

BUREAU OF MINES RESEARCH WILL IMPROVE HEALTH
AND SAFETY WITH NEW CUTTING CONCEPT

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ABSTRACT

Results are presented for two major areas of research that address solutions to problems associated with health and safety aspects of rotary drum mining machines. The results presented describe proof-of-concept testing for the Bureau's new Constant Depth Linear Cutting (CDLC) concept and use of computer analysis for Cutter System Modeling (CSM) of rotary cutting drums. The CDLC concept uses a triangular drum on an eccentric arm which operates at low rpm. Results of proof-of-concept tests show a reduction in respirable dust of greater than 90 pct with an increase in product size of 50 pct for the minus $\frac{1}{2}$ -in mesh with no loss of production when a 10 rpm linear drum is compared to a 50 rpm rotary drum. An exclusive license has been granted to a mining equipment manufacturer on four government-held patents to accelerate transfer of the technology to the coal mining industry. The CSMs have been developed for computer analysis of the cutting systems on continuous and longwall miners. Use of these CSMs will reduce the operators cut-and-try time needed to identify minimum dust generation for maximum production.

INTRODUCTION

The Bureau's Coal Cutting Technology group at the Twin Cities Research Center in Minneapolis has been working on the control of dust generation by rotary drum cutting since enactment of the Health and Safety Act of 1969. The working premise is; "If you don't want dust, don't produce it," but, since coal cannot be fragmented without producing dust, practical approaches to the problem rely on either minimizing the dust generation and entrainment or secondary control of the dust. While secondary control is appropriate to meet near-term regulatory concerns, the most economically advantageous approach for long-term is to reduce dust generation at the source. This may be done by either optimization of existing equipment or by redesign of the cutting system. Each of these solutions to the problem is being actively evaluated by the Bureau of Mines.

Current research activity in these two major areas of coal cutting technology at the Bureau's Twin Cities Research Center (TCRC) may be summarized as follows:

(A) Two versions of interactive computer programs have been developed for analysis of rotary cutting systems. The original

single version REDI(1) was not fully interactive. Newer versions of the CSMs have been developed for both longwall shearer drums (SD-CSM)(2) and continuous miners (CM-CSM).(3) While these newer versions integrate all available data base, other improvements are expected to be made to the programs as additional bit wear data becomes available. This will provide operators with a dynamic evaluation of multi-shift cutting for determining the most cost effective bit change points for different bit types cutting in various inclusive materials.

(B) The research which supplied the data base for the computer modeling also required an analysis of rotary drum cutting systems to establish the operational factors affecting dust generation and entrainment. This analysis provided the basic data on rotary cutting from which a new constant depth linear cutting (CDLC) concept has been developed. The ongoing comparative testing of linear and rotary cutting using the TCRC test facility is expanding the knowledge base about mechanical cutting technology.

CUTTING SYSTEM MODELING

Background: Many related factors are involved in dust generation making it necessary to first fully understand the individual elements of the cutting system and then integrate all of these elements into an interactive whole. The initial phase of the project to reduce dust generation required that a suitable data base of basic information on each individual element of the cutting system be developed.(4-8) The individual data base elements can only be used to optimum advantage by mine operators when they are integrated into computer programs which provide a complete cutting system analysis. The computer programs developed for analysis of longwall shearer drums and continuous miners provide the mine operator with the opportunity to evaluate system changes with minimal cost.

Program description: The CSM programs have been developed to analyze relative dust generated by double-drum ranging arm shearers (SD-CSM) and CM-CSM. The programs, written in BASIC, will run on any IBM pcXT or equivalent using MS-DOS. The programs are menu driven, allowing the user to make parametric changes in a minimum of steps. The menus which control the program flow allow the user to calculate relative dust values, change parameters, save modified data files and obtain printed copies of summary reports, lists of modifications and a listing of the entire data file. There are 60 parameters affecting the program analysis which may be set by the operator to fit their site-specific conditions. The parameters which may be changed include; operator controllable parameters, machine dimensions and power, seam geology and petrography, and bit tangential and normal forces. Both programs have "help" menus which provide the user with on-line assistance and descriptions of these parameters. The programs use the formula developed for rotary cutting in RI 8185(4) as the basis for the algorithms on advance rate, volume taken and depth of cut. The situations being analyzed may include taking of a middleman in addition to mining only coal. Once the user has set the parametric values, the programs compute the force requirements for each coal and rock (if present) strata being mined. If the machine does not have sufficient power available to advance the machine, then the advance rate is reduced and the calculations repeated. This iterative process continues until the point is reached where the machine can advance with the power available to it. At this point, the program calculates the relative dust values, power and bit costs, and production levels for a summary report. The program then returns the user to the main menu.

The dust values computed by the program are relative. A single value of 10.0, for example, has no meaning unless another number is generated by a change in some parameter(s). If the second number is lower than the original number, then the change should

result in lower dust generation at the face and vice versa. Preliminary verification of these programs has been done for both the SD-CSM and the CM-CSM using data from contractor reports on field studies.(9,10) The fit of the field data to these programs is shown in figures 1 and 2.

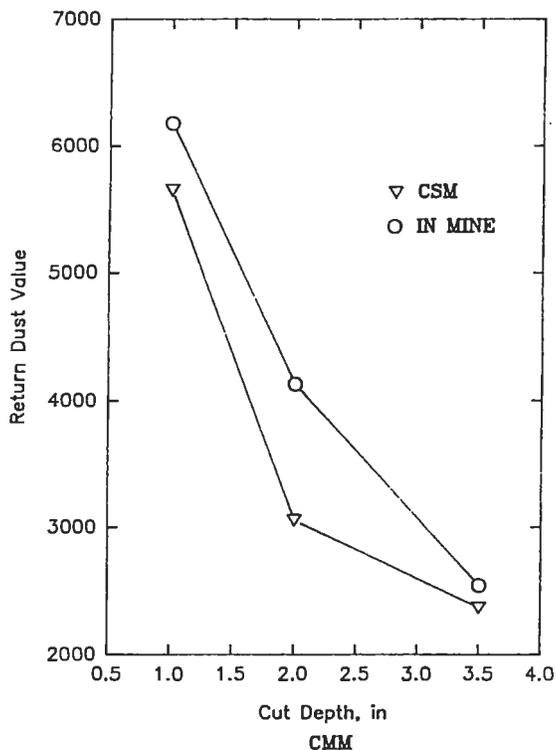


Figure 1. Comparison of CSM to Continuous Miner Field Data

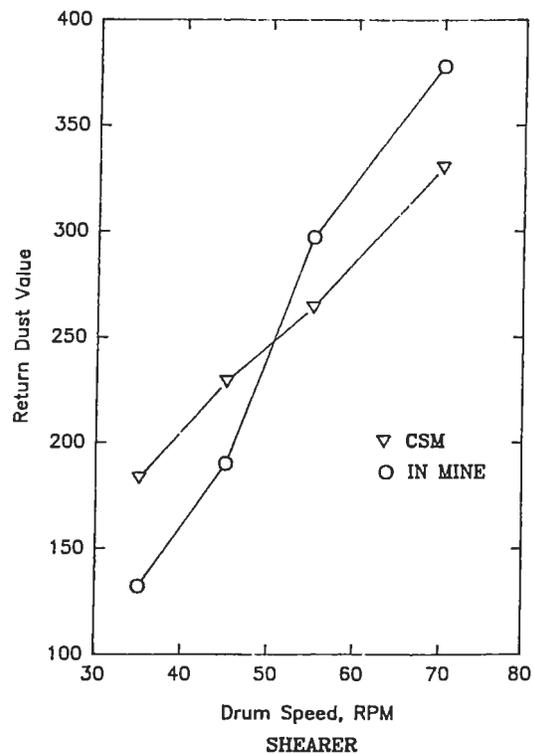


Figure 2. Comparison of CSM to Longwall Shearer Field Data

Program Use: The programs are user friendly, providing the operator with instructions for each successive step. The Main Menu controls all the program functions. Figure 3 shows an example of the summary report which is generated by the analysis. At this point, the user is given the option of printing a hard copy of the report or returning to the main menu. The user is returned to the Main Menu after printing, also. Two aspects of the analysis are controlled by the parameter values. Setting the rock band top (data element 21) and the rock band bottom (data element 22) equal to same value, eliminates the rock band from the calculations. Secondly, if the mining height (data element 24) and the drum diameter are the same, the program

the program will continue the calculations fixing the number of bits at this maximum. Should the program reach the maximum number of bits, a message stating this fact will appear on the screen.

In using the CSM to analyze drum designs, it is important to realize the user may not have access to values for all the parameters used by the program. A number of the variables in the program were included in anticipation of program expansion and/or development of broader data base to more fully support the program. The interaction between the parameters is complex and the effect of changing any single parameter is dependent on the values of the others. The variables which have the

major influence on dust generation are the depth of cut, the number of bits on the drum, and bit wear rate.

THE DRUM ADVANCE IS NOT LIMITED		THE BITS ARE 0 PERCENT WORN	
MAX. CUT DEPTH, VANE BIT (IN)	1.76	MAX. CUT DEPTH, GAUGE BIT (IN)	1.47
LINE BIT SPACING (IN)	4.93	NUMBER OF GAUGE LINES	5.00
BITS PER VANE	7.00	NUMBER OF GAUGE BITS PER LINE	3.60
BIT SPACE TO DEPTH RATIO	2.79		
AVAILABLE ADVANCING THRUST	6000	AVAILABLE CUTTER TORQUE	60000
LEAD DRUM ADVANCING THRUST	4606	LEAD DRUM CUTTER TORQUE	15863
TRAILING DRUM ADVANCING THRUST	2685	TRAILING DRUM CUTTER TORQUE	9167
ADVANCE (FT/MIN)	15.00	TONS PER SHIFT	2550.24
COST/TON - BITS AND POWER	0.25	COST/SHIFT - BITS AND POWER	649.19
VANE CONTRIBUTION (PCT)	57.45	GAUGE CONTRIBUTION (PCT)	42.55

 * FULL SHIFT RELATIVE DUST - 492.61 PER TON 3.42 PER CU. M. *

Figure 3. Typical Summary of Shearer Drum Analysis

Increasing the depth of cut and/or reducing the number of bits will reduce the dust generated by the drum until bit wear becomes a factor. While the number of bits is limited by only the bit block dimensions, the depth of cut may be limited by any of several variables. The depth of cut will be determined by the advance rate, drum rpm, number of starts, and bit wear condition. Wear has been shown to progress in discrete steps.(11) A simple form of this discrete step function is being used in the present programs until a more complete form is available.

The advance rate may be limited by either the volume of cut coal the drum can hold, or by high cutting or normal forces. These high forces could be due to either the presence of a rock band and/or worn bits. The bit wear rate will be exacerbated by either high linear bit velocity (high drum rpm) or by cutting an abrasive material, such as top rock or an inclusive band.

High linear bit velocity leads to frictional heating at the bit/mineral interface. It is widely recognized that this heating can increase the temperature to the point where methane ignitions may occur. What may not be recognized is that this heating also has a very serious deleterious effect on the bit wear rate and thus, bit life. With high bit speeds, the temperature at the bit interface

reaches a critical point above which phase shifts occur in the bit metals. These phase shifts rearrange the bit metallurgy leading to a more rapid wear rate. While bit wear, due to rock cutting is easily recognized, the effect of varying abrasivity is not well understood.

A preliminary abrasivity factor has been included in the present programs to help the user determine what effect increasing bit forces caused by wear may have on their dust and production levels. When the CSM developments have been completed, additional data bases, will relate wear for several bit types to dust generation and the cutting system.

Summary of future program developments:
 Two further developments are underway. The basic CSMs have been expanded to incorporate a minimization routine. This routine, which is being Beta tested now, allows the user to specify a limited number of variables with their range of values. The routine then determines which set of values can produce the minimum dust results. The second development incorporates a dynamic time dependent wear analysis into the CSM programs. This allows the user to see the effect of bit wear, over time. This will be useful in determining such factors as optimum bit change times for cost and production break-even points. Both of these developments require continuing wear testing to obtain an expanded data base on bit wear rates.

NEW CUTTING CONCEPT

Background of the concept development:
 The new cutting concept was originally part of the research presented in a Bureau publication in 1976.(4) This early research included an analysis of bits cutting on a rotary drum to identify the various cutting parameters. The results related the depth of cut for each bit on the drum to the dust and forces generated per unit volume of coal cut. This indicated that, since each bit on the drum enters the coal face at zero depth of cut, goes to some

maximum and exits at zero depth, the bits are only fragmenting coal efficiently when they are between 70 pct of maximum and their maximum depth. This means that only the last half of the first quadrant and the first half of the second quadrant, or the middle 50 pct of the drum, are cutting efficiently. The relationships of depth of cut and the volume recovered to drum rotation for any rotary drum mining machine may be seen in table I and figure 4.

Table I. Change in Volume Recovery with Changing Depth of Cut

Pct of cut depth	Degrees of rotation	Incremental pct recovered	Pct of total volume*
16	9	0.18	0.18
31	18	1.19	1.37
46	27	3.08	4.45
59	36	5.63	10.08
71	45	8.58	18.66
81	54	11.64	30.30
89	63	14.51	44.81
95	72	16.93	61.74
99	81	18.67	80.41
100	90	19.58	99.99

*There is a slight rounding error in the total volume.

It can be seen that the cutting action between zero and 70 pct maximum depth of cut produces less than 20 pct of the total volume recovered. All of that portion of a rotary cut at less than 70 pct depth is the shallow cutting, low coal recovery part of the drum rotation where the ratio of dust produced and energy used to the volume recovered is maximum. It follows from this that, if one wishes to design an optimum cutting system, the low recovery portion of the rotary drum must be removed from the system to minimize this dust and the energy to recovery ratio.

In addition to the shallow cutting portion of a rotary drum, there is an inherent secondary dust generation source in this design which may be 100 to 1,000 times greater than any primary dust generation due to cutter action.

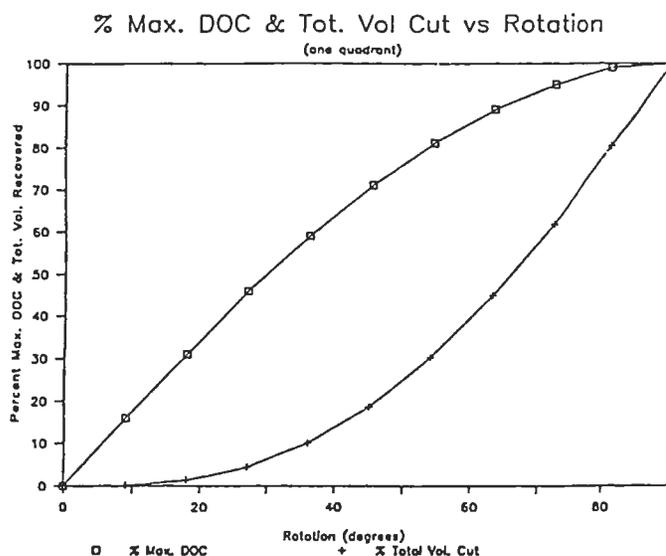


Figure 4. Volume Recovered as Depth of Cut Varies with Drum Rotation

It has been said that; "...using blunt high-speed bits, (continuous mining machines) probably are the best machines for forming dust that could be invented, except for a grinding stone."(12) This has been substantiated by Matta(13), who has shown that the sump cut of a continuous miner produces 70 pct of the total dust, the shear cut 20 pct, and the gathering and loading 10 pct. The sump portion of continuous mining would be the equivalent of a longwall miner advancing along the face. These differences in dust values between sump and shear may be attributed to: 1) two-quadrant cutting on sump and only one-quadrant cutting on shear; 2) breakout of the coal to a free face on shear; and 3) the grinding action of the head on fragmented coal caught between the drum and the face. These values suggest that one way to reduce dust generation is to eliminate regrinding by cutting to a free or open face. Additionally, any rotary drum operating at 45 to 70 rpm is operating as a large fan. A significant portion of the dust generated by both primary and secondary fragmentation may become entrained due to this high velocity fanning action.

The new CDLC concept is designed to reduce these problems by cutting at a lower speed to an open face all the

time. This new cutting concept, which is the only known method for solving these major design problems, is described fully in the patent applications.(14-17) An artist rendition of a continuous mining machine using the concept is shown in figure 5.

Description of the concept: The new CDLC system, is based on a geometric principle elucidated by Cardan in the early 1600's. The CDLC system consists of a triangular shaped drum with the bits mounted at the apexes. The drum is mounted on a spur gear at the end of

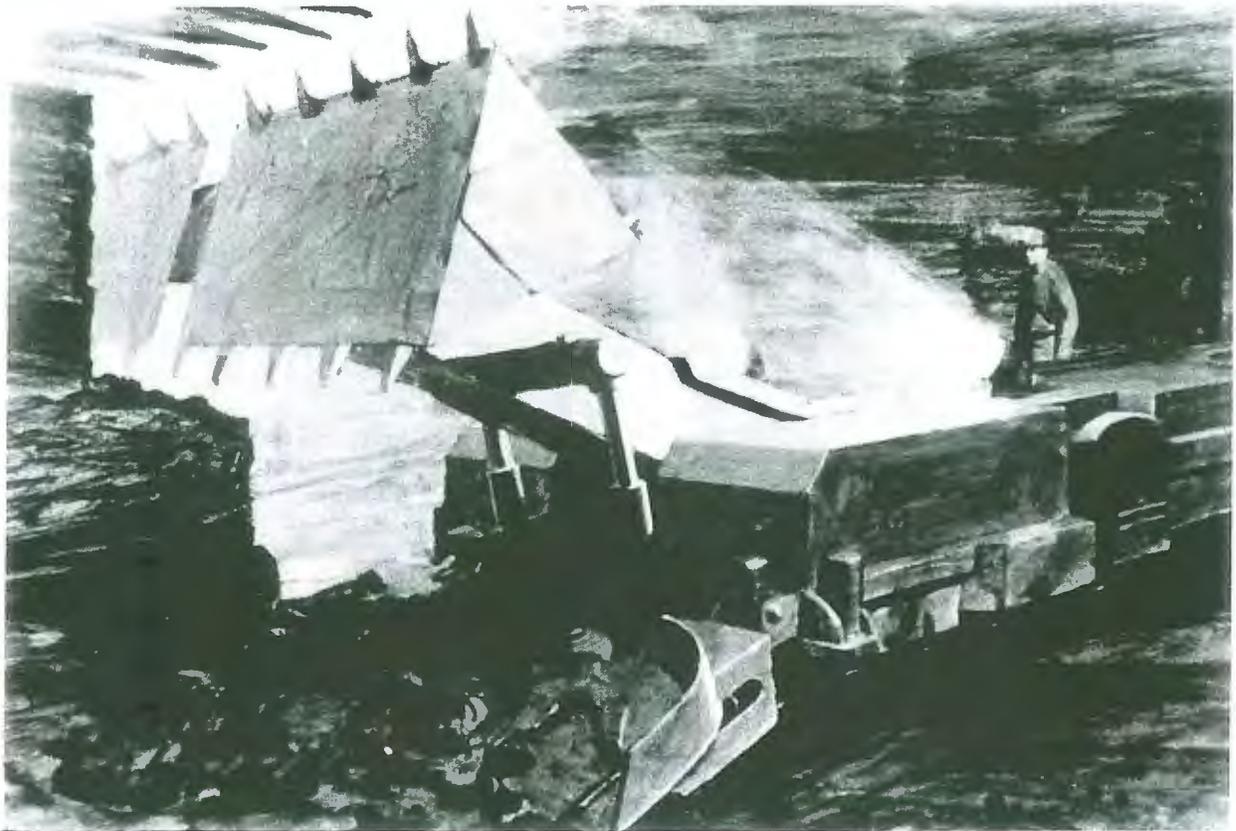


Figure 5. Artist Rendition of a Continuous Miner with the CDLC Drum

an eccentric arm inside a ring gear in such a manner that, as the triangular drum rotates each apex of the triangle generates a nearly square path. The amount of the rounding at the corners varies as the ratio of the distance, from the head center to the bit tips, to the radius of the spur gear on the same center. To achieve the best path, this ratio should be precisely 8:1. The orbital reduction concept, developed by Dojan(18), which has evolved from the Cardan generator has an eccentric arm which rotates three times for each rotation of the cutter head providing a mechanical reduction of 3:1. A comparison of the bit paths for

rotary and CDLC miners is shown in figure 6.

The CDLC will fragment coal at a lower rpm using optimum bit spacing over 80 pct of the cutting path with a constant depth of cut. In addition to breaking to an open face with no secondary fragmentation, the CDLC will have a significantly lower bit velocity which will reduce frictional heating and the potential for methane ignition and will improve bit life. The new CDLC system will reduce dust generation at the face and provide a product with fewer fines. This will reduce losses at the prep plant and improve the operators' competitive position in the

market by increasing their economic return, while improving health and safety for the miners.

Standard rotary vs slow linear cutting verification: The initial proof-of-concept testing for the new CDLC concept has been done using the Bureau's new low seam longwall test stand at

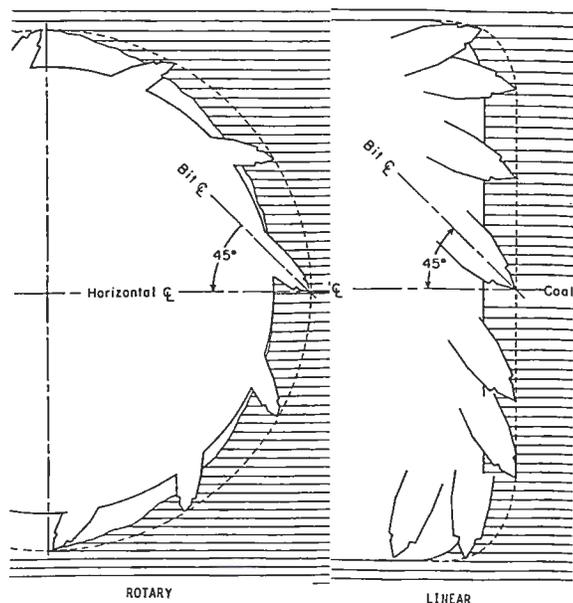


Figure 6. Comparison of Bit Paths for Rotary and CDLC Miners

their TCRC facility. The test stand was designed with three goals in mind: (1) evaluate the mechanics of the linear cutting concept; (2) provide a direct comparison for cutting capability and dust generation between the new CDLC concept cutting a 30-inch web in a 32-inch seam and a rotary drum cutting the same 30- by 32-inch seam; and (3) make the CDLC removable from the test stand in such a way that it could be used at an open pit face in the field by mounting it on a suitable transport. The first and second goals have been achieved, the test stand is functional with both a new linear drum and a standard rotary drum capability. Figure 7 shows the material cut during one of the tests with the linear drum. The low seam longwall simulation, cutting in an unfractured and uncleated synthetic coal face, has demonstrated the capability for development of a miner using a new, extra heavy-duty, high torque gerotor gearcase to frag-

ment material to an open face with a slow, deep, linear cutting action. Although the system has been designed to meet the third goal, it has not been field tested yet. We expect this to occur after the initial in-house laboratory tests have been completed, only if licensing is not completed and an underground prototype is not built first.



Figure 7. Completed Cutting Test with the CDLC Drum

Results have demonstrated the design efficacy of this new cutting concept. Results of the first tests made with this new concept have shown mechanical reliability with respirable dust reduced more than 90 pct when fragmentation with linear cutting at 10 rpm using modified forward attack bits was compared to rotary cutting at 50 rpm using standard conical bits. The screened product indicated an average decrease for the minus $\frac{1}{2}$ -in mesh of better than 50 pct. Torque and horsepower were down more than 40 pct and 60 pct, respectively.

A summary comparison of the respirable dust generation, torque, and median product size recovered by cutting with rotary and CDLC mining techniques, are given in table II for equal production.

Table II. Comparisons for CDLC and Rotary Cutting

Parameter	Rotary	CDLC	Pct change
Head speed (rpm)	50	10	-80
Avg. torque (ft-lb)	5165	2950	-43
Pk. torque (ft-lb)	7870	6301	-20
Sp. energy (ft-lb/cu-ft)	194739	66729	-66
Shaft power (hp)	49.2	16.8	-66
Sp. dust (mg/cu-ft)	17.11	1.33	-92
Pct Coarse product (+2 in)	8.0	26.4	230
Pct Fine product (-1/8 in)	23.0	7.5	-67

From the table, it is easy to see that the respirable dust is reduced by more than 90 pct, product size has increased reducing fines by more than 50 pct, and the peak torque is reduced by 20 pct. At 10 rpm frictional heating of the bits will be significantly reduced. This will improve bit life and reduce ignition potential.

Slow rotary vs slow linear: Tests have also been run using the same depths of cut for both drums. This means that the 2 vane rotary drum is rotating at a speed only 50 pct faster than the 3 vane linear drum to maintain the same production at the same depth of cut. Thus, testing at 15 rpm with the linear drum requires a 22½ rpm rotary drum speed. With these test conditions, very little difference is seen between the two systems, except for torque. Linear shaft torque is 50 pct less than the rotary drum shaft torque. We believe that the results on dust and fines are skewed by the homogeneity of the test material being used. Without any internal fracturing, no cleating,

and a much tougher material, (large pieces will not fragment when dropped on a cement floor as coal would) we do not believe that we are seeing a true representation of secondary dust generation. The artificial coal appears to produce substantially less dust and fines than would be normal for coal fragmentation. It is anticipated that this will not be resolved until field tests with the prototype linear drum system are completed. This testing used an atypical speed condition for the rotary drum system, since the mean speed for all rotary drum systems is 61.1 rpm. At the slow speed used for this test, standard rotary drum systems would not have the necessary gearcase strength and torque capability. These tests demonstrated one of the major advantages of the linear drum design, a high torque gearcase for slow, deep cutting.

Benefit: The CDLC will fragment coal to a free face at a low rpm using optimum bit spacing with no secondary fragmentation and reduced ignition potential. The new CDLC system will fragment the same or a greater volume of coal without increasing the dust generated. The system will provide a product with fewer fines, thus reducing losses at the preparation plant. This will improve the competitive position in the world coal market and increase the economic return for the operator, at the same time health and safety of the miners are improved by the new technology.

Patent Status: The Government holds the assignment on four base patents granted between 1977 and 1981 covering the new linear cutting concept. The pertinent patent serial numbers are shown in references 14 through 17. The first demonstration hardware for a comparative study of the linear/rotary systems was completed just over 2 years ago. Although the patents have been available for exclusive licensing since they were granted, requests to license have only been received since the test stand comparisons of actual cutting data started to become available. Notice was published in the Federal Register in April of this year,

indicating the intent to grant an exclusive license to Phillips Machine Service, Inc., at Beckley, WV. Any questions about exclusive licensing should be addressed to, Dr. Donald A. Ralston, Chief, Division of Technology Transfer, Department of Interior, Bureau of Mines, Columbia Plaza, 2401 E St., NW, Washington, DC 20241.

Summary of CDLC: A test stand has been fabricated to evaluate the Bureau's new Constant Depth Linear Cutting concept. Tests have been conducted using an eccentrically mounted triangular shaped drum, the linear cutter, and a standard rotary drum for direct comparisons. The initial tests have confirmed the validity of the new CDLC concept. Dust generation, without any secondary dust suppression, has been reduced by more than 90 pct with no loss in production capability. The minus $\frac{1}{4}$ -in mesh were reduced by more than 50 pct, indicating that problems with fines will be reduced significantly at a prep plant. The Government holds several patents which were made available for licensing to any firm wishing to pursue further development of this concept.

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