Dry Con	Dry Rad	250[1] Con	250[1] Rad	2,500[1] Con	2,500[1] Rad	5,000[1] Con	5,000[1] Rad	7,500[1] Con	7,500[1] Rad	10,000[1] Con	10,000[1] Rad
Coalcrete:												
0.3	-505	-197	-292	-208	-165	-222	-182	-188	-247	-263	-187	-185
0.6	-211	-194	-127	-166	-331	-165	-291	-192	-341	-138	-221	-117
0.8	-240	-154	-188	-223	-307	-184	-215	-201	-209	-177	-239	-199
1.0	-189	-204	-321	-178	-293	-209	-274	-196	-424	-212	-224	-177
Sandstone:												
0.3	-53	-56	-418	-176	-283	-202	-119	-226	-191	-11	-137	-52
0.6	-97	-2	-305	-82	-203	-29	-59	1	61	-157	-228	-147
0.8	18	-18	-53	-119	-312	-93	-187	-54	-236	-94	-210	-157
1.0	-79	-89	-625	-125	-286	-28	277	-142	-123	-50	-211	32
Limestone:												
0.3	-211	-469	-361	-337	-309	-57	-269	-344	-256	-422	-261	-196
0.6	-88	-361	-207	-135	-203	-431	50	-581	-678	-283	-115	-126
0.8	-287	-121	309	-355	-251	-346	-931	-303	-212	-357	-344	-104
1.0	-378	-186	-518	-266	243	-27	-54	-16	54	-116	-334	-205

Con Conical continuous miner bit.
Rad Radial longwall miner bit.
[1]Water pressure, pounds (force) per square inch, gauge.

Table A-4.—Resultant force, pounds (force)

Nozzle diam, mm	Dry Con	Dry Rad	250[1] Con	250[1] Rad	2,500[1] Con	2,500[1] Rad	5,000[1] Con	5,000[1] Rad	7,500[1] Con	7,500[1] Rad	10,000[1] Con	10,000[1] Rad	Av wet force Con	Av wet force Rad	Improvement, pct Con	Improvement, pct Rad
Coalcrete:																
0.3	1,107	843	899	937	682	920	881	918	897	948	948	805	852	898	4.7	-2.5
0.6	926	999	973	763	886	606	803	823	792	644	728	792	802	716	10.3	18.3
0.8	752	836	824	762	931	799	755	863	786	769	635	684	777	779	13.1	11.1
1.0	728	906	942	964	975	838	1,013	778	915	880	756	762	915	815	-2.3	7.0
Sandstone:																
0.3	1,197	1,034	1,390	865	1,323	1,197	1,197	1,030	1,384	768	1,427	742	1,332	934	12.6	-11.6
0.6	1,311	690	2,019	829	1,534	890	1,381	957	16,697	767	1,415	746	1,502	839	1.4	-.2
0.8	1,424	747	1,847	737	1,673	719	1,558	712	1,537	885	1,386	845	1,539	790	-1.0	5.6
1.0	1,434	821	1,568	973	1,267	746	1,593	847	1,326	715	1,362	630	1,387	734	9.0	12.3
Limestone:																
0.3	2,040	1,769	1,664	1,607	1,998	1,680	1,484	1,421	1,978	1,935	1,314	1,690	1,694	1,682	11.1	.8
0.6	1,865	1,984	1,143	1,400	1,985	1,706	2,481	1,805	2,001	1,733	1,529	1,374	1,999	1,655	-4.9	2.4
0.8	2,121	1,675	2,584	2,000	1,493	1,647	2,167	1,472	1,943	1,577	1,489	1,779	1,773	1,619	6.9	4.5
1.0	1,850	1,626	1,969	1,508	2,099	1,620	1,920	1,329	2,478	1,758	1,508	1,123	2,001	1,458	-5.0	14.0

Con Conical continuous miner bit.
Rad Radial longwall miner bit.
[1]Water pressure, pounds (force) per square inch, gauge.

Table A-5.—Power, horsepower

Nozzle diam, mm	Dry		250[1]		2,500[1]		5,000[1]		7,500[1]		10,000[1]		Av wet force	
	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad	Con	Rad
Coalcrete:														
0.3	0.75	0.72	0.70	0.76	0.65	0.84	0.64	0.67	0.69	0.77	0.72	0.62	0.68	0.73
0.6	.82	.69	.67	.67	.81	.64	.76	.58	.84	.49	.72	.88	.78	.65
0.8	.63	.62	.61	.71	.72	.69	.71	.72	.75	.69	.63	.66	.70	.69
1.0	.53	.70	.79	.77	.80	.71	.60	.67	.89	.61	.57	.51	.72	.63
Sandstone:														
0.3	.97	.83	1.11	.70	1.05	.95	.93	.83	1.09	.62	1.12	.60	1.05	.75
0.6.	1.06	.56	1.56	.67	1.23	.71	1.08	.74	1.29	.62	1.0	.61	1.20	.67
0.8	1.14	.62	.85	.59	1.31	.59	1.19	.58	1.13	.69	1.08	.68	1.18	.64
1.0	1.11	.65	1.15	.78	1.01	.60	1.19	.68	1.04	.57	1.02	.51	1.07	.59
Limestone:														
0.3	1.49	1.36	1.22	1.26	1.44	1.30	1.14	1.11	1.52	1.43	.99	1.27	1.27	1.28
0.6	1.48	1.54	.92	1.1	1.50	1.35	1.62	1.35	1.58	1.35	1.20	1.09	1.48	1.29
0.8	1.59	1.35	.82	1.52	1.17	1.30	1.59	1.16	1.39	1.23	1.18	1.44	1.33	1.28
1.0	1.38	1.23	1.45	1.20	1.18	1.25	1.40	1.08	1.65	1.33	1.14	.90	1.34	1.14

Con Conical continuous miner bit.
Rad Radial longwall miner bit.
[1]Water pressure, pounds (force) per square inch, gauge.

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