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**Report BRL/TR-74-7020**

USBM Contract H0133052

# **DESIGN OF A HYDRAULIC-JET COAL MINER**

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**Bendix Research Laboratories  
Bendix Center  
Southfield, Michigan 48076**

**Approved April 1974**

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**Prepared for**

**TWIN CITIES MINING RESEARCH CENTER  
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NOTICE

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<b>15. Supplementary Notes</b>		<b>14. Sponsoring Agency Code</b>	
<b>16. Abstract</b> <p>Results are described of a design study investigating the feasibility of using high-pressure water-jet cutting in the continuous mining of coal in underground mines. The potential advantages of this approach include the reduction of dust and sparking hazards and the minimization of damage to overlying rock strata thus reducing the roof fall hazard.</p> <p>An analysis is presented of previously obtained data on the kerfing of coal during tests performed both in the laboratory and underground. This is used to predict kerf depth as a function of cutter nozzle horsepower and traversing speed. A jet cutter head design concept suitable for use on a continuous mining machine is developed. This includes mechanical cutters to maintain a uniform geometry at the periphery of the working face and wedging devices which ride the kerfs made by the cutter jets and break coal from the face. A design layout and other design information is given showing the adaptation of a Joy 12CM mining machine to provide a vehicle suitable for prototype testing of the jet cutter concept.</p> <p>Based on a study of the predicted coal cutting characteristics of the high-pressure jet cutter continuous miner, it was concluded that achievement of a competitive production rate would require more power than is practical to install on an underground machine. Recommendations are given that no further development on this concept be undertaken until further investigation into the kerfing and fracturing of coal with high-pressure water jets is performed.</p>			
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## PREFACE

This report was prepared by Bendix Research Laboratories, Bendix Center, Southfield, Michigan, 48076, under USBM Contract H0133052. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Twin Cities Mining Research Center with Mr. Jacob N. Frank acting as the Technical Project Officer. Mr. A. G. Young was the Contract Administrator for the Bureau of Mines.

Work at the Bendix Research Laboratories was conducted in the Machine Systems Department under the direction of Mr. R. G. Read, Project Supervisor, with the assistance of Messrs. W. R. Kee, C. R. Kelso, C. K. Smith, J. H. Tarter, A. Tomala and R. P. Walter. Significant contributions were made to this program by Messrs. C. W. Fitzgerald and R. A. Lehner of Joy Manufacturing Company, Franklin, Pennsylvania; Drs. H. D. Dahl and D. Choi of the Continental Oil Company, Ponca City, Oklahoma; and Mr. G. L. Judy of G. L. Judy Associates, McLean, Virginia.

This report is a summary of the work recently completed as part of this contract during the period 1 July 1973 to 1 January 1974. This report was submitted by the authors on 4 February 1974.

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## EXECUTIVE SUMMARY

The objective of this program, conducted by the Bendix Research Laboratories, was to develop the design for a continuous mining machine using high-pressure water jets for cutting coal. A four-member team headed by Bendix and assisted by the Joy Manufacturing Company, Continental Oil Company and G. L. Judy Associates conducted the six-month design study completed in January 1974.

The program objectives and the machine design specifications, which are described in the introduction to this report, may be summarized as follows:

Develop a design for a practical, prototype, hydraulic coal mining machine to produce coal at 6 tons per minute in seams 5 to 8 feet high using water at cutting pressures up to 65,000 psi. Operator safety, visibility, exposure to machine noise and equipment permissibility are important design parameters.

The analysis of water jet cutting of coal, as described in the section of this report titled "Analysis of Jet Cutting of Coal," was based on the results of field tests conducted by the Continental Oil Company in 1972. Based on this data a set of equations have been derived which relate important jet cutting parameters, such as kerf depth, kerf distance, space between kerfs, traverse velocity, nozzle flow and pressure characteristics, and production rates. These tests also indicated that mechanical cutting/wedging means were necessary to assure coal extraction between kerfs and to clean-up the roof and ribs of the mining area.

The mining-machine cutter-head configuration was derived as described in the section of this report titled "Development of Cutter Head Concepts." This concept was based on a tradeoff study of various configurations of water-jet nozzle arrangements augmented with mechanical cutting wheels, wedges and/or cutting chains. The cutter head and water jet system has been designed for the adverse mine environment with intensifiers and high-pressure lines and nozzles protected on the miner boom.

Based on a study of existing continuous-miner designs as discussed in the section of this report titled "Continuous-Miner Design," the Joy 12CM machine was selected as the basis of the hydraulic jet miner design. High-pressure water intensifiers analytically evaluated included Kobe, Flow Research and Bendix designs. The power supply equipment required to drive the jet cutting system was sized. System integration layout drawings for the installation of all subsystems on the modified Joy 12CM chassis and an auxilliary trailing vehicle also used for equipment installation are described in the section titled "Continuous-Miner Design."

The analysis of the hydraulic-jet coal-mining machine considering operating sequences, operator safety, impact on mine environment and the economic comparison with present continuous miners is discussed under "Mining Machine Analysis."

The conclusions and recommendations resulting from the work done on this contract are discussed at the end of this report. An abstract of the conclusions is as follows:

- (1) The machine design evolved is a feasibility design and not a production prototype. A prototype design would require a major redesign of existing continuous miners.
- (2) The necessary power demand of the hydraulic-jet continuous miner is excessive in that it would exceed 1200 horsepower.
- (3) The probability of the jet-cutter mining machine producing 6 tons of coal per minute is very low without (a) substantial increase in jet cutter power, (b) an effective use of mechanical cutting and/or wedging means to augment the hydraulic jets, (c) or an increase in water flow rates to allow high-horsepower jet operation at low (below 15,000 psi) cutting pressures.
- (4) The initial cost and maintenance of the hydraulic jet machine will be greater than those of existing continuous-mining machines.
- (5) The hydraulic-jet continuous-miner design does not improve operator visibility, does not eliminate completely the hazard of sparking and has a minimum operating seam height of approximately 6 feet.

It is recommended that no further development of the hydraulic-jet continuous miner should be undertaken at this time until further developmental tests are performed. Specifically, data is required on (1) jet pressure-flow characteristics to find the optimum power input-to-production output ratio at high flow-low pressure values and (2) fracture characteristics and methods of fracturing coal weakened by jet kerfs with fracture assist by wedging or other mechanical means.

## INTRODUCTION

### PROGRAM OBJECTIVES

The general objective of this program was to determine the practicality of mining coal by water-jet cutting. The specific objectives were to (1) develop the design for a prototype, hydraulic coal-mining machine; (2) base the design on meeting practical performance goals in terms of seam height, production rate and improved health and safety aspects and others; and (3) prepared manufacturing drawings of the mining machine.

The background leading to this program was discussed in the Statement of Work issued by the Bureau of Mines on 19 March 1973 and was stated as follows:

"The main objective of mining research in the Bureau of Mines is to develop the scientific, technological, and engineering base for increasingly safe, healthful, and efficient mining methods having minimal impact on the environment. The Nation's needs for energy will double between now and 1985, and coal is expected to satisfy a large measure of this demand.

"Among the more promising techniques for underground coal mining which may meet the health and safety requirements implicit and explicit in the Federal Coal Mining Health and Safety Act of 1969 and the Nation's energy and economic requirements is hydraulic mining. Health and safety advantages of hydraulic mining are: (1) Dust problems are greatly reduced, (2) methane ignition is substantially reduced, and (3) damage to rock from vibrations is greatly reduced when compared to conventional methods. Hydraulic mining may also lend itself to the use of other subsystems for loading and transporting which are inherently safer than those in use today.

"The state of the art of hydraulic cutting technology is such that hydraulic jet mining machines are technically feasible today. There exists an urgent need to determine the practicality of hydraulic mining of coal utilizing new and advanced hydraulic technology, to promote the development of mining systems assuring the health and safety of the miner while meeting the energy needs of the Nation."

The objective of the program, as defined in the Statement of Work:

". . . is to develop the design for a practical prototype hydraulic coal mining machine. The use of hydraulic mining

technology, depending on the configuration adopted, may make possible the combination of functions and/or the introduction of other new technologies. The basic design desired is a replacement for the continuous miner used for more than fifty percent of our underground production."

## DESIGN SPECIFICATIONS

The project objective and design specifications listed in Contract H0133052, dated 29 June 1973, were as follows:

### Objective

"The objective of this project is to develop the design for a practical prototype hydraulic coal mining machine. The hydraulic coal mining machine shall be a hybrid cutting system consisting of a cutting head with five intensifiers with twin nozzles and a series of wedging wheels or disk cutters mounted on a modified Joy 12 CM miner."

### Design Specifications

- The Contractor shall design a hydraulic coal miner for use in underground coal mines in flat lying seams from 5 to 8 feet in height underlain by clay or shale.
- The hydraulic coal miner shall be designed to be movable and selfpropelled and it shall move through its work cycle at the same rates as present continuous miners.
- The hydraulic coal miner shall use water as the cutting medium with jet pressures up to 65,000 psi.
- The hydraulic coal miner shall be designed so that the side of the finished cut will be plumb to eliminate dangerous overhangs.
- The hydraulic coal miner shall be designed to mine coal from the floor to 8 feet above the floor of the work place.
- The miner shall be designed to control the line of the top of the cut to leave a smooth roof of roof rock or top coal.
- The hydraulic coal miner shall be designed so that the operator is physically protected from falling and flying objects.
- The hydraulic coal miner shall be designed so that the operator has visibility to the coal face.
- The hydraulic coal miner shall be designed so that it is "permissible" to work in underground coal mines, in accordance with Schedule 2G, electric motor driven mine equipment and accessories and other appropriate Bureau of Mines regulations.

- The hydraulic coal miner shall be designed so that it can load the broken coal and discharge it onto conventional coal transport equipment.
- The hydraulic coal miner shall be designed so that the jet noise will be suppressed so that the noise level within the area occupied by the operator and support personnel will be within the tolerance range as provided by the Federal Coal Mine Health and Safety Act.
- The hydraulic coal miner shall be designed to mine coal at the same cutting and extraction rate of present continuous miners. The instantaneous mining rate shall be at least six (6) tons per minute.

## DESCRIPTION OF TASKS

The program plan for the design of a hydraulic-jet coal miner was based on a schedule of seven major tasks to be completed in the period from July, 1973, to the end of January, 1974. The seven major tasks, which are described in detail below, were as follows: (1) jet cutter design and analyses, (2) continuous-miner design modifications, (3) production analysis, (4) design integration (5) system schematics, (6) permissibility analysis, and (7) detailed design and specifications. Tasks 1 and 2 were conducted concurrently and were scheduled to be completed three months after the start of the program. Tasks 3 and 4 were scheduled to be started three months after the start of the program and completed within six months. Publication of the final report was scheduled for on or before 1 February 1974.

The detailed descriptions of Tasks 1 through 7 are as follows (it should be noted that work was conducted only on Tasks 1, 2, 3, and 4, and that, because of the closing of the program, authorization was not given by the Bureau of Mines to proceed with Tasks 5, 6, or 7):

Task 1 - Jet Cutter Design and Analyses - The Contractor shall optimize the jet cutter machine design. The Contractor shall prepare, determine, and analyze preliminary layout drawings, sizing, and performance prediction calculations, correlation of Contractor's and other pertinent test experience including review of applicable jet cutter test data from Government and industry sponsored programs, component sizing and selection analyses, and matrix tradeoff studies of parametric data concerning the following technical areas: (1) intensifier, (2) nozzle, (3) hoses and plumbing, (4) power supply, (5) control, (6) noise suppression, and (7) interfaces.

Task 2 - Continuous-Miner Design Modifications - The Contractor shall determine the necessary design modifications to the continuous miner machine. The Contractor shall prepare, determine, and analyze preliminary layout drawings, sizing and performance prediction calculations, component

sizing, selection and installation studies, equipment design reviews, and matrix tradeoff studies of parametric data concerning the following technical areas: (1) cutter boom, (2) cutter head, (3) loader mechanisms, (4) operator station, (5) power supply, and (6) interfaces.

Task 1 and Task 2 shall run concurrently and shall be completed three (3) months after effective date of contract. The Contractor may proceed with Task 3 and Task 4 prior to completion of Task 2 if approved by the Government Technical Project Officer.

Task 3 - Production Analysis - The Contractor shall determine the man-machine interfaces, the operating procedures and the studies of production necessary to meet the instantaneous coal-tonnage production rate of six (6) tons per minute, and at the same time meet the health, safety, and permissibility requirements.

Task 4 - The Contractor shall accomplish a layout design study which shall integrate the jet cutter candidate concepts and the continuous-miner design configurations into a final machine design concept. The preliminary results of this total machine design configuration study shall be presented at the design review. The output of the layout design shall be a preliminary assembly drawing showing existing components for the hydraulic-jet continuous miner. The final layout drawings of this task shall be in sufficient detail such that the detail drawings of all components can be prepared from these layout drawings.

Task 3 and Task 4 shall run concurrently and shall be completed four (4) months after date of contract. The Contractor may proceed with Task 5 and Task 6 prior to completion of Task 4 if approved by the Government Technical Project Officer.

Task 5 - The Contractor shall prepare schematics for the continuous miner systems and shall include but not be limited to all necessary electrical, mechanical, and fluid power schematics necessary to define the operation and functioning of the hydraulic-jet continuous-miner machine. A preliminary set of schematics shall be prepared and presented at the design review at the U.S. Bureau of Mines.

Task 6 - The Contractor shall determine that the design of the hydraulic-jet continuous-miner machine shall comply with all permissibility requirements established in Schedule 2G, electric motor driven mine equipment and accessories, and other appropriate U.S. Bureau of Mines regulations. The layout design shall be compatible with normal safe mining procedures. The currently employed man-machine operations for the continuous miner shall be compared to the revised man-machine procedures for the hydraulic-jet continuous miner so that the man-to-hazard environment potential is in no way increased and, whenever possible, reduced. Task 5 and Task 6 shall be completed four (4) months after the effective date of the contract.

Design Review - On or before the fourth month of this contract, the Contractor shall prepare and present to the Bureau of Mines personnel at the Twin Cities Mining Research Center a two-day critical design review of the proposed hydraulic-jet coal miner.

Task 7 - Detail Design and Specifications - The Contractor shall prepare detail drawings in accordance with Military Specification MIL-D-1000, as specified by Category E of Form 3 of this specification, or an equivalent design specification as directed by the U.S. Bureau of Mines. As part of this task, all design drawings, which shall include subsystem assembly drawings, system assembly drawings, detailed component parts, engineering schematics, and engineering specifications of detailed component parts, shall be submitted and delivered with an unpublished, rough-draft final report to the U.S. Bureau of Mines. The report shall be prefaced by an executive summary not to exceed three pages.

## ANALYSIS OF JET CUTTING OF COAL

### SUMMARY OF TEST DATA SOURCES AND EXPERIENCE

In November 1969 a series of tests on the jet cutting of coal was performed at Bendix Research Laboratories on a block of coal in the approximate form of a 1.5-foot cube provided by Continental Oil Company. Data from these tests is shown in Table 1. Standoff distance varied from 0.25 to 0.50 in.

In 1972 Continental Oil Company ran a series of tests on the jet cutting of coal underground at Humphrey No. 7 Mine near Morgantown, West Virginia. In these tests, cutter nozzles were mounted on the cutter bar of a modified Joy 1CM continuous miner. Both Bendix and Conoco nozzles were used in these tests. Table 2 shows typical test data taken with the larger nozzle sizes designed and built by Conoco for moderate pressures. During these tests, an attempt was made to keep standoff distance to a minimum. It was observed that if the spacing between kerfs was roughly  $2/3$  of the kerf depth, coal would break out freely between kerfs. As a result of the analysis of this data, Bendix concluded that the power requirements for the mining of coal by high-pressure hydraulic jet cutting without mechanical assistance would be excessive.

### REDUCTION OF TEST DATA TO EMPIRICAL DESIGN DATA

To be useful, the coal cutting data must be reduced to some form of empirical expression which is capable of analytic manipulation. This provides a tool which can be used as an aid in selecting the best jet cutting parameters.

For the study being reported here, the most important coal cutting parameter is the depth of kerf, since it is assumed that this defines the depth to which the coal is extracted in a given operation of the mining machine. The depth of kerf may be assumed to be a function of the following parameters:

- (1) Properties of the coal
- (2) Standoff distance, i.e., distance of nozzle from surface being cut
- (3) Speed at which the jet is traversed across the surface being kerfed
- (4) Angle at which jet strikes the surface being kerfed
- (5) Nozzle diameter
- (6) Nozzle supply pressure

Table 1 - Summary of Test Data on Jet Cutting of Coal Taken  
by Bendix Research Laboratories

Nozzle diameter, in.	Pressure, ksi	Traverse speed, in/sec	Depth of kerf, in.	Water flow rate, gpm	
0.008	70	1	2	0.44	
		5	1		
		10	0.75		
		20	0.62		
	45	5	10	0.75	0.36
			20	0.62	
			20	0.50	
	25	5	10	0.44	0.28
			10	0.38	
20			0.25		
0.012	45	5	1.2	0.81	
		10	1		
		20	0.88		
		30	0.75		
	25	5	10	0.75	0.61
			10	0.62	
			20	0.50	
			30	0.38	
	15	5	10	0.38	0.47
10			0.25		
20			0.19		
30			0.19		

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Table 2 - Summary of Test Data on Jet Cutting Taken by Conoco - 1972

Nozzle diameter, in.	Pressure, ksi	Traverse speed, in/sec	Depth of kerf, in.
0.030	10	1.2	2.25
		3.6	1.50
		5.1	1.25
		12.0	1.00
	8	1.2	2.00
		2.0	1.625
		6.0	1.250
		16.0	0.875
	6	1.6	2.00
2.9		1.25	
8.9		1.00	
	15.4	0.75	
0.040	10	1.2	3.25
		2.0	2.50
		3.9	2.25
		6.7	1.50
		20.0	1.00
		1.0	2.75
		3.6	1.75
		6.7	1.25
		12.0	0.875
		1.2	2.25
		2.0	1.50
		4.0	1.50
		7.5	1.125
		20.0	0.625
		0.050	10
1.8	4.75		
1.4	5.00		
3.4	4.00		
7.3	3.00		
16.0	2.25		
8.7	3.00		
6	1.25		3.00
	1.90		3.00
	2.50		2.50
	5.26		1.25
	14.81		1.25
8	0.95		4.50
	1.6		4.00
	3.07		2.50
	6.06	2.00	
	14.28	1.50	
0.060	10	1.64	6.00
		0.83	8.00
		1.70	7.00
		3.40	5.50
		5.22	4.50
		15.33	2.00
	8	0.93	7.00
		2.3	5.50
		4.10	4.00
		6.57	2.00
		14.37	2.00
	6	0.97	2.00
		2.07	1.50
		4.18	3.00
		6.96	2.50
	15.33	2.00	
0.075	7	0.99	7.00
		1.71	5.25
		3.06	4.50
		6.05	4.25
		14.37	2.75
	6	1.10	6.25
		1.84	5.50
		3.65	4.50
		3.02	4.00
		9.2	2.5
	15.33	1.75	

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The last two parameters may be replaced by others such as nozzle power, nozzle flow and velocity, momentum, or kinetic energy.

In the data shown in Tables 1 and 2, the coal properties and the angle at which the jet intersected the surface tend to be fixed; the coal was from the same seam and the jet angle was nominally perpendicular to the surface being cut, varying only because of local irregularities. In addition, standoff tended to be a fixed minimal value, but would vary because of the irregular geometry of the surface. This would be most difficult to control in the underground environment. The data shown in Table 2 is for larger nozzle sizes where the effect of standoff is less important. Underground data taken with smaller nozzle sizes was not used to derive the correlation, because of inconsistencies which may be caused by unintentional variations in standoff distance.

As a first step in determining if an empirical correlation of the jet cutting data could be derived, the kerf depths from Tables 1 and 2 were plotted on a logarithmic scale as a function of traversing speed. These plots show an approximate tendency to linearize, as is shown in Figure 1. This implied a correlation of the form:

$$D_K = \frac{a}{V_K^K} \quad (1)$$

where

$D_K$  = Kerf depth, in.

$a$  = Constant, dependent on pressure and nozzle diameter,  
in<sup>1+K</sup>/sec<sup>K</sup>

$V_K$  = Traversing speed, in/sec

$K$  = Exponent, dimensionless

The value of the exponent  $K$  for each of the curves shown in Figure 1 was calculated and is tabulated in Table 3. In addition, to obtain a single parameter indicative of the properties of the jet, the jet horsepower has been calculated for each set of data and is tabulated in Table 3. The jet horsepower was calculated from

$$P_j = \frac{Q \Delta P}{1714} \quad (2)$$

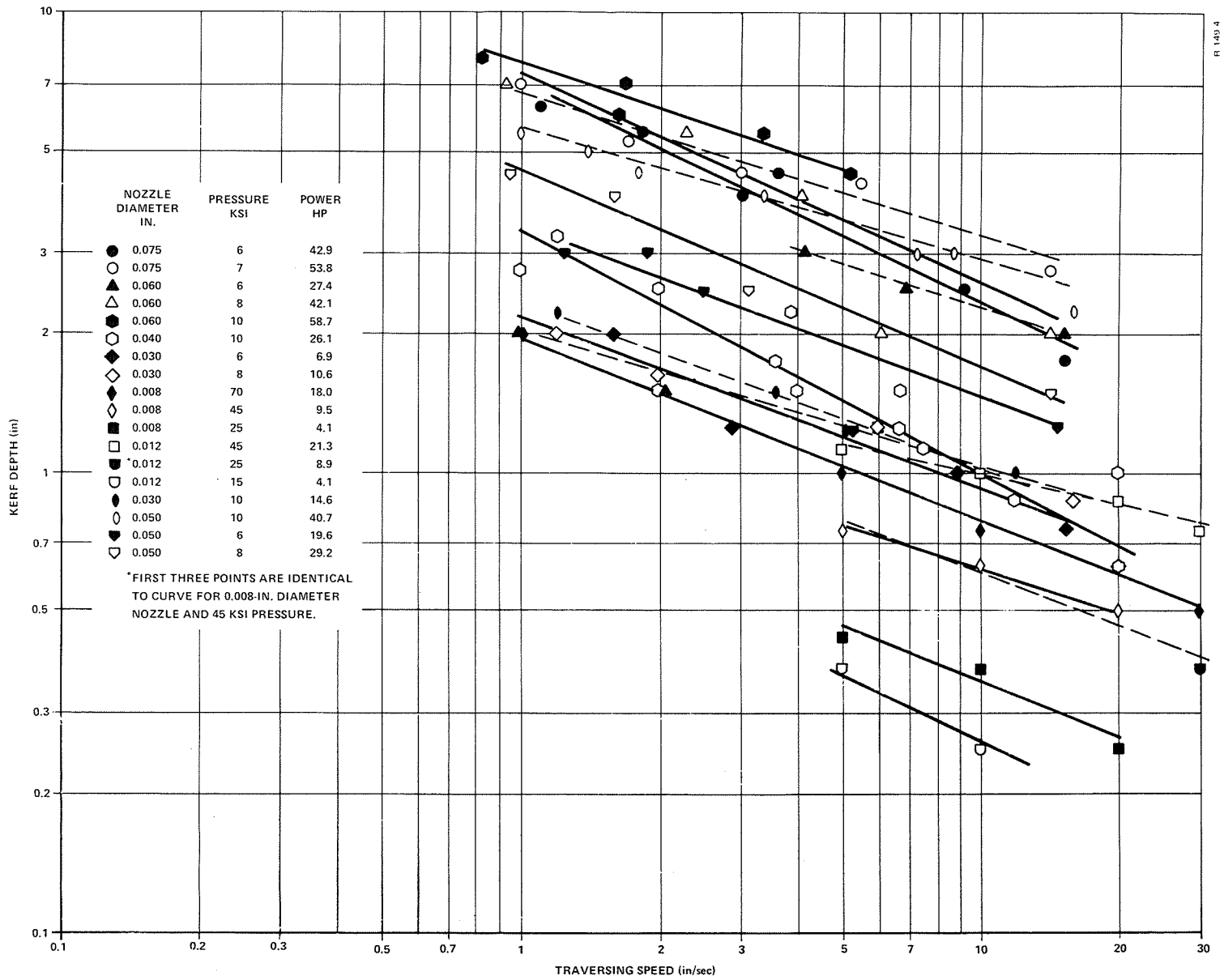


Figure 1 - Logarithmic Plot of Kerf Depth Versus Traversing Speed

Table 3 - Jet Cutting Parameters from Logarithmic Plot of  $D_K$  vs  $V_K$

d in.	P ksi	K from Fig. 1	$P_j$ , hp	$D_K$ at $V_K = 7$ in/sec, in.
0.008	70	0.393	18.0	0.91
	45	0.314	9.5	0.69
	25	0.405	4.1	0.40
0.012	45	0.222	21.3	1.07
	25	0.390	8.9	0.69
	15	0.489	4.1	0.31
0.030	10	0.353	14.6	1.16
	8	0.262	10.6	1.15
	6	0.370	6.9	1.05
0.040	10	0.529	26.1	1.20
0.050	10	0.293	40.7	3.20
	8	0.428	29.2	1.98
	6	0.379	19.1	1.67
0.060	10	0.328	58.7	4.10
	8	0.441	42.1	3.05
	6	0.324	27.4	2.55
0.075	7	0.309	53.8	3.70
	6	0.482	42.9	2.78

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where

$P_j$  = Jet horsepower

$Q$  = Jet flow, gpm

$\Delta P$  = Differential pressure across jet, psid

If not otherwise measured,  $Q$  was calculated from:

$$Q = 223.8 d^2 \sqrt{\frac{\Delta P}{\gamma}} \quad (3)$$

where

$d$  = Nozzle diameter, in.

$\gamma$  = Specific weight of water, lb/ft<sup>3</sup>

Equation (3) assumes an orifice coefficient of 0.95. The value of  $\gamma$  was assumed to be 70.2 lb/ft<sup>3</sup> at 65,000 psi and to be a linear function of pressure between this value and the zero pressure value of 62.4 lb/ft<sup>3</sup>.

Also tabulated in Table 3 are the values of  $D_K$  corresponding to  $V_K = 7$  in/sec. This value of  $V_K$  was selected since it lies on most of the plots shown in Figure 1 without a great deal of extrapolation.

The average of the eighteen values of the exponent  $K$  shown in Table 3 is 0.373. The distribution of the eighteen values of  $K$  appears to be nearly Gaussian.

Another observation that immediately becomes apparent on studying Table 3 is that kerf depth increases with the horsepower of the jet. Plotting the kerf depth at  $V_K = 7$  in/sec as a function of jet horsepower, as has been done in Figure 2, indicates that the relationship is linear.

Based upon  $K = 0.373$  and using the linear relationship between jet horsepower and kerf depth implied by Figure 2, the following relationship for  $D_K$ , based on average values, can be derived

$$D_K = \frac{0.15 P_j}{V_K^{0.37}} \quad (4)$$

To avoid extrapolation, use of equation (4) would have to be limited to values of  $D_K$  less than 8 in, to values of  $P_j$  from 4 to 60 hp, and to values of  $V_K$  of 0.8 to 30 in/sec.

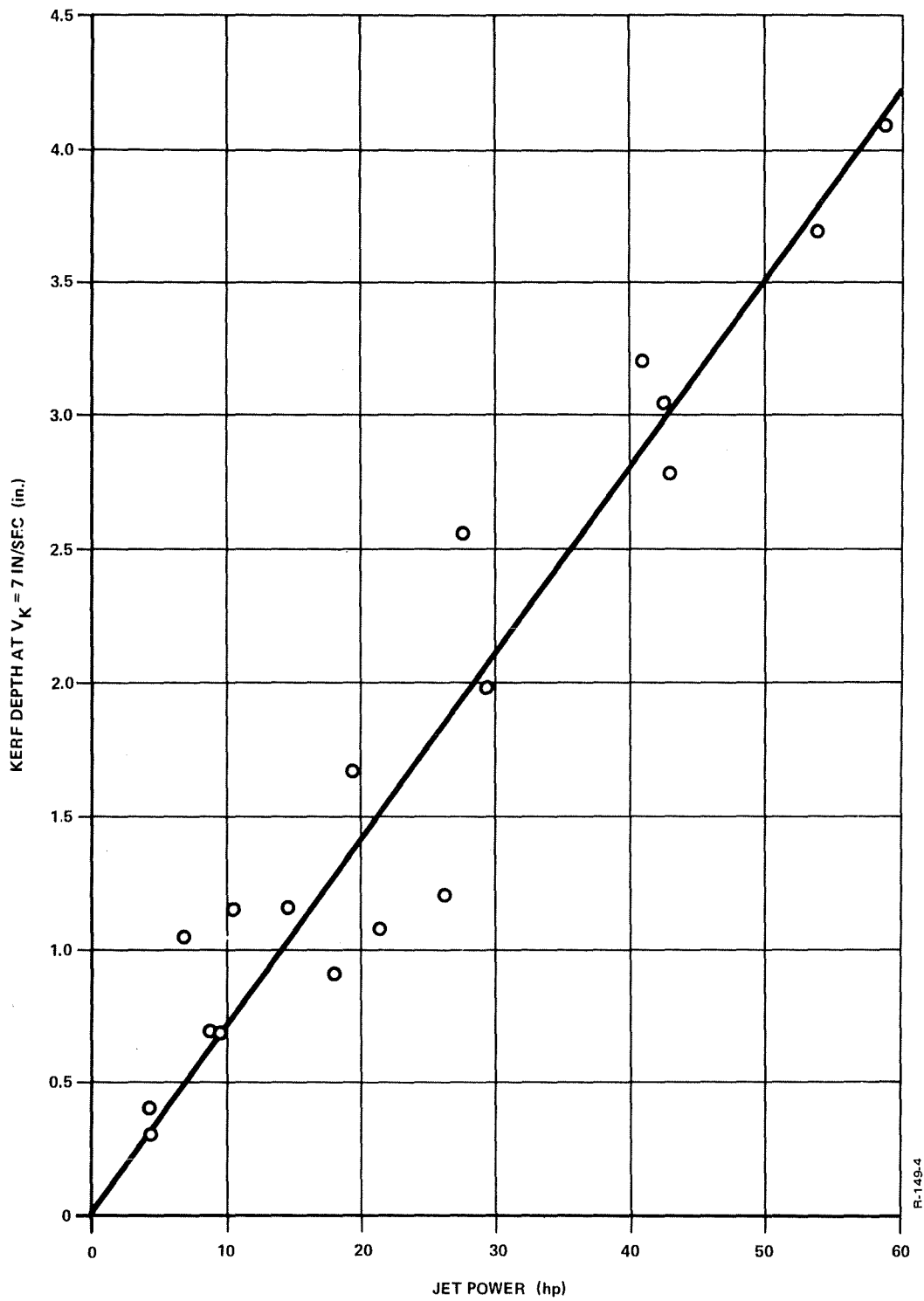


Figure 2 - Kerf Depth at  $V_K = 7$  in/sec as a Function of Jet Horsepower

An effort was made to confirm equation (4). Review of jet cutting performance, predicted by personnel from Continental Oil Company consulting on this program, showed that the predicted kerf depths could be correlated by

$$D_K = \frac{0.15 P_j}{V_K^{0.5}} \quad (5)$$

A Russian paper, Reference 1, gives an equation for kerf depth as follows, using notation from the reference,

$$h_s = \frac{0.5 d_o}{\left(\frac{V_t}{V_o}\right)^{0.5}} \left(\frac{P_o}{100f} - 0.2\right) \quad (6)$$

where

$h_s$  = Kerf depth, mm

$d_o$  = Nozzle diameter, mm

$V_t$  = Traversing velocity, m/sec

$P_o$  = Nozzle pressure,  $\text{kg/cm}^2$

$f$  = Protodyakonov hardness (approximately equal to square of compressive strength divided by Young's modulus),  $\text{kg/cm}^2$

$V_o$  = Emission velocity from nozzle =  $13.3 \sqrt{P_o}$ , m/sec

The factor  $(P_o/100f - 0.2)$  is very nearly equal to  $P_o/100f$ . Since the term  $d_o \sqrt{V_o}$  is approximately proportional to  $\sqrt{Q}$ , then equation (6) is equivalent (for a given coal) to

$$D_K = \frac{b \Delta P \sqrt{Q}}{V_K^{0.5}} \quad (7)$$

while equations (4) and (5) are equivalent to

$$D_K = \frac{c Q \Delta P}{V_K} \quad (8)$$

where b and c are constants which depend on coal properties. Equation (6) is based on experimental data which, for coal, involves pressures no higher than 500 kg/cm<sup>2</sup> (7113 psi) which is near the lower limit of the data shown in Tables 1 and 2. Equation (6) appears to predict deeper kerf depths than are shown by the data of Tables 1 and 2, recognizing that the number f is undefined. The divergence appears to increase as pressure increases.

Equation (5) was selected for use in performing the baseline analysis for this project. This selection was based on the fact that the use of K = 0.5 is more conservative than the use of K = 0.37. Equation (6) also is viewed as offering some support to the use of K = 0.5. It should be noted that there is considerable scatter in the data, and a factor of 2, either way, applied to equation (5), does not quite take in all the data points of Tables 1 and 2. This is shown in Figure 3.

#### APPLICATION OF EMPIRICAL DESIGN DATA TO HYDRAULIC-JET COAL MINER

Prediction of the performance of the hydraulic mining machine based upon the empirical equation derived in the previous subsection requires that additional equations be developed which combine the jet cutting parameters with the geometry of the mining machine to express a production rate as follows:

$$T_{pm} = 1.41 \times 10^{-3} (V_K D_K W) \quad (9)$$

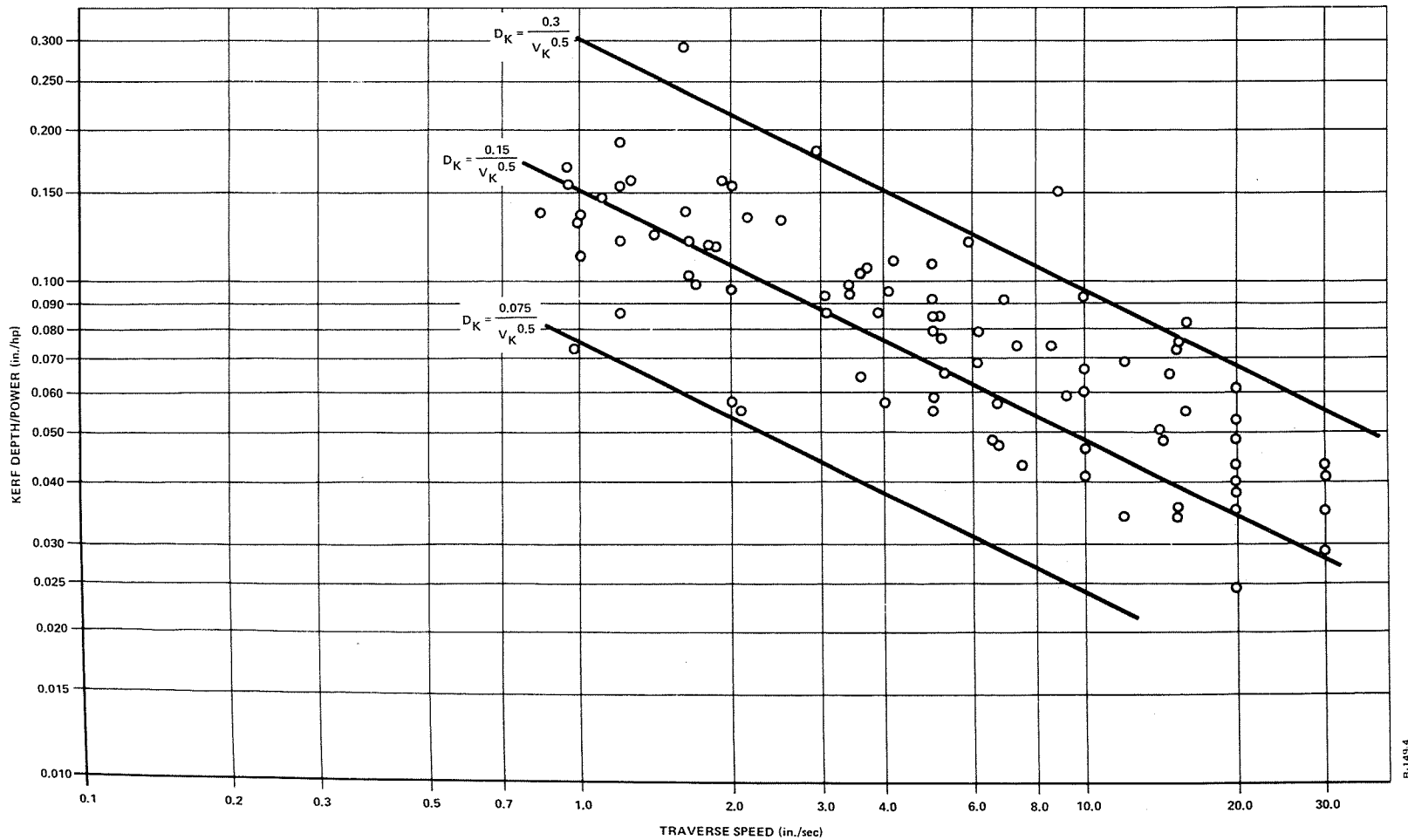
where

$T_{pm}$  = Rate at which coal is extracted, tons per minute (tpm)

W = Width of the face from which coal is being extracted, in.

$D_K$  and  $V_K$  as previously defined.

In writing equation (9), it is assumed that the specific weight of coal is 81 lb/ft<sup>3</sup> and that coal is extracted fully to the depth of the kerf.



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Figure 3 - Logarithmic Plot of Specific Kerf Depth Versus Traversing Speed

Based on equations (4) and (5),

$$V_K = \left( \frac{K_P P_j}{D_K} \right)^{1/K} \quad (10)$$

where  $K_P$  is a constant of proportionality relating the depth of kerf in inches to the horsepower of the cutter jet.

There is some critical ratio,  $n$ , of the kerf pitch,  $p_K$ , to the kerf depth,  $D_K$ , that allows coal to be extracted completely to the full depth of kerf. That is, given  $n = p_K/D_K$ , if  $n$  is greater than the critical value, complete extraction will not occur; if  $n$  is less than the critical value, complete extraction will occur. During their underground testing, Conoco observed that with no mechanical assistance, the critical value of  $n$  was approximately 0.67. It is assumed that with mechanical assistance, such as a wedging blade or wheel, the critical value of  $n$  will be increased.

Substituting equation (10) into equation (9) and substituting  $D_K = p_K/n$  into the resulting equation gives

$$T_{pm} = 1.41 \times 10^{-3} \left( \frac{n}{p_K} \right)^{\frac{1-K}{K}} \left( K_P P_j \right)^{1/K} W \quad (11)$$

If it is assumed that  $N$  jets are equally spaced across the width,  $W$ , then

$$p_K = \frac{W}{N+1} \quad (12)$$

Substitution of equation (12) into equation (11) gives

$$T_{pm} = 1.41 \times 10^{-3} [n(N+1)]^{\frac{1-K}{K}} \left( K_P P_j \right)^{1/K} \left( \frac{1}{W} \right)^{\frac{1-2K}{K}} \quad (13)$$

Another expression of interest is obtained by substituting equation (10) into equation (9) to eliminate  $D_K$  and solving for  $V_K$  to give

$$V_K = \left( \frac{709 T_{pm}}{W K_P P_j} \right)^{\frac{1}{1-K}} \quad (14)$$

One final expression is derived by noting that the total hydraulic power,  $P_T$ , is given by

$$P_T = N P_j \quad (15)$$

Substituting equation (15) into equation (13) gives

$$\frac{T_{pm}}{P_T} = 1.41 \times 10^{-3} [n(N+1) P_T]^{\frac{1-K}{1}} \left(\frac{K}{N}\right)^{1/K} \left(\frac{1}{W}\right)^{\frac{1-2K}{K}} \quad (16)$$

If, as was stated previously, it is assumed that

$$K_p = \frac{0.15 \text{ in. (in/sec)}^K}{\text{hp}}$$

and

$$K = 0.5$$

then

$$K_p = \frac{0.15 \text{ in. (in/sec)}^{0.5}}{\text{hp}}$$

and the significant equations become

Equation (11)

$$T_{pm} = 1.41 \times 10^{-3} \left(\frac{n W}{P_K}\right) \left(0.15 P_j\right)^2 \quad (17)$$

Equation (13)

$$T_{pm} = 1.41 \times 10^{-3} n (N+1) (0.15 P_j)^2 \quad (18)$$

Equation (14)

$$V_K = \left( \frac{709 T_{pm}}{0.15 W P_j} \right)^2 \quad (19)$$

Equation (16)

$$\frac{T_{pm}}{P_T} = 1.41 \times 10^{-3} n (N+1) P_T \left( \frac{0.15}{N} \right)^2 \quad (20)$$

Equation (17) defines the peak extraction rate in terms of  $W$ ,  $P_K$ ,  $P_j$ , and  $n$ . This extraction rate occurs at a given value of  $V_K$ , which is defined by equation (19). If a lower value of  $V_K$  is used, complete extraction will be obtained, but the extraction rate will be less than the value given by equation (17). If a larger value of  $V_K$  is used, extraction of coal between kerfs will be incomplete. Equation (17) illustrates the importance of obtaining a high value of  $n$  and the importance of minimizing  $P_K$ .

The significance of equation (18) is that it shows that it is better to operate a small number of high-power jets than a large number of low-power jets. This is a consequence of the fact that doubling the number of jets by cutting the power per jet in half will less than double the term  $(N+1)$  while reducing the term  $(K_p P_j)^2$  by a factor of four.

Equation (20) indicates that the tons per minute per horsepower increases as the total jet cutting power increases. The term  $(N+1)/N^2$  confirms the desirability of minimizing  $N$ .

In order to evaluate the effect of the exponent  $K$  on these conclusions, the value  $K = 0.37$  has been substituted into the appropriate equations to obtain

Equation (11)

$$T_{pm} = 1.41 \times 10^{-3} \left( \frac{n}{P_K} \right)^{1.7} (0.15 P_j)^{2.7} W \quad (21)$$

Equation (13)

$$T_{pm} = 1.41 \times 10^{-3} [n(N+1)]^{1.7} (0.15 P_j)^{2.7} \left( \frac{1}{W} \right)^{0.7} \quad (22)$$

Equation (14)

$$V_K = \left( \frac{709 T_{pm}}{0.15 W P_j} \right)^{1.6} \quad (23)$$

Equation (16)

$$\frac{T_{pm}}{P_T} = 1.41 \times 10^{-3} [n(N+1)P_T]^{1.7} \left( \frac{0.15}{N} \right)^{2.7} \left( \frac{1}{W} \right)^{0.7} \quad (24)$$

Equations (21) through (24) do not change any of the conclusions drawn from equations (17) through (20). However, the change in exponent changes the strength of certain parameters. For example, in equation (21) the influence of the parameters  $n$ ,  $p_K$ , and  $P_j$  on  $T_{pm}$  has been increased. Equation (22) still shows that it is advantageous to use a few high-power jets, rather than distributing the available jet horsepower over many jets. However, with  $K = 0.5$ , the term  $W$  did not appear in equation (18), while it does appear as a negative 0.7 power in equation (22). This indicates that some advantage in production rate would result by extracting coal across a narrower face width, although a higher value of  $V_K$  would be required. Equation (23) shows that with  $K < 0.5$ , smaller values of  $V_K$  are required to obtain a given value of  $T_{pm}$ . The conclusions drawn from equation (24) are similar to those drawn from equation (20), with the relative influence of certain parameters changed. Once again, it is shown that if  $K < 0.5$ , some advantage results from minimizing the value of  $W$ .

#### CRITICAL PARAMETERS AFFECTING PRODUCTION RATE

Based on the dimensions of the Joy 12CM gathering head, the face width across which coal is extracted,  $W$ , will be 32 in. A cutter boom frame compatible with a Joy 12CM mining machine chassis can contain a maximum of eight intensifiers which, because of constraints on installed power, as described under "Power Supply" below, can operate 53.5-hp cutter nozzle.

Substitution of values  $T_{pm} = 6$  tpm,  $W = 132$  in., and  $P_j = 53.5$  hp into equation (19) yields  $V_K = 16.1$  in/sec. Substitution of this value of  $V_K$  into equation (5) gives  $D_K = 2.00$  in.

If the eight jets were equally spaced across the width of the face, the kerf pitch,  $p_K$ , would be 14.7 in. However, in order to use standard parts for the cutter chain, a slightly uneven spacing of jets was adopted, as will be shown in the next section. Because of this uneven spacing, the maximum value of  $p_K$  is 16.5 in., which gives a maximum required value of  $n$  equal to 8.25.

Considerable concern has been expressed that wedging coal out from between kerfs as widely spaced as described above is impractical. The feeling is that the coal may break out some distance on either side of

the kerf, leaving most of the coal central to the kerfs to be removed by the cutter wheels and chains. This would, in effect, give a cutting mechanism which would be best described as a hydraulically augmented mechanical cutting process which would possess most of the combined disadvantages of mechanical cutting and jet cutting while giving few, if any, of the advantages expected to accrue from jet cutting. Unfortunately, there is no information available regarding the magnitude of the maximum kerf pitch-to-depth ratio at which complete extraction by wedging can be obtained.

The numbers presented above presume that coal is being extracted on both the upward and the downward sweep of the boom. If this can be done, the instantaneous production rate will approach the value of  $T_{pm}$  used in equation (19). However, the question arises regarding the ability of the mining machine to extract coal on an upward stroke, working against the weight of the boom. If coal can be wedged out only on a downward stroke, when the weight of the boom is aiding, then the best sequence of methods is to use the upward swing of the boom to place kerfs in positions intermediate to the kerfs made during the downward stroke, but without attempting to wedge or extract coal. As will be shown in the next section, this will reduce the kerf pitch range from 7.5 to 9 in., which reduces the maximum required value of  $n$  to 4.5. This is a great reduction from the previous value of 8.25, but it is still not evident that a complete breakage between kerfs can be achieved over this wide a span. Moreover, if the procedure of extracting coal only on the downward stroke is used, using the upward stroke to place intermediate kerfs, then the instantaneous production rate can approach only half the value of the peak rate,  $T_{pm}$ . For a value of  $V_K = 16.1$  in/sec, the instantaneous rate will then be less than 3 tpm.

Another area requiring investigation is the power demand required to traverse the boom at a 16.1 in/sec velocity. Scaling the preliminary mining machine layout, BRL drawing number 2179161, (refer to Figure 13) shows that the tip of the cutter head is 138 in. from the cutter-boom pivot point. The shear cylinders attach to the cutter boom at a point 27 in. from the pivot point. The shear cylinders are at an angle of approximately 45 degrees to the line of action in their most unfavorable orientation and at an angle of 9 degrees to the line of action in their most favorable orientation. The most favorable position is when the boom is raised to the 8-foot height. The shear cylinder bore is 8.44 in. and the rod diameter is 3.75 in. Flow into the rod end of the cylinder raises the boom.

Based on these numbers, a flow of 130 gpm into the piston end of the shear cylinders (boom going down) and a flow of 104 gpm into the rod end of the shear cylinders (boom going up) is required to produce a value of  $V_K = 16.1$  in/sec. These values correspond to a cutter head height of 8 feet; with the cutter head on the floor, the corresponding flows are 92 and 74 gpm.

The flow rate for the standard Joy 12CM hydraulic pump is 33 gpm at 2000 psig. Hence, achievement of the traversing rate required to obtain a peak production rate of 6 tpm would require a hydraulic pump in the service hydraulic circuit having a capacity four times that of the presently used pump.

A final task of the jet cutting analysis considered how various variations in assumed jet cutting parameters would affect the required critical value of  $n$  (ratio of kerf pitch to kerf depth). The results of this part of the analysis are summarized in Table 4. These comparisons all assume an instantaneous production rate of 6 tpm. (This requires  $T_{pm} = 12$  tpm for the mode in which coal is wedged out on the downstroke only.) In these calculations, it is assumed that jets are equally spaced across the width of the face, which yields slightly different values of  $n$  from those obtained in those calculations based on the dimensions shown in Figure 12.

The first two entries in Table 4 show that if an instantaneous rate of 6 tpm is to be achieved, there is no advantage in using the mode in which intermediate kerfs are cut on the upstroke of the boom and coal is wedged out and extracted on the downstroke of the boom. In fact there is a definite disadvantage, since the required critical value of  $n$  increases slightly even though the kerf pitch is cut in half, and this is all at the expense of a four-fold increase in the required traversing velocity. The only advantage in cutting intermediate kerfs is that it reduces the absolute kerf pitch. If it would prove impossible to provide enough boom force to wedge out coal while acting against the weight of the boom, then this mode should be used, but the instantaneous rate will be less than 6 tpm.

The spread in the data, as shown in Figure 3, is such that, at least under some conditions, the value of  $K_p$  may be higher than the assumed value of 0.15 in. (in/sec)<sup>0.5</sup>/hp. The third and fourth entries in Table 4 show that if the value of  $K_p$  is doubled, the required values of  $V_K$  and  $n$  are divided by four, producing values that would appear to be achievable, at least for removal on both sweeps of the boom.

Unfortunately, the spread in the data makes it likely that  $K_p = 0.075$  in. (in/sec)<sup>0.5</sup>/hp, which leads to impractical values of  $V_K$  and  $n$  as shown in the fifth entry in Table 4.

The available data suggests that the value of  $K = 0.5$  may be high. If a correlation according to equation (4) is assumed ( $K = 0.37$ ), then  $V_K = 9.24$  in/sec and the critical value of  $n = 4.17$ . This value of  $n$  may still be high, but the numbers are more acceptable than those that result from assuming that  $K = 0.5$ . The spread in the data is such that a value of  $K = 0.37$  is not precluded.

The final entry in Table 4 shows the effects of using seven 60-hp jets, which are very nearly equivalent to eight 53.5-hp jets. This confirms the previous observation that, based on the assumed correlation, it is best to concentrate the available jet horsepower in a few nozzles.

Table 4 - Effect of Variations in Parameters on Critical Value of n

Mode	$P_j$ , hp	N	$K_p, \frac{\text{in. (in/sec)}^K}{\text{hp}}$	K	V, in/sec	$D_K$ , in.	n
Kerf & wedge up, kerf & wedge down	53.5	8	0.15	0.5	16.1	2.00	7.34
Kerf up, kerf & wedge down	53.5	8	0.15	0.5	64.5	1.00	8.25
Kerf & wedge up, kerf & wedge down	53.5	8	0.3	0.5	4.03	7.99	1.83
Kerf up, kerf & wedge down	53.5	8	0.3	0.5	16.1	4.00	2.06
Kerf & wedge up, kerf & wedge down	53.5	8	0.0075	0.5	64.5	0.500	29.36
Kerf & wedge up, kerf & wedge down	53.5	8	0.15	0.37	9.24	3.52	4.17
Kerf & wedge up, kerf & wedge down	60	7	0.15	0.5	12.8	2.52	6.55

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The results and conclusions of this section, based on the assumed correlation of the test data, may be summarized as follows:

- (1) The available jet cutter power should be concentrated in a few nozzles, rather than dispersed among many nozzles.
- (2) Total jet cutter power should be maximized to obtain best efficiency.
- (3) Achievement of an instantaneous rate of 6 tpm using jet cutting parameters based on averaged correlations requires traversing velocities ( $V_K = 16.1$  in/sec for  $K = 0.5$  and  $V_K = 9.24$  in/sec for  $K = 0.37$ ) higher than are possible with the existing by 12CM hydraulic power supply, which in one case is four times higher than is possible with the existing 50 hp 12CM hydraulic power supply, and also requires that mechanical means be used to break out coal between relatively widely spaced kerfs ( $n = 7.34$  for  $K = 0.5$  and  $n = 4.17$  for  $K = 0.37$ ). There is no test data information to support the assumption that complete break out across spans of this magnitude is possible. Although some increase in the flow capacity of the existing 12CM hydraulic power supply could undoubtedly be achieved by use of a more efficient hydraulic pump, any substantial increase in flow output would require an increased power level in the hydraulic power supply. This would introduce some severe packaging problems. In addition, as will be described under "Power Supply" below, installed power required to supply the eight 53.5 hp intensifiers is already at the limit of what can be provided through a practical trailing cable.

- (4) If kerf depths approximately double those predicted by averaging the test data are obtained, apparently realistic values of  $V_K$  and  $n$  result. However, this requires extraction of coal on both the upward and downward sweeps of the cutter boom. If the wedging action can be performed only on a downward sweep, attainment of the instantaneous rate of 6 tpm requires a traversing speed  $V_K = 16.1$  in/sec, approximately four times that possible with the existing Joy 12CM mining-machine hydraulic power supply.

## DEVELOPMENT OF CUTTER HEAD CONCEPT

### CUTTER HEAD REQUIREMENTS

The cutter head is one of the most important parts of the mining machine. Investigation of cutter head concepts and derivation of the cutter head configuration, therefore, received major emphasis during this program.

The cutter head of the hydraulic-jet coal miner must provide for the performance of the following functions:

- (a) Kerfing of the coal by the hydraulic jets.
- (b) Extraction of the kerfed coal by some means of mechanical assistance.
- (c) Trimming of coal from the roof, walls, and floor to maintain required control of passage dimensions.
- (c) Providing assistance in gathering of coal.
- (e) Providing a backup means of cutting coal so that local failures of the basic kerfing and mechanical fracturing process will not stall the overall operation.

The kerfing of the coal by the action of the hydraulic jets is the basic operation to be performed by the hydraulic coal mining machine. This requires that the cutter head be provided with one or more sets of jet cutter nozzles so located as to place kerfs in the coal face at appropriate locations. If more than one set of nozzles is used, means to switch operation from one set of jets to another is required. Since the pressure of the water supplied to the cutter nozzles may be expected to be at a value higher than would normally be used with conventional hose of flexible construction, provision must be made for installing the intensifiers on the cutter head side of any articulation of the cutter boom.

As was mentioned in the preceding section, cutting of coal by purely hydraulic means requires excessive consumption of power. Some form of mechanical assistance to extract the coal from the face after it is kerfed must, therefore, be used. However, to minimize the spark and dust hazard and disturbance of the overlying strata, the mechanical assistance mechanism should be relatively nonviolent in nature. The hydraulic-jet continuous-miner design described in this report is based on the use of wedging wheels or blades which ride in the kerfs, breaking out the coal between the kerfs as the cutter boom traverses the face.

Maintaining the dimensions of the passage cut through the coal seam at desired values is of obvious importance. If passage dimensions

decrease as the mining machine advances, the depth of penetration along any path is obviously limited. Preliminary studies indicated that it would be nearly impossible to obtain reliable extraction of coal by kerfing and wedging at the outer boundaries of the envelope traversed by the cutter head. Therefore, it was concluded that provision for mechanical cutting at the outer boundaries of the face would be required to prevent passage dimensions from decreasing as the mining machine advanced and to obtain a sufficiently uniform surface to minimize the falling of coal from the roof and wall after the mining machine had passed.

A continuous mining machine must have the ability to extract coal from below the floor level. This is required to enable the operator to follow the undulations of the seam. Without this feature, a machine having once adopted a climb angle would be unable to resume a level attitude again. The ability to mine coal from below the floor level implies that the cutter head must extend beyond the gathering head. Hence, coal will pile up on the floor in front of the gathering head. The design must provide for the cutter head to work its way through this accumulated coal without either jamming or propelling coal lumps away from the face toward the operator. Some mechanical motion must be provided which will direct coal piled in front of the gathering head onto the gathering head.

Because of the character of the kerfing and wedging process and because of the non-uniform properties of coal, it may be expected that, from time to time, complete fracturing of the coal from the face between kerfs will not occur. In order that this event not bring the coal mining process to a halt, the cutter head design must provide for the removal of any coal protruding from the face which was not extracted by a previous pass of the cutter head.

## CUTTER HEAD CONCEPTS CONSIDERED

As part of the preliminary investigation of cutter head concepts, the following means of traversing the face were considered.

- (a) Horizontal swing of cutter boom.
- (b) Combined horizontal and vertical swing of cutter boom.
- (c) Vertical swing of extensible boom.
- (d) Vertical swing of boom with variable-position pivot.
- (e) Vertical swing of fixed-radius boom.

The first alternative was eliminated because it is fundamentally inconsistent with a variable seam height capability.

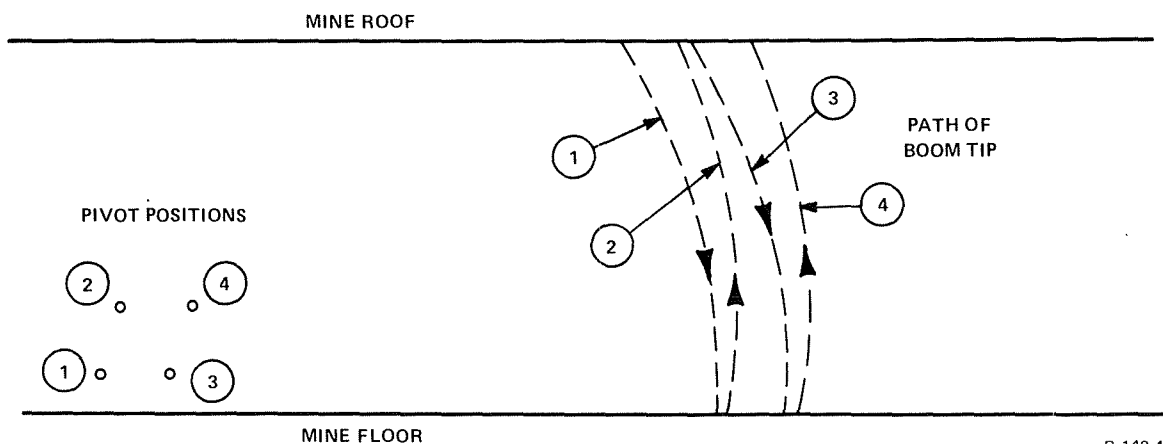
The second alternative describes a cutter boom similar to that of the Joy ICM miner. This alternative provides a definite flexibility in experimental applications and, thus, has appeal. It was given serious consideration during the study. However, it is mechanically more complex than the approach finally selected and does not appear to offer any productive advantages.

Alternatives (c) and (d) were considered together. Consideration of both was based on the theory that there might be some functional advantage in having the cutter boom follow a zig-zag path as it traversed up and down as shown in Figure 4.

Figure 4 shows the path generated by a boom with a two-position pivot. Here the downward stroke of the boom is made with the pivot in its low position; the upward stroke of the boom is made with the pivot in the upper position. Between strokes, the machine is moved forward and the pivot point is switched to the other position. The advance of the machine is greater between strokes 2 and 3 than between 1 and 2 or 3 and 4.

The sequence for the extendible boom is not shown. However, the boom would be gradually extended on either an upward or downward stroke. At the end of the stroke, either up or down, the boom would be retracted as the machine moved forward to keep the cutter head in contact with the coal and the cycle would be repeated.

The potential advantage of the zig-zag path is that the gradually increasing intersection of the cutter head with the surface of the face would appear to enhance the wedging action to break out coal between kerfs. On the other hand, production rate would be expected to be lower since the initial extraction depth on any stroke would be less than the maximum. A very serious objection is the greater mechanical complexity and lack of ruggedness compared with some of the other approaches considered. The concept of using an extendible boom was rejected on the basis that it would be almost impossible to design an extender mechanism that would be sufficiently rugged for the application. A two-position pivot having adequate strength probably could be designed. Unfortunately, the upper pivot position must be repositioned each time the seam height changes. It appeared that solving the problems in control and



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Figure 4 - Zig-Zag Path Generated by Cutter Boom Having Two-Position Pivot

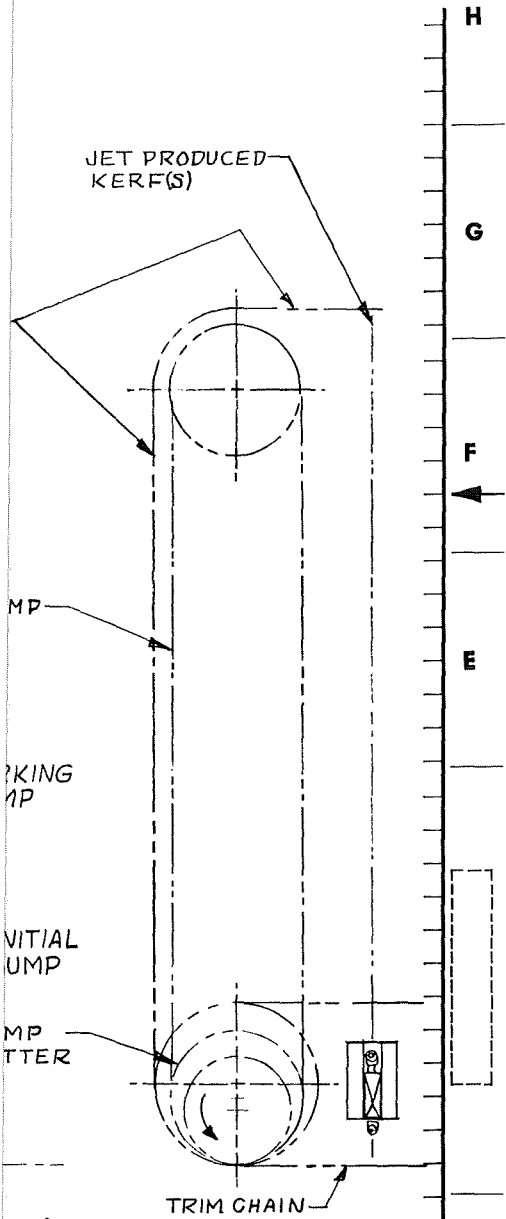
strength for a continuously variable pivot position would be quite difficult.

The approach involving a fixed-radius boom swinging vertically is used on the present Joy 12CM miner. It is mechanically simple, can be made strong, and since it is already used, is compatible with the structure and controls of the 12CM miner chassis. The production rate potential of this approach is equivalent to or better than that of any of the other approaches considered. Therefore, this approach was selected.

Having defined the boom mechanism and motion, the next step was to define the basic cutter head configuration. Sketches of six different cutter head approaches were prepared. For purposes of identification during discussions, these were designated Concepts "A" through "F". Reproductions of these sketches are shown in Figures 5 through 10. In most of these concepts, the coal removal mechanism is based on the kerfing and wedging method previously discussed, and the differences between the concepts lie in the method of trimming coal from the boundaries of the passage.

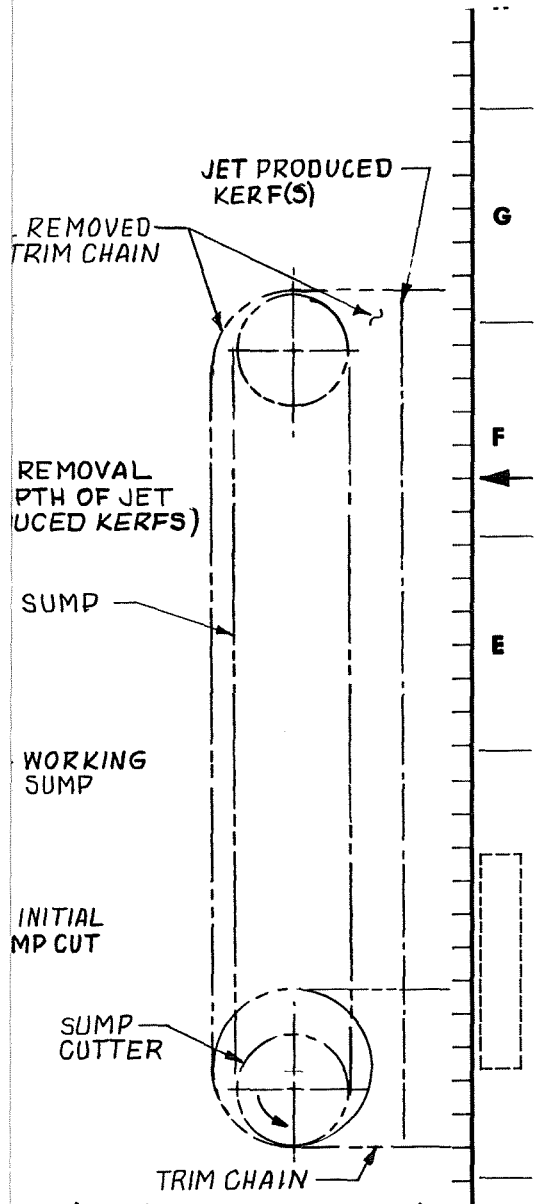
In cutter head concept "A" (Figure 5) two cutter wheels are mounted on shafts whose axes are parallel to the mining machine axis. These cutter wheels are placed at the sides of the cutter head. The cutter wheel bit envelope is in the form of a frustum of a cone. The cutter head is encircled by a trim chain. Wedging devices are used to extract kerfed coal. It is intended that the cutter wheels trim coal from the wall. The conical bit envelope is required to prevent the cutter wheels from gouging the roof at the greatest seam height. The trim chain is intended only to trim the roof and floor, but also has the ability to remove any protrusions from the face that might otherwise interfere with the traversing of the boom. There are at least two objections to the Concept "A" configuration. The first of these is that the trim chains are required to cut coal at an angle oblique to their path plane. Trim chain life under these conditions would be expected to be quite limited. The other objection to this arrangement is that there is no good mechanism for removing coal piled up under the boom in front of the gathering head. It appears quite likely that the boom would be unable to penetrate the piled up coal. Moreover, the trim chains could conceivably pick up lumps of coal and project them up into the space above the cutter head exposing the operator to ricocheting fragments.

Cutter head Concept "B" (Figure 6) is nearly identical to Concept "A" as far as the arrangement of trim chains and outer cutter wheels is concerned. However, there are no wedging devices and the trim chain position is further forward than is the case with Concept "A". The coal removal from the walls by the cutter wheels and from the roof and floor by the trim chains is identical to that intended for Concept "A". However, in Concept "B" it is intended that the kerfed coal will be removed by the trim chains. In effect, the hydraulic jets cut kerfs in the coal to weaken it prior to a mechanical cutting operation. The objections to



CODE IDENT	PART OR SPECIFICATION NO.	ITEM
MATERIALS		
x Research Laboratories		
SOUTHFIELD, MICHIGAN		
CONCEPT A		
IDENT NO.	REV.	
272	2179129	X1
PT	WT	SHEET

DEPT NO. 840



CODE IDENT	PART OR SPECIFICATION NO.	ITEM
OF MATERIALS		
<b>ix Research Laboratories</b> SOUTHFIELD, MICHIGAN		
ONCEPT B		
IDENT NO.	REV.	
1272	2179130	X <sub>1</sub>
HEIGHT	WT	SHEET

DEPT NO. 840

Concept "A" also apply to Concept "B". Since the trim chains are now used over the whole surface of the face, the objection to using the trim chains at an oblique angle becomes more serious. Furthermore, the use of the trim chains to bring down the kerfed coal would appear to eliminate almost entirely any of the potential advantages which would be obtained by using jet cutting.

Cutter head Concept "C" (Figure 7) is identical to Concept "B" except that the cutter wheels are removed, leaving the trim chains to remove coal from the wall. Concept "C" has all of the objections of Concept "B".

Concept "D" (Figure 8) shows a cutter head arrangement in which a series of cutter wheels or drums are mounted on a shaft which extends across the cutter head at a right angle to the mining machine axis. The cutter jets and the wedging devices are placed in the spaces between the cutter wheels. The bit envelopes on the cutter wheels at the shaft ends are arranged to trim coal from the walls. The cutter wheels along the length of the shaft trim most of the coal from the roof or the floor. A breaker bar, similar to that used on the drum mounting flanges of existing continuous miners, is used to remove the ridge of coal left at the roof or floor by the space between the cutter wheels. Concept "D" has a number of advantages compared to those described previously. The elimination of the trim chains is a positive advantage. Another very important advantage is that the cutter wheels rotate in a direction that will throw coal piled up under the cutter head on the gathering head. It appears that the cutter wheels cover enough of the frontal area to insure that the cutter boom will be capable of working its way through any quantity of coal piled up in front of the gathering head.

Cutter head Concept "E" (Figure 9) is identical to Concept "D" except that the cutter wheels are replaced by cutter chains.

Concept "F" (Figure 10) is another approach in which no wedging devices are used, with the removal of the kerfed coal being performed by mechanical cutters. Those concepts in which wedging devices are used are visualized as requiring two sets of jets, one set for the upstroke, another for the downstroke. Concept "F", as shown, requires only one set of jets, but requires two sets of mechanical cutters. These are mounted on pivoted bars, which swing either the upper or lower cutter wheels forward, depending on the direction of the cutter boom travel. The pivoting of the cutter wheels requires that they be chain driven. Concept "F" is fairly complex mechanically. Since, as is the case with Concepts "B" and "C", the hydraulic jets cut kerfs in the coal to weaken it prior to a mechanical cutting operation, this concept can almost be considered to be a hydraulically augmented mechanical device from which most of the potential advantages of jet cutting have been eliminated.

## SELECTED CUTTER HEAD CONFIGURATION

Figure 11 is a section from the complete hydraulic mining machine layout and shows the cutter head and boom. The final cutter head configuration is a combination of cutter head Concepts "D" and "E". The

cutter head contains two end cutters, ten cutter wheels, and four cutter chains. The cutter chains are used to drive the cutter shaft. There are 15 spaces between the cutter devices (wheels or chains). Eight of these spaces are occupied by so-called primary jets. There are two sets of jets designated secondary jets. One set of secondary jets occupies the same spaces as the primary jets and are above them. The other set of secondary jets occupies the seven spaces which do not contain primary jets. The wedging devices, where used, are placed between the primary jets and the first set of secondary jets.

The wedging devices are intended to ride in the kerf, acting to separate the two surfaces exposed by the kerf. This separating force will cause a fracturing of the coal between kerfs, desirably to the full depth of the kerf. Wedging devices are placed in alternate kerfs, with the empty kerfs providing clearance for the deflection caused by the wedging action. Technical effort on this project came to a halt before the exact configuration of the wedging devices was defined; however, it was intended that they would either be in the form of blades, teeth (similar to cutter bits used on present mining machines) or wheels (similar to the toothed roller cutters used in certain rock cutting applications).

The narrowest Joy 12CM gathering head is 10 ft 2 in. wide. The cutter head width was selected to be 11 ft (132 in.), to provide the needed clearance on either side of the gathering head. Figure 12 shows how the various cutter head components are distributed across this width.

The selection of eight primary cutter nozzles is based on the fact that this is the maximum number of intensifiers which can be carried on the boom frame. As was determined in the analysis of jet cutter parameters reported in the previous section, there is no advantage in splitting jet cutting power among multiple jets; it should be concentrated as much as possible. On the other hand, intensifiers do not share loads well; that is, if two intensifiers are connected to a single load, one intensifier will dominate, causing the other to stall. This situation exists because one intensifier will be capable of supplying water at a slightly higher pressure than the other. This is caused by small differences in configuration between the intensifiers allowed by necessary manufacturing tolerances. The check valve arrangement used in the high-pressure outlets of most intensifiers on the market today also contribute to the phenomenon. The higher pressure of the stronger intensifier will cause a pressure difference to exist across the check valves of the weaker intensifier which will close the valves and stop the weaker intensifier. Extensive intensifier modifications would be required to avoid this situation without sacrificing performance. Hence, eight intensifiers require at least eight nozzles.

Normally, eight nozzles spaced equally across a 132-inch span would give a kerf pitch (lateral spacing between kerfs) of 14.7 in. However, requirements for realistic dimensions for the chains, wheels, and the flanges holding the nozzles and the wedging devices have led to the selection of the proportions shown in the upper view of Figure 12.

JET PRODUCED  
KERF(S)

OVAL

TRIM CHAIN

G

F

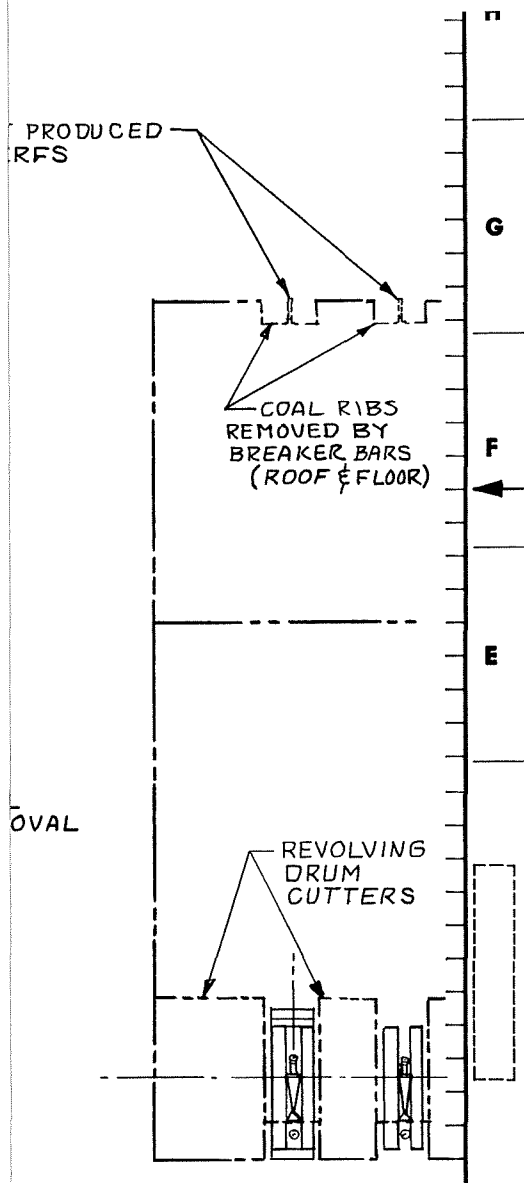
E

B

A

CODE IDENT	PART OR SPECIFICATION NO.	ITEM
OF MATERIALS		
Dix Research Laboratories SOUTHFIELD, MICHIGAN		
CONCEPT C		
IDENT NO. <b>1272</b>	<b>2179131</b>	REV. <b>X<sub>1</sub></b>
1/Pt	WT	SHEET

DEPT  
NO. 840



CODE IDENT	PART OR SPECIFICATION NO.	ITEM
MATERIALS		
ix Research Laboratories		
SOUTHFIELD, MICHIGAN		
CONCEPT D		
IDENT NO.	2179132	REV. X1
FT	WT	SHEET

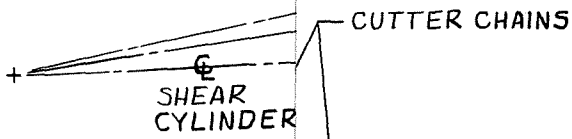
DEPT NO. 840

H

G

F

E



NET(S)

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MATERIALS

**x Research Laboratories**  
SOUTHFIELD, MICHIGAN

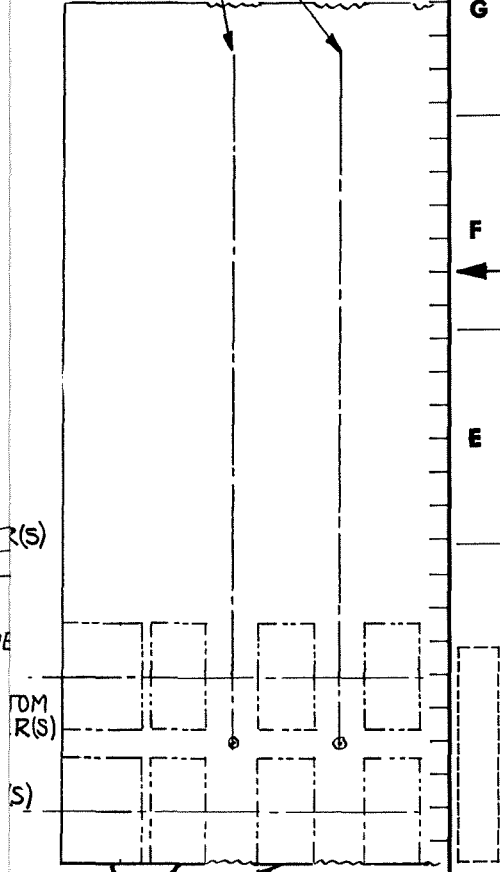
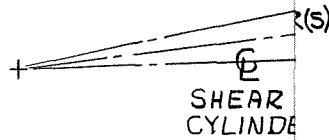
CONCEPT "E"

DENT NO.		REV.
<b>272</b>	2179137	X <sub>1</sub>

FT	WT	SHEET

DEPT NO. 840

PRODUCED  
F(S)



MCHANICAL  
TERS

CODE IDENT	PART OR SPECIFICATION NO.	ITEM
MATERIALS		
x Research Laboratories		
SOUTHFIELD, MICHIGAN		
ONCEPT "F"		
IDENT NO.	REV.	
272	2179138	X <sub>1</sub>
WT	SHEET	

DEPT NO. 840

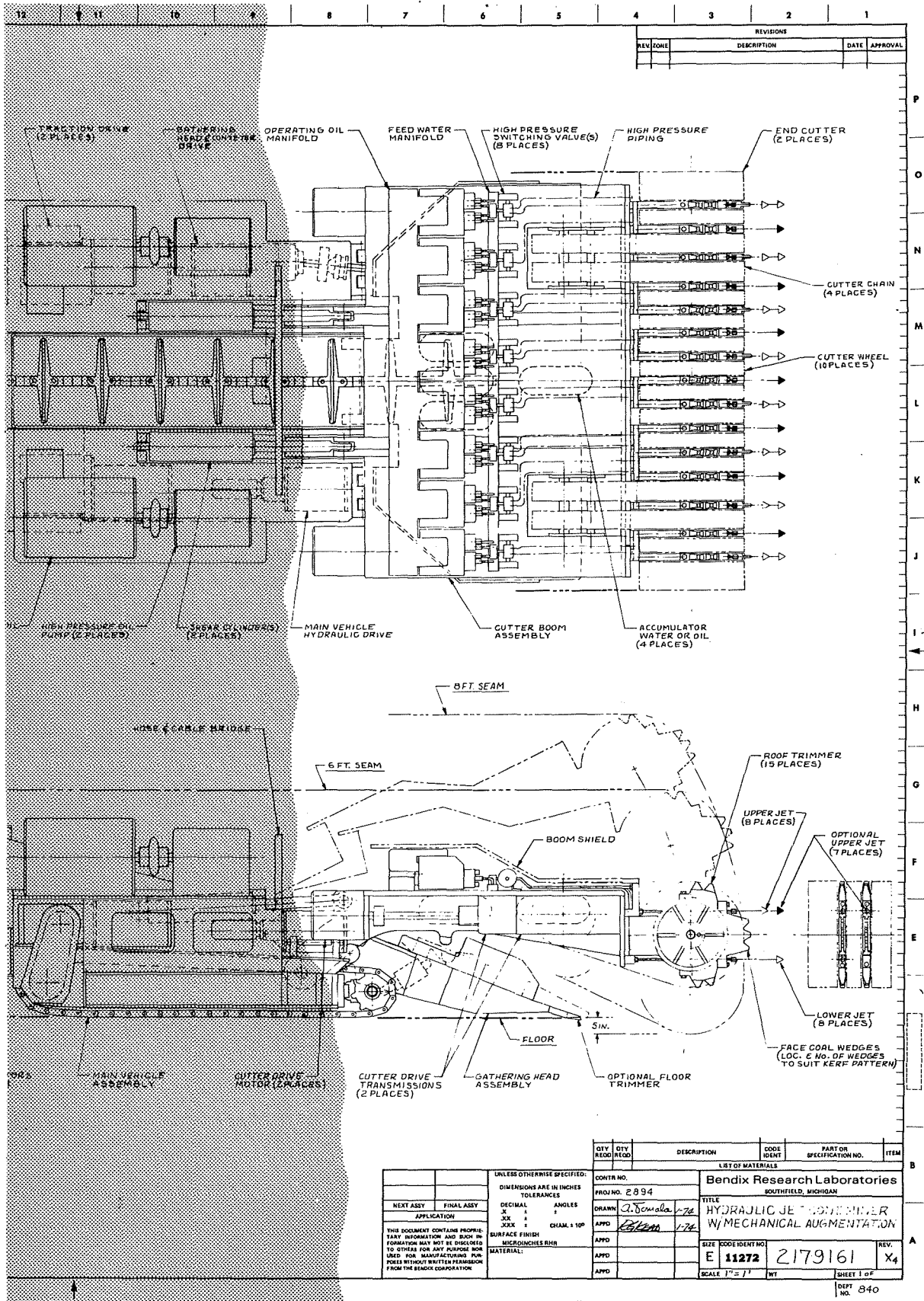
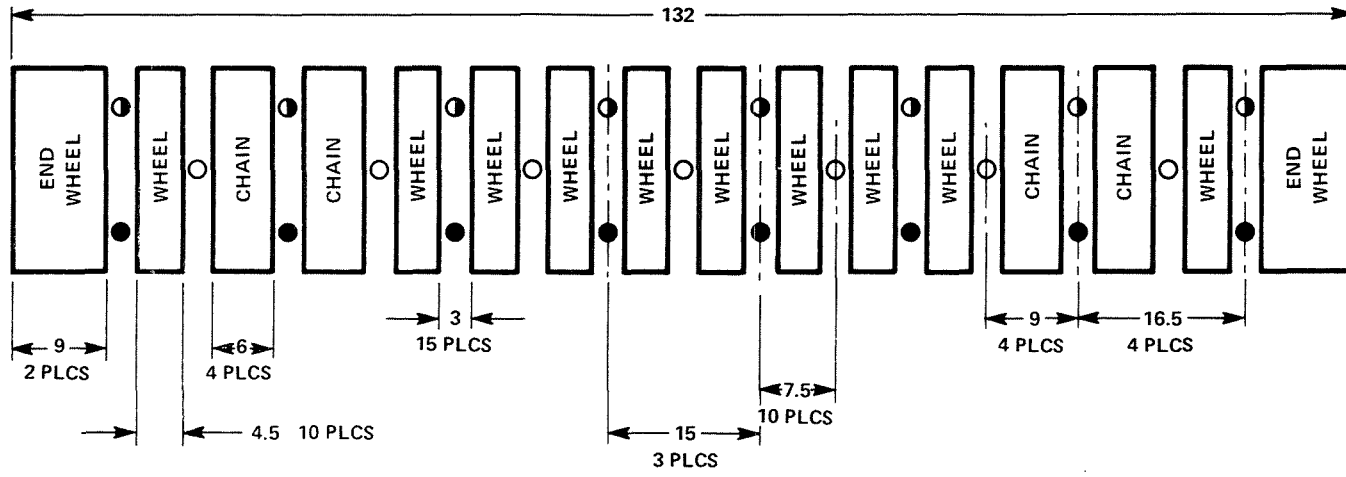
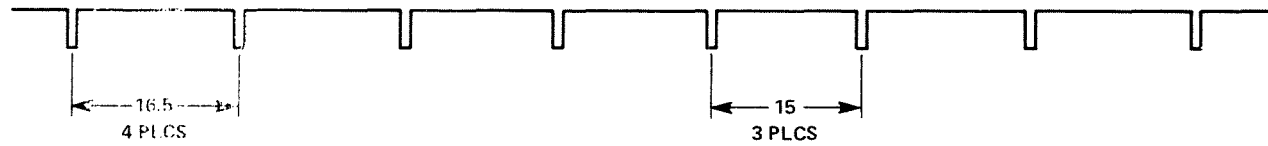


Figure 11 - Final Configuration of Cutter Head and Boom

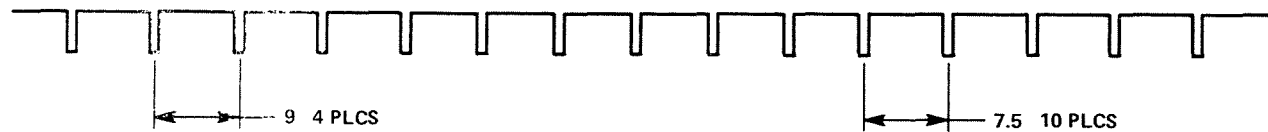
QTY	DIV	DIV	DESCRIPTION	CODE	PART OR	ITEM
REQD	REQD	REQD		IDENT	SPECIFICATION NO.	
LIST OF MATERIALS						
UNLESS OTHERWISE SPECIFIED:			CONTR. NO. <b>Bendix Research Laboratories</b>			
DIMENSIONS ARE IN INCHES			SOUTHFIELD, MICHIGAN			
TOLERANCES			PROJ. NO. <b>2894</b>			
DECIMAL			DRAWN <i>A. Demala</i> / <i>7/74</i>			
ANGLES			APPRO <i>ES/2000</i> / <i>1/74</i>			
XX			APPRO			
XXX			APPRO			
CHAM. 1:10P			APPRO			
SURFACE FINISH			SIZE CODE IDENT NO.			
MICROMETRES RMS			E <b>11272</b> <b>2179161</b>			
MATERIAL			REV. <b>X4</b>			
THIS DOCUMENT CONTAINS PROPRIETARY INFORMATION AND SUCH INFORMATION MAY NOT BE DISCLOSED TO OTHERS FOR ANY PURPOSE NOR USED FOR MANUFACTURING PURPOSES WITHOUT WRITTEN PERMISSION FROM THE BENDIX CORPORATION			SCALE 1"=1' WT SHEET 1 OF			
			DEPT NO. <b>840</b>			



SPACING OF CUTTER HEAD COMPONENTS



KERF SPACING PATTERN "A"



KERF SPACING PATTERN "B"

ALL DIMENSIONS IN INCHES

- PRIMARY JETS
- SECONDARY JETS FOR "A"
- SECONDARY JETS FOR "B"

Figure 12 - Cutter Head Component and Kerf Spacing

The cutter head design has been set up for two modes of operation. The preferred mode (since it has the maximum potential production rate) is one in which kerfing and extraction of the kerfed coal takes place on both the upward and downward sweeps of the cutter boom. The primary jets are actuated on the downward stroke; the secondary jets in the same spaces as the primary jets are actuated on the upward stroke. The kerf pattern is as is designated "A" in Figure 12 and the kerf pitch varies from 15 to 16.5 in. Since there is reason to question the ability of the boom hydraulic system to produce enough force to extract coal on an upward stroke of the boom, and kerfs are placed at points midway to those placed on the downward stroke when wedging and extraction of coal takes place. The kerf pattern is as is designated "B" in Figure 12, giving a pitch of 7.5 to 9 in.

If the instantaneous rate of production is defined as the tons of coal per minute produced during a single cycle of the machine (starting with the boom in one position and continuing until the boom has returned to that same position), then the instantaneous production rate will approach the peak rate for the first mode of operation. For the second mode of operation, the instantaneous rate will always be less than half the peak rate.

## CONTINUOUS-MINER DESIGN

### DESCRIPTION OF EXISTING CONTINUOUS MINERS CONSIDERED

The generation of a completely new design for the hydraulic-jet continuous miner would be expensive and time consuming. Adaptation of an existing miner would reduce construction and development time and expense and increase machine reliability. The major requirement which influences the selection of an existing miner for adaptation is that the hydraulic jet miner must be capable of mining coal in seams from 5 to 8 feet high at a minimum rate of 6 tons per minute.

The design of most existing continuous miners consists of a coal cutting mechanism located at the front of the machine, a mechanism to remove the coal from the floor and around the cutting mechanism, a conveyor to transport the coal to the rear of the machine, and tracks for tramming the miner. The major differences between machines are in the coal cutting methods employed.

Three types of continuous mining machines were considered for adaption to hydraulic jet mining. The first type considered was a boring machine. Boring machines such as the Joy 2BT-6 use the same method of cutting coal as the Bendix hydraulic miner concept (kerfing and wedging). However, consideration of this machine type was eliminated because of the inherent difficulty in adjusting to varying seam heights. In addition, the rotating cutter arms would have required rotating hydraulic couplings for transmitting hydraulic power to the cutter arms.

The Joy 1CM machine is representative of the second type of miner considered for adaption to hydraulic mining. This machine has cutter chains mounted on a narrow boom (42 inches wide) which can be moved both vertically and horizontally. The Joy 1CM machine is capable of cutting a passage up to 8.5 feet high and producing 4-5 tons of coal per minute.

This machine was eliminated because of the chassis height (47 in.) and the cutter bar width which would add to the difficulty of packaging the intensifiers and their power supply.

The third type of miner considered uses cutters mounted on a rotating drum. The boom is wide (usually in the range of 10 to 14 feet) and is only moved vertically. The Joy 10CM, 12CM, and 14CM machines are typical of this type of miner. The Joy 14CM machine is the most recent Joy design and has the lowest chassis height, but it will not cut as high as 8 feet.

The Joy 12CM machine was selected as the basis of the hydraulic-jet miner design. This machine is a more recent design than the Joy 10CM machine and has a lower chassis height. Without modifications the

12CM will cut to a 10-foot maximum height and produce 8 to 12 tons of coal per minute. The 12CM chassis height is 40 inches over the conveyor and 36 inches over the tracks.

#### DESCRIPTION OF JOY 12CM MINING MACHINE

The Joy 12CM mining machine is a ripper-type continuous miner capable of producing 8 to 12 tons of coal per minute. The machine weighs 45 tons and is approximately 32.3 feet long and, in the narrowest version, 10.2 feet wide with the cutter drum collapsed.

The 12CM is available in two versions which differ in chassis height and cutting height capabilities. See Table 5.

Table 5 - Major Chassis Differences in Joy 12CM Models

Characteristic	A Model	B Model
Ground clearance, in.	9	13
Chassis height, in.	36	40
Minimum seam height, in.	46	50
Maximum seam height, in.	116	120

The cutter drum is boom mounted and has a diameter of 36 inches. The cutting width is 10 feet 10 inches in the narrowest version. Boom height is controlled hydraulically by the operator.

Coal cut from the face falls on or in front of the gathering head which loads the coal onto the conveyor. The conveyor transports the coal from the gathering head to the rear of the miner. The conveyor extends 9.3 feet beyond the rear of the miner chassis and is designed to facilitate the loading of a shuttle car. The rear extension is pivoted and may be swung up to 45 degrees to either side with hydraulic controls at the operator's station. Conveyor height may be adjusted in a like manner.

The 12CM machine is AC-powered from a trailing cable. It is equipped with two 175-hp cutter motors, a 60-hp gathering head/conveyor motor, a 50-hp pump motor, and two 35-hp traction motors. All electric motors are water cooled and total rated power is 530-hp.

The Joy 12CM continuous miner was selected as a basis for the hydraulic-jet miner design over other Joy machines considered because:

- (1) It has the lowest chassis height of the ripper-type continuous miners capable of cutting to an 8-foot height.

- (2) It is of modern design and currently in production.
- (3) Without modifications it is capable of satisfying contractual seam height and production requirements.
- (4) Of those miners considered, it would require the least amount of modification for adaptation to hydraulic jet mining.

## CUTTER BOOM AND HEAD

The boom design of the hydraulic-jet miner is nearly identical to that of the present Joy 12CM miner. The boom has a fixed radius and swings vertically. The control of the boom is the same and it is positioned by using shear cylinders as is done on the 12CM miner.

The design of the Joy 12CM miner allows the cutter drum to be extended or collapsed which provides greater maneuverability. However, it was decided to design the jet cutter head with a constant 11-ft width to minimize complexity.

The cutter head has two end cutters, ten cutter wheels, and four cutter chains. The cutter chains are used to drive the cutter shaft. There are fifteen spaces between the cutter devices (wheels or chains). Eight of these spaces are occupied by the primary jets. There are two banks of secondary jets. One bank of secondary jets occupies the space above the primary jets. The other bank of secondary jets occupies the seven spaces which do not contain primary jets. The wedging devices, where used, are placed between the primary jets and the first set of secondary jets. Wedge bars are used to trim both the floor and roof and are located both on the top and on the bottom of the spaces between the cutter wheels or chains. The two end cutters are used to trim the walls.

Figure 13 (BRL drawing 2179161) shows the design of the boom and cutter head. There are eight intensifiers and twenty-three nozzles. These twenty-three nozzles are divided into the three banks of primary and secondary jets. At any one time, one bank will be pressurized. This is controlled by remotely operated selector valves which are located near the intensifiers on the back section of the boom. The high-pressure piping between the intensifiers and nozzles is rigid and stationary. Accumulators and manifolds are required and these are also located on the boom as shown in Figure 13. A boom shield is located over all of the hydraulic components to protect them from damage and for purposes of containment.

Two cutter-drive motors along with two cutter-drive transmissions are located on the boom. These motors are much smaller than those on the present 12CM miner. The cutter motors on the hydraulic jet miner are of approximately 75 hp while the cutter motors on the 12CM continuous miner are 175 hp. The location of these cutter motors is also shown in Figure 13.

The cutter head has been designed for two modes of operation. The preferred mode (since it has the maximum potential production rate) is one in which kerfing and extraction of the kerfed coal takes place on both the upward and downward sweeps of the cutter boom. The primary jets are actuated on the downward stroke; the secondary jets in the same spaces as the primary jets are actuated on the upward stroke. The kerf pattern designated "A" in Figure 12 has a kerf pitch that varies from 15 to 16.5 in. Since there is reason to question the ability of the boom hydraulic system to produce enough force to traverse the boom upward against the reaction to the wedging action and the force of gravity and, since there is also concern about the magnitude of the kerf pitch, the alternate mode of operation is available. In this mode of operation, no extraction of coal takes place on the upward stroke of the boom and kerfs are positioned at points midway to those placed on the downward stroke when wedging and extraction of coal takes place. The kerf pattern designated "B" in Figure 12 gives a pitch of 7.5 to 9 in.

It should be noted that the layout in its present form does not show a means of adjusting the cutter chain tension. This would be required in a final design. Moreover, the assembly process will require that proper precautions be taken to insure that link-length tolerance stack-ups do not result in unacceptably unequal cutter-chain lengths.

## WATER-JET CUTTING SYSTEM

The water-jet cutting system may be divided into three subsystems: the high-pressure water source (pumps or intensifiers), the low-pressure water supply system, and the high-pressure water delivery system. Various designs of very-high-pressure pumps and intensifiers were surveyed and those showing the most promise for use in high-pressure jet mining were investigated in detail.

### Selection of a High-Pressure Water Source

Five models of high-pressure pumps and intensifiers capable of supplying water for the jet cutting nozzles at pressures between 20,000 and 65,000 psi and at total flow rates up to 30 gpm were investigated. These devices were: The Kobe, Inc., 70,000-psi intensifier; the Flow Research, Inc., 50-hp intensifier; the Bendix Research Laboratories' high-pressure intensifier; and the Kobe triplex pumps, sizes 3 and 4. The selection of the optimum design for the intensifier hardware was based on performance, safety, weight, size, and maintenance requirements.

Because the jet cutting nozzles are to be boom mounted and because a reliable, flexible conduit is not readily available for piping the high-pressure water onto the boom, only boom mounting of the pump(s) or intensifier(s) was considered. For this reason, the performance and size constraints were based on obtaining the largest amount of output horsepower from the smallest device volume.

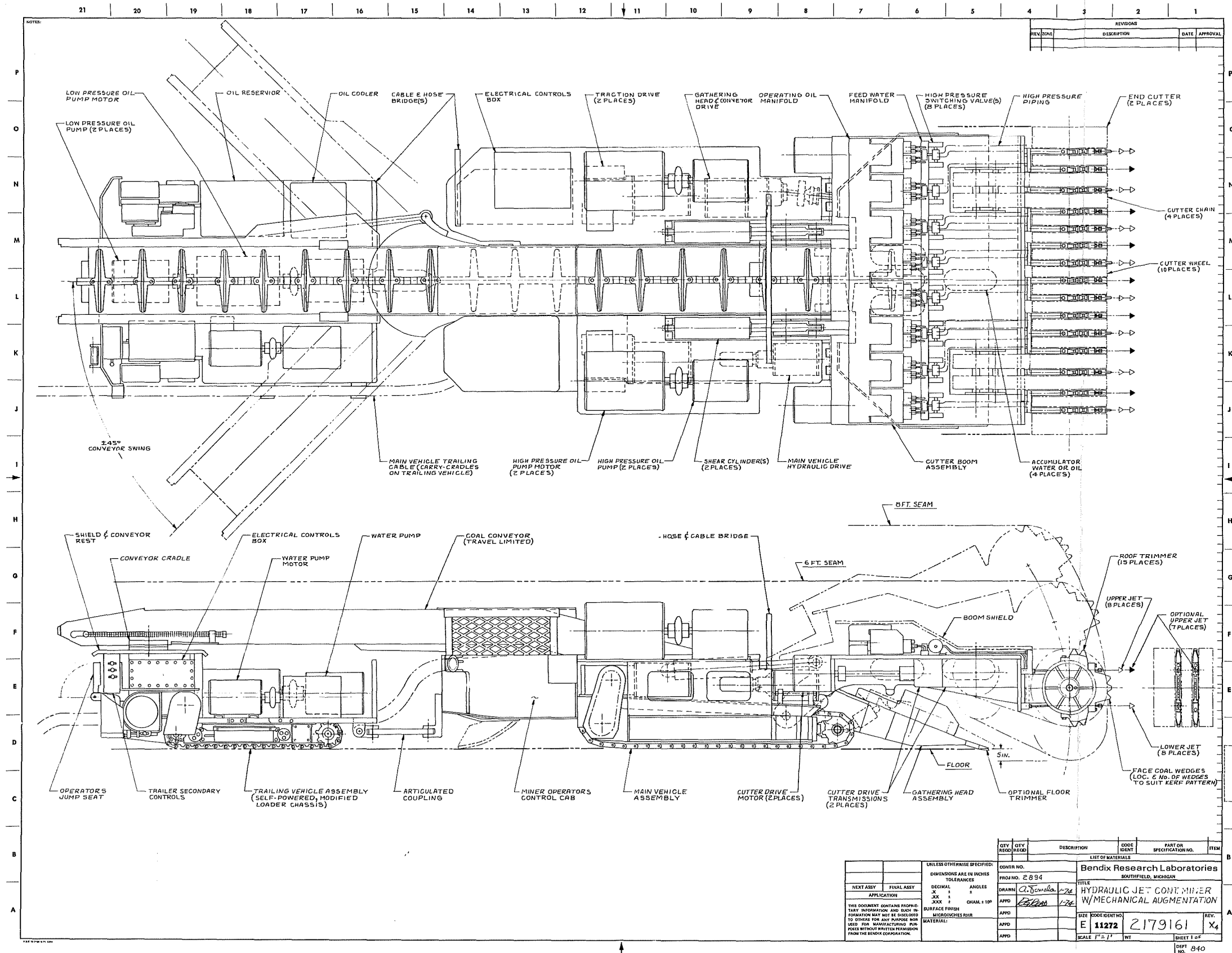


Figure 13 - Layout Drawing of Hydraulic-Jet Coal Miner

The Kobe triplex pumps are very reliable, require very little maintenance, and would be well suited for use in low-pressure hydraulic mining where the pumps could be mounted on the miner chassis and the water piped to the boom using hoses or swivel connectors at the boom pivot. However, these pumps are very bulky and heavy. No more than two of either the size 3 or size 4 Kobe triplex pumps could be easily mounted on the boom of a Joy 12CM continuous miner. Such installations would yield approximately 120 or 260 output horsepower, respectively, and add approximately 4,000 to 12,000 pounds to the boom weight. Since neither power level was deemed sufficient for mining coal at 6 tons per minute, Kobe triplex pumps were eliminated from consideration.

The high-pressure intensifier manufactured by Kobe, Inc., produces a 50-hp output and operates in the range of 30,000 to 70,000 psi. The device is 9.3 feet long, weighs 450 pounds, and includes a high-pressure accumulator which reduces output pressure variations to  $\pm 2,000$  psi at 70,000 psi. Maintenance of each high-pressure pump end may be performed in one hour or less, and maintenance intervals range from 750 to 2000 hours of operation, depending on operating pressure. Eight of these intensifiers mounted on the boom of a Joy 12CM continuous miner would yield a total output power of 400 hp and add approximately 3600 pounds to the boom weight.

Flow Research, Inc., produces four models of 50-hp intensifiers with output pressures ranging from 12,000 to 60,000 psi. A 50-hp model designed to produce a 35,000 psi output has a package size of 11.6 x 9.9 x 33.3 inches and weighs 190 pounds. This model includes an accumulator which reduces output pressure variations to  $\pm 3,500$  psi. Nine of these intensifiers installed on the boom would produce a total output power of 450 hp and increase the boom weight by 1710 pounds.

The Bendix high-pressure intensifier will produce up to 60-hp output with an output pressure in the range of 30,000 to 70,000 psi. The intensifier constructed for the hydraulic jet miner produces 53.5 hp at 35,000 psi. This model has a package size of 14.4 x 10.8 x 19.7 inches and weighs approximately 300 pounds. Eight of these intensifiers can be installed on the boom of a Joy 12CM continuous miner to produce a total output of 428 hp with a total weight of 2400 pounds.

The Bendix intensifier has been designed for easy maintenance. Both sets of high-pressure seals can be replaced in less than 60 man-minutes and all four high-pressure check valves may be replaced in less than 10 man-minutes. Maintenance intervals have not been determined because of incomplete life tests.

Although no high-pressure water accumulator is used with the Bendix intensifier, output pressure variations of the 53.5-hp, 35,000-psi model are expected to be less than  $\pm 5$  percent. The unique design of the Bendix intensifier allows the pressure strokes of the high-pressure pistons to be overlapped. Consequently, the device supplies high-pressure output

throughout 100 percent of its machine cycle. Most other intensifiers do not supply high-pressure output during the two intervals of their machine cycle when their high-pressure pistons are reversing directions of travel; consequently these devices require an energy storage device (usually an accumulator) to supply high-pressure water during these intervals, if output pressure variations are to be maintained at a reasonable level.

Output power levels of the Bendix, Flow Research, and Kobe intensifiers are nearly equal. The Kobe intensifier is expected to require the least maintenance; however, its design requires a lubricant to be added to the water. In addition, the Kobe units are bulky. They require almost twice as much space as the Bendix unit and weigh more than twice as much as the Flow Research unit.

The output pressure variations of all three units are within acceptable limits. The Kobe and Flow Research intensifiers use accumulators in their high-pressure water circuits to reduce pressure variations. The Bendix intensifier is designed for minimal pressure variations without the use of an accumulator. Because of the possibility of a high-pressure water-circuit rupture occurring because of a mine accident or a mechanical failure, the total volume of water maintained under compression at high pressures should be minimized. Therefore, for reasons of safety, high-pressure accumulators are not desirable.

Based on the above comparisons, the primary and secondary intensifier choices for use on the hydraulic jet miner are the Bendix and the Flow Research intensifiers, respectively.

#### Low-Pressure Water Supply System

The Bendix high-pressure intensifier model selected for use on the jet miner requires an inlet water pressure of 300 psi or greater. Joy specifications for an unmodified 12CM continuous miner call for a 250-psi water supply. Consequently a boost pump has been included in the jet miner design for supplying the intensifiers.

The water boost pump is located on the trailing vehicle and supplies water to the boom-mounted manifold which distributes water to the eight intensifiers. Each intensifier draws water from the manifold twice during one of its machine cycles or approximately six times per second. Since the machine cycles of the eight intensifiers are not synchronized, and all eight may use water from the manifold at the same instant, the total instantaneous rate of water being used from the manifold by the intensifiers may vary greatly. Therefore, to reduce water pressure variations at the intensifier inlets, and to allow the boost pump to be sized to satisfy averaged intensifier inlet flow requirements, a low-pressure water accumulator has been added to the water supply circuit at the manifold.

## High-Pressure Water Delivery System

The 35,000-psi water supplied by each intensifier is routed through a three-way valve to a primary or secondary cutting nozzle. These eight three-way selector valves are pilot operated and operator controlled through the valves and logic explained in the section titled "Operator's Station." Valve actuation is such that an intensifier's output is diverted to a primary nozzle, a secondary nozzle, or both - but never blocked.

Each of the eight intensifiers has a primary nozzle and a secondary nozzle. Seven of the intensifiers also have auxiliary nozzles connected in parallel with their secondary nozzles. The auxiliary nozzles are used as optional secondary nozzles and are capped when not in use. To use the auxiliary nozzles, the caps are removed and installed on the corresponding secondary nozzles.

All 23 cutter nozzles used on the jet continuous miner are of the same design. This design has been patented by the Bendix Corporation under U.S. Patent No. 3,756,106. The nozzles are constructed of sapphire to resist wear caused by abrasion and designed to produce a coherent fluid jet at high pressures. Inside diameter of the nozzles is 0.23 inch.

## POWER SUPPLY

It was determined early in the program that achievement of any reasonable coal production rate requires that as much jet cutting power be installed on the mining machine as possible. At least three limitations on jet cutter power exist. The first is that of the intensifiers. This is known to be in excess of 60 hp per intensifier although the detailed stress calculations to establish the exact upper limit have not been performed. The second limitation is the size of the intensifier power supply which can be transported with the mining machine. The final limitation on jet cutting power is the size of the trailing cable. It is generally accepted that a 4/0 trailing cable is as large as should be used in the underground environment. Reference 2 suggests that a 4/0 cable can supply 1200 hp to a mining machine at a 950-volt level. This power value has been confirmed in discussions with personnel of Joy Manufacturing Company. Some concern has been expressed because of the fact that the duty cycle of the hydraulic-jet continuous miner involves a much longer period of time at peak load compared with the duty cycle of the normal continuous miner. This may provide an inadequate time for cooling the cable between applications of the peak load.

It was desired that the intensifiers be operated at a jet power level of at least 60 hp each. However, as detailed estimates of intensifier efficiency and the size of pumps and electric motors were developed, it was determined that the intensifier power level would have to be

limited to 53.5 hp each for a total nozzle power of 428 hp. To supply the intensifiers at this level requires a power supply which consists of:

High-pressure hydraulic supply	700 hp
Two 350 hp, 950 vac, 3 $\phi$ , 60 Hz, 1800-rpm motors	
Two Sundstrand Series 27 pumps @ 3600 psi; 20.36 in <sup>3</sup> /rev with 2 in <sup>3</sup> /rev charge pumps	
Low-pressure hydraulic supply	175 hp
One 175 hp, 950 vac, 3 $\phi$ , 60 Hz, 1800-rpm motor with dual shaft	
Two Sundstrand Series 27 pumps @ 800 psi; 20.36 in <sup>3</sup> /rev with 2 in <sup>3</sup> /rev charge pumps	
Water precharge	20 hp

Hence an installed power of 895 hp is required to obtain an output of 428 hp. The overall efficiency of the intensifiers is thus estimated to be 48 percent. The intensifiers themselves are estimated to be 57 percent efficient and the hydraulic pump to be 89 percent efficient. This last figure includes the charge pump losses as well as the efficiency of the main pump. The water precharge pump was assumed to be 50 percent efficient. Approximately 25 percent of the output of the water precharge pump is used for dust control spray purposes and properly should not be charged against the intensifiers.

Besides the intensifier load, the next greatest power demand is that of the mechanical cutters used to trim the roof, floor, and walls. The Joy 12CM miner can cut 2 ft deep into wide face up to 14 ft wide. The mechanical cutters on the hydraulic-jet mining machine need to cut no more than 2/3 ft deep with a total width generally no greater than 2 ft out of a total face width of 11 ft. Even taking into account the roof and the floor, the mechanical cutters on the hydraulic-jet mining machine should remove in one pass less than 10% of the material removed by the mechanical cutters of the Joy 12CM miner. The mechanical cutters on the hydraulic jet miner probably will be less efficient than the cutter drums on the 12CM and the hydraulic jet miner will make more passes per unit time than the normal continuous miner, so that the hydraulic continuous miner will undoubtedly require more than 10% of the cutter power used by the 12CM.

Moreover, it should be noted that continuous-mining-machine cutter motors are generally selected on the basis of torque rather than power. At this time there is no rigorous basis for defining the required cutter motor power. Arbitrarily, it was decided that the mechanical cutters on the hydraulic-jet mining machine would be powered by two 75-hp motors replacing the two 175-hp motors used on the present machine.

Assuming that the pump, gathering head, and traction motors are the same as now used on the 12CM miner, the installed power on the hydraulic-jet coal miner should be as follows:

Intensifiers	895 hp
Mechanical cutter, 2 @ 75	150 hp
Gathering head	60 hp
Pump motor*	50 hp
Traction, 2 @ 35	<u>70 hp</u>
	1225 hp

It is assumed that the intensifier load is removed except when coal is actually being cut, and that the full traction load is not applied simultaneously with the intensifier load.

#### Water Circuit

Approximately 60 gpm of water is required to supply the cooling and intensifier circuits. The water flow is divided into five branches. One branch is used to cool the motors and reservoir equivalent to those in the present Joy 12CM miner. The second branch is used to cool the motors and reservoir power supply for the intensifiers. The third branch is the water supply to the intensifiers. This has a maximum flow rate of 25.5 gpm. The fourth branch supplies the dust control nozzles and the fifth branch supplies the fire control nozzles. These are shown in hydraulic system schematic, Figure 14 (BRL drawing 2179024).

The fire control nozzles will operate only when required through valves which can be operated from either side of the machine. The other four circuits will flow continuously when the machine is operating. The cooling circuits exhaust into a common line which connects to a hose which carries the heated water. This water, used in the intensifiers and the dust control nozzles, will either vaporize, be removed with the coal, or be deposited on the mine floor. By the use of orifices (valves in the prototype), the amount of flow through each circuit can be controlled.

The water that is delivered to the intensifiers passes through a boost pump. This insures that the water has a sufficient pressure to prevent cavitation at the intensifier inlet.

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\* In the previous section, titled "Critical Parameters Affecting Production rate," it is noted that the existing hydraulic pump on the Joy 12CM mining machine is not large enough to supply the flow required to traverse the boom at the velocity needed to obtain the desired production rate. The impact of this fact on the design of the mining machine and on the level of the installed power has not been investigated.

## Hydraulic Circuit

The power supply for the intensifiers, with the associated control circuits and interfaces with the hydraulic system already used in the mining machine, are shown in Figure 14 (BRL drawing 2179024). The outlets of both high-pressure pumps are manifolded together as are the outlets of the low-pressure pumps. Because of the high pressure, a 1-in. ID is the largest available hose to transmit the flow from high-pressure supply to the intensifier. To minimize pressure drop, ten of these hoses are required. For the low-pressure hydraulic circuits, a 2-in. ID hose is available. Therefore, only two parallel hoses are required to have a reasonable pressure drop for the required intensifier flow.

Accumulators are required in both the low- and high-pressure circuits because of the fluctuation in system demand. The accumulators allow the use of pumps sized to supply less than the peak flow.

The hydraulic circuit was designed to allow the operator three choices in operating the boom and intensifiers. They are the operation of:

- (1) Intensifiers only
- (2) Boom only
- (3) Boom and intensifiers together

The hydraulic logic in the upper left section of Figure 14 is used to provide the above functions plus the following:

- (1) There is approximately a one-second delay before the boom will move after the operator activates a control valve. This allows the intensifiers time to attain full operating pressure.
- (2) There is an adjustable 5- to 20-second delay after an intensifier control lever is centered; then the pump outputs will be reconnected to the return line to avoid unnecessary heating of the hydraulic fluid.
- (3) Nozzle selector valves are normally open. As the direction of boom movement is determined by control lever movement, one bank of nozzles (either primary or secondary) will be automatically shut off.
- (4) Logic has been designed to supply an intensifier "reset" signal before each intensifier "on" signal.

## AUXILIARY VEHICLE

An auxiliary trailing vehicle is required to carry some of the components which are needed for the power supply. The high-pressure hydraulic pumps will be installed on the Joy 12CM miner chassis along

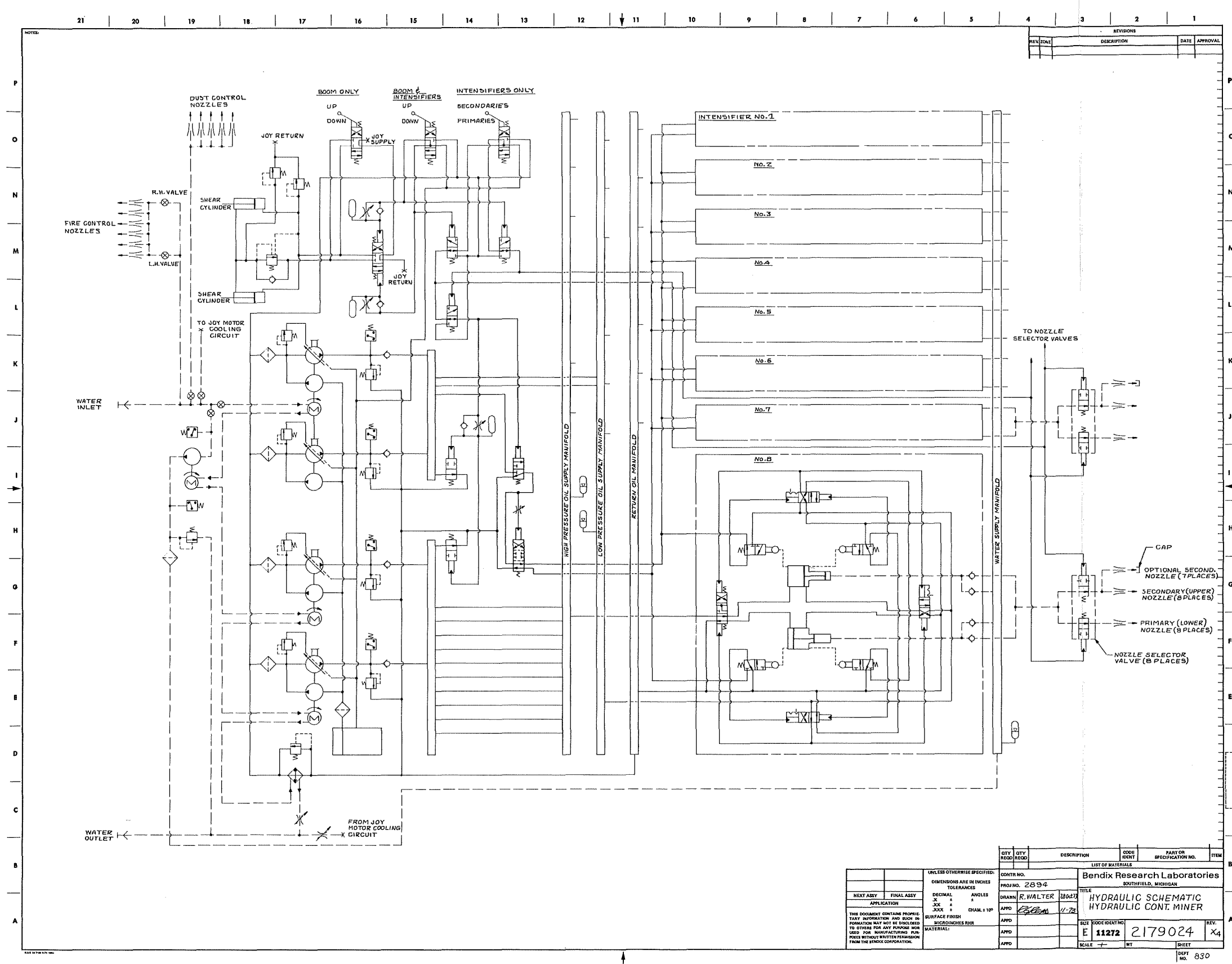


Figure 14 - Hydraulic System Schematic

with the electrical motors which drive these pumps. This is done to prevent the transmission of high pressure from one vehicle to another. The low-pressure pumps and motors with the reservoir, oil cooler, and electric control boxes will be installed on the auxiliary vehicle.

This auxiliary vehicle is a modified Joy loading machine (14BU10-11A). The chassis is almost identical, but the conveyor and the gathering head will be removed. The Joy loading machine uses electric motors to drive crawler tracks through a transmission. These electric motors will be replaced since the low-pressure pumps used in the intensifier power supply will be available to power hydraulic traction motors. This can be done because the intensifiers are not operating when the auxiliary is powered away from the face.

A cradle will be installed above the shield for the electrical control boxes. The auxiliary vehicle along with intended power supply packaging is shown with the hydraulic jet miner in Figure 13.

## SYSTEM INTEGRATION

Figure 13 shows the layout of the hydraulic-jet continuous mining machine. As previously described, the machine consists of the Joy 12CM chassis with the tracks and traction drive, conveyor, gathering head, and control system. The boom structure is similar to the boom of the normal Joy 12CM continuous mining machine. The boom is raised and lowered by shear cylinders exactly as is done with the present machine. As was previously noted, traversing the boom at the speeds required to obtain an instantaneous production rate of 6 tpm would require an increase in the flow capacity of the Joy 12CM hydraulic power supply. The cutter head has been described in the previous section and the cutter head and boom earlier in this section.

Other than the alterations in the fluid and electrical power systems, there will be little change in the basic mining machine to the rear of the boom. The most obvious addition will be the two electric-motor-driven, hydraulic, high-pressure pumps which are mounted on the track boxes, one on each side of the machine. The explosion-proof box, containing the starters and controls for the high-pressure pump motors is placed on the rear of the high-pressure power supply mounting on the side of the machine opposite to the operator station.

The 350-hp high-pressure pump motors are the highest components on the mining machine. The distance from the top of these motors to the lower track is 63 in. This obviously precludes operation of the machine in a 60-in. seam. Since there must be clearance between the top of the machine and the roof to allow for objects protruding from the roof and to provide for clearance as the machine negotiates discontinuities in the floor, the machine, as shown in Figure 13, is probably limited to operation in 6-foot seams as a minimum and, where rough floor conditions prevail, is probably limited to 6.25-foot seams.

Another necessity of the design of the machine which interferes with operation in 5-foot seams is the location of the intensifiers on the boom. These are covered by a boomshield which is intended to protect high-pressure components from external damage and to provide containment in the event of a rupture in the high-pressure circuit. Under a 5-ft-high roof, the boomshield contacts the roof before the mechanical cutters do. The roof must be 68 or 69 inches high before the cutters contact the roof ahead of the boomshield.

The low-pressure hydraulic power supply for the intensifiers and the water precharge system are carried on the auxiliary vehicle which is towed behind the main vehicle as it advances in the direction of the face. This is a loading machine chassis with the gathering head, conveyor, and electric traction drive eliminated. The two pumps for the intensifier low-pressure hydraulic power supply are driven by a single 175-hp electric motor with dual output shafts. These occupy the space that would normally contain the loading machine conveyor.

The auxiliary vehicle also contains the electric-motor-driven water precharge pump and the explosion-proof box containing the starters and controls for the auxiliary-vehicle-carried electric equipment. Also carried is the oil reservoir and the oil cooler which are common to both the low- and high-pressure hydraulic power supplies.

A cradle is provided on top of the auxiliary vehicle for supporting the mining-machine conveyor extension. Valves will be incorporated in the conveyor swing and elevate control circuits so that they can be open-centered when the conveyor extension is resting on the auxiliary vehicle. This will allow the conveyor to accommodate relative motions between the two vehicles as they are moved. Closing the valve used to short the control circuits will permit the conveyor extension to be raised or lowered and swung in a normal manner.

As shown in Figure 13, the length of the conveyor extension is suitable for dumping the mined coal on the floor in back of the miner. A somewhat longer conveyor extension would permit coal to be loaded into a shuttle car in a normal manner.

When it is necessary to move the mining machine and the auxiliary vehicle away from the face, the auxiliary vehicle becomes the leading vehicle. Since coal is not being mined when travel is in this direction, the intensifiers are not needed and the intensifier low-pressure hydraulic power supply can be used to supply two hydraulic traction motors which drive the auxiliary-vehicle crawler tracks.

The hoses and electric cables connecting the mining machine and the auxiliary vehicle are clamped to vertical plates at the extremities of the vehicle (designated "bridges" in Figure 13). A similar "bridge" near the boom pivot is used to anchor the hoses connecting the boom-mounted components with the rest of the system.

Figure 14 shows a block schematic of the fluid and electric power system of the hydraulic-jet continuous mining machine with emphasis on those components which are additional to those used on the normal Joy 12CM continuous mining machine. The allocation of components to the trailing vehicle, the main mining-machine chassis, and the cutter boom are also shown.

Water enters the auxiliary vehicle through a trailing hose. It is immediately divided into three branches. Figure 14 shows the flow of water to the three branches being controlled by fixed-area, manually adjustable throttle valves. This approach is appropriate for an experimental or a prototype machine; in a production machine, a closed-loop, pilot-operated control approach to controlling the division of the water among the three branches would undoubtedly be used.

The first of the branches in the water circuit connects to the normal water inlet on the main mining-machine chassis and is used to cool the electric traction controls, the tram motors, the cutter motors, the gathering-head motor, the hydraulic-pump motor, and other components exactly as is done on the existing Joy 12CM machine. This branch also supplies the dust and fire control sprays, again in a manner identical to that used in the existing Joy miner.

The second branch in the water circuit is used to cool the intensifier power supply. This branch passes through the water pump motor, the low-pressure hydraulic pump motor, the two high-pressure hydraulic pump motors, and finally the oil cooler in the intensifier power supply before being combined with the water exiting from the first cooling circuit and being carried away from the mining machine in a second trailing hose.

The third branch in the water circuit is the intensifier water supply. This is pressurized by a boost pump prior to being routed to the intensifiers.

In addition to the intensifier water precharge pump, the trailing vehicle also carries the intensifier low-pressure hydraulic power supply and the oil reservoir and oil cooler common to both intensifier hydraulic power supplies. Since the intensifiers are not operated when the mining machine is backing away from the face and it is necessary to power the trailing vehicle while backing, the intensifier low-pressure hydraulic power supply is also used to provide traction power to the trailing vehicle. The outputs of the two pumps in the low-pressure intensifier hydraulic power supply are connected separately to a supply manifold. When the intensifiers are not operating, the intensifier control circuit shorts the outlet of the low-pressure hydraulic pumps to their inlets. Two proportional four-way valves divert flow from one of the low-pressure hydraulic pumps to the two hydraulic traction motors before returning the oil to the supply manifold. These hydraulic motors drive the trailing-vehicle crawler tracks, either directly, or through a transmission. With the four-way valves centered, no flow is diverted to the hydraulic motors. Actuation of the valves in one direction causes the

crawler tracks to move forward while actuation of the valves in the other direction causes the crawler tracks to move in reverse. The trailing vehicle may be steered by moving one crawler track forward and the other in reverse.

As was previously mentioned, three additional control valves are installed at the operator station on the mining machine chassis. One of these is used to traverse the boom up and down without activating the hydraulic cutter jets. The second control valve is used to traverse the boom with the cutter jets operating; primarily when the boom is descending, secondarily when the boom is rising. The third control valve is used to operate either the primary or secondary control jets without traversing the boom.

Flexible connections are required between the trailing vehicle and the mining machine and between the chassis and boom on the mining machine. Hoses provide the needed articulation. However, because of the pressures involved, a multiplicity of hoses is required to provide the needed flow. Where hard piping is used, a single conductor is provided. Manifolds are used to interface single-piped conductors with the multiple hoses at the vehicle boundaries. Manifolds are also used to distribute the water and oil flows to the eight intensifiers on the boom and to collect the return oil from the intensifiers. Accumulators are connected to the hydraulic power supply manifolds on the boom so that the power supply can be sized for average demand rather than peak demand.

Figure 11 shows the unused set of secondary cutter jets capped off. Some method of preselecting the set of secondary jets to be used will be required. However, care must be taken to insure that no air is trapped in the cutter-jet supply lines. Very little trapped air would generate an impressive reduction in intensifier delivery.

Explosion-proof electrical enclosures will be required on both the trailing vehicle and the main mining-machine chassis to contain the starters and controls for the electric motors associated with the intensifier power supply. Pressure switches monitor critical supply pressures and provide a signal which can be used to trigger an automatic shut-down to avoid component damage in the event of a power supply failure.

If the mining machine chassis were to be completely redesigned, some saving in total system volume could be achieved by combining the low-pressure-intensifier hydraulic power supply and the general-service hydraulic power supply. An increase in the lower intensifier hydraulic supply pressure would be needed to satisfy pressure requirements in the general service circuit. A further reduction in total component volume would be realized by using a hydraulic tramping drive powered by the low-pressure hydraulic power supply to replace the electric traction drive used in the Joy 12CM mining machine. However, it must be recognized that this approach would run counter to the most recent practice in the design of coal mining machinery which favors the electric traction drive over the hydraulic drive because of the improved reliability and maintainability.

## MINING MACHINE ANALYSES

### OPERATING SEQUENCE

#### Operator Station

The operator's station and controls for the hydraulic miner will be almost identical to those on the standard Joy 12CM machine, except for the additional controls for the intensifier system. The intensifier controls will include an on-off pushbutton switch to start the electric motors in the intensifier power supply and three valves to enable the operator to operate either the boom, the intensifiers, or the boom and intensifiers together. The three valves are of the three-position, spring-centered, lever-operated type. Operation of only the boom will be controlled exactly as it is now controlled on the Joy 12CM machine. Pushing the lever away from the operator lowers the cutting head and pulling the lever toward the operator elevates the cutting head.

To operate only the intensifiers, the second valve is operated. Pushing the lever away from the operator will activate the intensifiers and also will activate the primary bank of nozzles.

The third valve will activate both of the above functions together. By pushing the lever away from the operator, the boom will be lowered and the intensifiers and the primary bank of nozzles will be activated. Pulling the lever toward the operator will raise the boom with the intensifiers and secondary bank of nozzles working. As the operator moves the lever to activate the boom, there will be a delay of less than one second before the boom moves to allow the intensifiers to develop sufficient pressure at the nozzles for cutting.

If, after being turned off, the intensifiers are not reactivated within a certain length of time (adjustable between 5 to 20 sec), the output of the hydraulic supply pumps for the intensifiers will be depressurized to reduce fluid heating. As the control valve is switched from the neutral position, the intensifiers will again be pressurized.

The physical location of the conveyor elevating valve and the conveyor swing valve will not change. But, instead of the present three-position valves, four-position valves will be used. The additional position will allow the conveyor to "float," that is, to enable the conveyor to rest on the auxiliary vehicle and freely move as the auxiliary vehicle moves.

The interlocks incorporated in the design of the Joy 12CM miner will be retained. These include the following:

- (1) Control switch must be in "run" position before machine can be started.

- (2) Service pump cannot be started unless cutter motor switch and traction control levers are in "off" positions.
- (3) No other motor can be started until service pump has been started.
- (4) Cutter motors can be started only by simultaneously actuating cutter motor and service pump motor switches.
- (5) While the cutter motors are on, the machine can only move forward at the slowest speed. However, the miner may be trammed in reverse in both the low or second speeds with the cutter motors running.
- (6) Machine cannot be trammed unless tram safety pedal is operated.

In addition to the above, the following interlock features will be added to the hydraulic mining machine.

- (1) Intensifier pump motors cannot be turned on unless cutter motors are on.
- (2) Two switches must be simultaneously actuated to turn on intensifier pump motors.
- (3) Turning off cutter motors turns off intensifier pump motors.
- (4) Intensifier pump switch must be in "off" position to start service pump motor or cutter motors.

#### Operating Procedure

The miner should be trammed to a new working face following the procedure outlined in the Joy Manufacturing Company manual on the Joy 12CM machine. An additional operator is required to control the auxiliary vehicle. To supply pressure to the nozzles, the procedure outlined below must be followed.

- (1) Place control switch in "run" position.
- (2) Start service pump by turning pump and traction motor switch to "on" position. Traction levers, cutter motor switch, and intensifier pump motor switches must be in "off" position.
- (3) Start cutter motors by simultaneously actuating service pump motor and cutter motor switches. Intensifier pump motor switch must be in "off" position.
- (4) Start intensifier pump motors by simultaneously actuating cutter motor and intensifier pump motor switches.
- (5) Activate intensifier hydraulic control circuit.
- (6) Cutter jets may now be actuated by moving shear cylinder control lever.

- (7) Placing any of the controls in this sequence in the "off" position will prevent operation of the cutter nozzles, since this will turn the intensifier pump motors off.

The operating procedure is somewhat different between the two alternative mining approaches (i.e., cutting during sweep up and down versus cutting during sweep down) which are discussed in detail in the section titled "Development of Cutter Head Concept." Each procedure will be defined, starting with the approach where the miner will be removing coal on both the up and down strokes. The cycle begins with the wedges contacting the top of the coal face. The operator then pushes the lever of the boom and intensifier control valve away from him. This will lower the boom and activate the primary (lower) bank of nozzles which will have wedges following in these kerfs. As the boom reaches the end of the sweep, the operator releases the lever and the boom and intensifiers will stop. The operator then actuates the safety tram control and pushes both traction control levers forward which enables the breaker bars to trim the floor while the cutter chains and cutter wheels clean up the walls and coal face.

Having advanced the miner forward, the operator then pulls the lever toward him to raise the boom while the secondary (upper) jets are on. During this upward stroke, the wedges will also follow in the kerfs of these nozzles. After the boom reaches the roof, the operator will release the safety tram control and push both traction control levers forward which will move the vehicle forward. This will allow the breaker bars to clean up the roof while the cutter chains and cutter wheels trim the unremoved sections on the walls and coal face. The cycle is then repeated as the operator pushes the levers away from him and moves the boom down with the primary jets working.

The second approach will only remove coal mechanically on the downward stroke, but will employ jet cutting on both the up and down strokes. This cycle should start with the miner being trammed to the new coal face with the boom lowered to the floor and slightly back from the coal face.

The operator then pulls the lever of the valve which controls both the intensifiers and the boom. This will raise the boom and have the secondary nozzles working which do not have wedges following in these kerfs. The operator releases the lever to the neutral position as the boom reaches the top of the seam. The operator then trams the miner forward until the wedges contact the coal face. Next, the operator lowers the boom and activates the primary bank of nozzles which has wedges to follow in these kerfs. The operator keeps this lever pushed away from him until the breaker bars contact the floor. The operator then releases this valve lever and trams the machine forward to clean up the floor and coal face. He positions the miner so that the wedges are slightly back from the coal face. He now repeats the cycle.

During either of these mining approaches, the operator must be sure that the conveyor boom is positioned over the shuttle car. During normal

operations, the conveyor boom would be resting on the auxiliary vehicle and allowed to float with this vehicle. If required, the operator can manually control the conveyor boom.

Tramming away from the coal face will be somewhat cumbersome and will require a man to operate the miner and a man to operate the auxiliary vehicle. It is possible that the mining plan would have to be altered. Currently 90-degree turns are required which would be difficult for the miner and the auxiliary vehicle to make. Maneuvering of these vehicles will be much easier if the pillars are in the form of a parallelogram instead of a rectangle.

## OPERATOR SAFETY

Operator health and safety have been given careful consideration during the planning and design of the hydraulic-jet coal miner. In most cases the new design is as safe or safer than the unmodified Joy 12CM miner.

A hazardous condition could exist because of the use of high-pressure hydraulic systems on the hydraulic jet miner. The new design requires two of these systems to be installed on the miner: (1) a 35,000 psi water system, and (2) a 3,800 psi hydraulic system. If ruptured while at pressure, either system would be potentially hazardous to an operator. For this reason, all high-pressure fluid conduits are either inside the miner framework or protected by external shielding.

Personnel danger attributable to the use of high-pressure water jets has been minimized. After the water has traveled three feet or more from the nozzles, no danger of skin penetration exists. Consequently, the miner operator, who is greater than 15 feet from the face, is in no danger from water jets being reflected from the coal face. When the miner is not at the coal face, personnel could get close enough to the nozzles to be injured if the nozzles were activated. However, because of the interlocks described above, the nozzles and intensifiers cannot be activated unless the cutter motors are turned on. Therefore, the rotating ripper-cutters would serve as a warning device to personnel near the front of the mining machine. In addition, the control valves which activate the intensifiers and nozzles are spring-centered and will not remain in the "on" condition unless held by the operator.

The problem of visibility, however, has not been solved. Visibility of the coal face from the operator's station has necessarily been reduced by the location of equipment on top of the miner chassis and boom. For example, an oil pump and motor are mounted on the miner chassis directly in front of the operator's station and will block approximately 50 percent of his view of the face. The intensifiers are mounted on top of the boom and will require the boom to be lowered several feet before the face is visible. In addition, hoses, tubing, and mountings which connect the boom and chassis hydraulics will further

block the operator's view of the face. This reduction of visibility is undesirable. However, during the operation of at least one standard Joy 12CM, it was observed that the coal face was not visible to the operator because of coal dust created by the ripper cutter. No difficulty was observed in machine operation because of the lack of face visibility.

Operation of the hydraulic jet miner is expected to produce less sparking and coal dust than the operation of an unmodified Joy 12CM. This reduction is expected because the use of high-pressure water jets to cut the coal should require less mechanical cutting and release fewer unwetted fine coal particles to the circulating air.

The noise standards provided under the Walsh-Healey Public Contracts Act are prescribed as applicable to coal mines by Section 206 of the Federal Coal Mine Health and Safety Act of 1969. The Walsh-Healey Act specifies the maximum periods of time that an employee may be subjected to certain average noise levels during a work shift. For example, exposure to an average noise level of 90 dBA may not exceed eight hours and exposure to 97 dBA may not exceed three hours.

A 1971 Bureau of Mines report, Noise in Underground Coal Mines, by J. A. Lamonica, R. L. Mundell, and T. L. Muldoon, indicates that the mean of average noise level readings taken in 21 mines during the cut and load operations of continuous miners was 97 dBA at the operator's positions. The noise level recorded during the Continental Oil Company underground jet-cutting tests, conducted in the Humphrey No. 7 mine, reached a maximum of 97 dBA at the miner operator's position (approximately 16 feet from the jets). This noise level was recorded when the jets were operating at 30,000 psi and discharging into the air. The noise level produced when the jets are cutting will be reduced because a shorter length of each jet will be exposed to the air, thereby reducing the noise producing entrainment of air by the jets. Bendix' experience with high-pressure jets supports these values.

Based on the above noise levels and the assumption that the jets are the predominant noise sources during coal cutting, the noise level produced by the hydraulic jet miner during cutting and loading operations is expected to be approximately the same as for existing continuous miners. Noise levels during other miner operations not requiring jet cutting (such as tramping and maneuvering) will be kept to a minimum by turning off the jets. In addition, during waiting periods, the operator can further reduce the noise level by turning off the intensifier hydraulic power supplies.

## IMPACT ON MINE ENVIRONMENT

During the operation of the hydraulic miner, a maximum water flow of 25.5 gpm at 35,000 psi will be striking the coal face. This water will be heated on impact and either evaporate or fall to the floor. For the analysis conducted, it was assumed that air enters the working area at a temperature of 70°F and a relative humidity of 75%. Temperature

of the water before striking the coal face was assumed to be 60°F. These assumptions are considered to be conservative and entering temperatures may very well be lower.

The results of the model analyzed show that the air leaves at a maximum of 88°F (about 100 feet from the face) and is nearly saturated with water. The temperature of the water will be 115°F. Figure 15 shows the model that was used.

The assumptions that were made for this simplified model are:

- (1) All of the water used to cool the pumps and motors is returned from the miner.
- (2) A separate supply of water is used for coal cutting and has an initial temperature of 60°F.
- (3) As the water impacts the coal, all of the kinetic energy is transferred to heating of the water. This is a conservative assumption, concerning the maximum temperature of the air and water.
- (4) After this water falls to the floor, none of the water is soaked into the coal floor. Therefore, the water forms a large puddle or pool.

#### COMPARISON WITH PRESENT CONTINUOUS MINERS

The rated capacity of the present Joy 12CM continuous miner is 8 to 12 tpm in 44- to 120-inch high seams. The instantaneous production rate of the hydraulic-jet continuous miner is undetermined because of various unknown factors as discussed in the section titled "Analysis of Jet Cutting of Coal," but is probably less than 2 tpm. Because of the smaller depth of cut which will be taken with the hydraulic jet continuous miner, a proportionally greater amount of time per unit weight of coal mined will be required to move the machine between operating cycles of the boom. Based on these factors, it is estimated that the production rate of the hydraulic-jet continuous miner will be one-fifth to one-eighth of the production rate of a Joy 12CM miner operating under equivalent

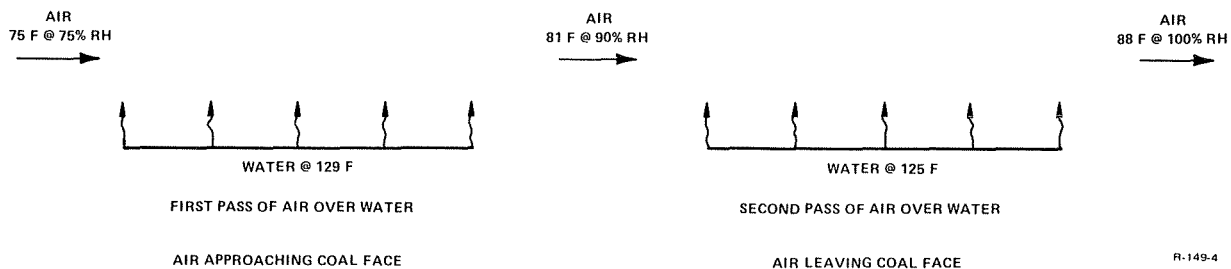


Figure 15 - Model Used to Calculate Temperatures of Air and Water

conditions. This estimate is based on the assumption that the hydraulic-jet continuous miner will be able to extract coal only on the downward sweep of the boom and that the boom sweep of 16.8 in/sec calculated to be necessary in the section referenced above cannot be achieved in a practical situation.

During the actual mining of coal, the hydraulic-jet continuous miner will require one operator, the same as existing continuous mining machines. During movement away from the face and from one place to another, a second operator will be required to operate the auxiliary vehicle. If it is assumed that this second operator can operate a shuttle car or perform other duties while coal is being mined, this requirement is not severe. Moreover, a complete redesign of the hydraulic-jet chassis from the ground up would probably eliminate the need of the second operator. Therefore, the manpower penalty, on a shift basis, chargeable against the hydraulic-jet continuous miner, is not great. However, because of the reduced production rate, the manhours per ton of coal is greatly increased.

One significant characteristic of the hydraulic-jet continuous miner is that when the intensifiers are operating, they demand a constant power regardless of the amount of coal being mined. That is, a hydraulic-jet continuous miner, in the open, away from the face, requires as much intensifier power as a hydraulic-jet continuous miner mining coal at its maximum possible rate. On the other hand, a normal continuous miner, in the open, with its cutter drum revolving, draws only that cutter power needed to overcome friction, windage, and other parasitic losses. Moreover, the cutter power demand of the normal continuous miner varies as the difficulty of extracting coal varies. Cutter motors on the normal continuous miner are actually selected on the basis of their torque capability and may instantaneously draw more than their rated power. The installed power on the hydraulic-jet continuous miner is over twice that installed on the Joy 12CM continuous miner. Because of uncertainties regarding the duty cycle imposed on the normal machine, comparison is difficult, but it appears that the electrical energy requirements for the hydraulic-jet continuous miner per ton of coal will be 10 to 20 times that of the Joy 12CM continuous miner. This estimate is based on the double installed power and the one-fifth to one-eighth production rate with an approximate allowance for the continuous duty cycle.

One of the most obvious objections to the design of the machine described in this report is that it is suitable for operation only in coal seams having a height in excess of 6 ft. This severely limits its general usefulness. In this regard, the machine is more suitable as a feasibility evaluation vehicle than as a production prototype. The heights of a completely redesigned machine would undoubtedly be reduced. A significant reduction in height would require an increase in the length of the mining machine. An increase in length would require that the vehicle be articulated to enable it to turn corners and move from place to place. The articulation point should divide the machine into approximately equal weight sections. Both sections would be equipped with traction drives so that the leading half could always be powered. This would permit the

machine to be controlled by one operator at all times. Although, in theory, an articulated vehicle could be maneuvered in a coal mine, it would undoubtedly be more awkward than the standard machine and would require a higher level of operator training and skill.

No attempt has been made to compare the capital costs of the hydraulic-jet mining machine with the standard machine. However, the presence of more-than-doubled installed power level and the intensifier system which requires high-pressure components of high quality suggests that the increased capital cost of the hydraulic-jet continuous miner will be substantial.

Concern must also be felt regarding the reliability and maintainability of the hydraulic-jet continuous miner. Not only is the machine more complex because of the increased number of fluid and electrical power circuits, but many of the added hydraulic components operate at pressures higher than are normally used in underground coal mines. The coal mine environment has traditionally been quite harsh with hydraulic systems. Maintenance of the hydraulic-jet continuous miner will undoubtedly require more careful maintenance procedures and precautions than are normally encountered in underground coal mines today.

Stringent precautions will be taken to protect high-pressure lines and components from external damage and to contain fragments resulting from a rupture. However, the high-pressure systems, especially if not properly maintained, will present a potential safety hazard. Fortunately, the highest pressure, at the cutter jets, is isolated from the operator and occupies a relatively small space.

It is not believed that the cutter head of the hydraulic-jet continuous miner presents any significantly increased safety hazard compared with that on the standard continuous miner. The cutter jets are expected to be dangerous only within a range of approximately one yard. With the mining machine completely shut down, the system should be interlocked so that the general service hydraulic pump must be running before the intensifier power supply can be started. Hence, any individual at the front of the machine, when it is turned off, would have reasonable warning before the cutter jets could be actuated. If it became necessary, for maintenance reasons, for personnel to be near the cutter head with the jets operating, extreme care would be required.

Although the hydraulic-jet continuous mining machine will operate at a higher voltage (950 volts) than is normally in use at present, this is not viewed as a significantly increased safety hazard. A detailed discussion of the operation of mining equipment at these voltage levels is presented in References 2 through 5.

One potentially hazardous aspect of the hydraulic-jet continuous mining machine is that with either the version described in this report or a completely redesigned version, the machine will be of greater bulk, with less maneuverability and visibility, compared with existing machines.

This will make it more difficult to avoid running into a wall while maneuvering the machine and make it more difficult for the operator to see and take measures to avoid contact with other personnel in the immediate vicinity.

It should also be noted that a reduced production rate in itself has hazardous aspects, since the manhours of exposure to the coal mine environment on a per-ton basis is thereby increased.

The potential advantages of the hydraulic-jet continuous miner, which led to this program being started, are (1) reduction of dust hazard, (2) reduction of spark hazard, (3) less disturbance of overlying strata, thus reducing roof fall hazard and (4) reduction of bit wear.

Since the removal of coal by the process of wedging and jet cutting is expected to be an inherently low dust producer and since the face will be liberally sprayed with water, there is no doubt that the dust hazard will be reduced. However, since mechanical cutting will still be used at the edges of the face, the dust hazard will not be completely eliminated.

One of the potential advantages of the hydraulic-jet continuous miner not realized by the present concept is the total elimination of the spark hazards. The jet cutting and mechanical wedging process will undoubtedly be able to bring down very small pyrite inclusions with little probability of sparking. However, very small inclusions probably present little sparking hazard with the present machines. Above a certain size, pyrite inclusions will probably be quite resistant to the cutting action of the jets and will not be extracted by the mechanical wedging devices. This will leave a protrusion in the face which will have to be removed by the cutter wheels on chains with a probability of striking a spark very nearly equivalent to that of the present machines. It is probable that the inclusion size which cannot be removed by the mining machine and which must be removed by hand will be much smaller in the case of the hydraulic-jet continuous miner than is the case with existing continuous miners.

The hydraulic-jet continuous miner will undoubtedly cause less damage to the roof than present machines. Some of this reduction will be inherent to the process, but some of the reduction will be a consequence of the shallower depth of coal removed by the hydraulic-jet continuous miner.

There will undoubtedly be a reduction of wear in the bits of the cutter wheels and chains since they will cut only a fraction of the coal. However, there will also be wear of the wedging devices. There is no information available to permit an estimate of wedging device wear to be made, but it is believed that overall tooling wear will be reduced since the wedge velocity is smaller than normal cutter bit velocity.

## CONCLUSIONS AND RECOMMENDATIONS

### CONCLUSIONS

The following conclusions have been reached as the result of the work done under this program.

- (1) The machine design described in this report, or any other hydraulic-jet continuous miner design based on adding components and systems to the chassis of an existing mining machine, will be suitable as a feasibility demonstration device only and will not be a production prototype. A true prototype must have a completely redesigned chassis with significant changes in structure and arrangement, compared with existing continuous mining machines.
- (2) The power demand of the hydraulic-jet continuous miner described in this report is at or over the limit of what can be supplied at 950 volts through a 4/0 cable. The power consumption is great enough to have a significant effect on the production cost of coal and to cause concern regarding possible adverse effects on the environment at the face.
- (3) The hydraulic-jet continuous miner design described in this report will have a very low production rate. An increase in production rate (and an improvement in power consumption per ton of coal) will require either a substantial increase in jet cutter power or an efficiency improvement in coal extraction rate above that of current jet cutting designs.
- (4) The initial cost and the maintenance cost of the hydraulic-jet continuous miner will be significantly greater than those of existing continuous mining machines.
- (5) The hydraulic-jet continuous miner, as presently defined, does not offer any significant advantages in operation, economics, or safety, when compared with existing continuous mining machines.

The existing design does not improve operator visibility of the face, and cannot operate in five-foot seams of coal. A closer achievement of these goals might be obtained by a complete redesign of the mining machine chassis.

### RECOMMENDATIONS

Based on the above conclusions, the following recommendations are made:

- (1) No further development of the hydraulic-jet continuous miner configuration developed under this contract should be undertaken at this time.

- (2) Prior to the performance of any further development of the hydraulic-jet continuous miner, a test program should be performed to obtain additional data on the kerfing of coal with high-pressure water jets and on the fracture characteristics and methods of fracturing coal which has been kerfed by high-pressure water jets.

## PATENT STATUS

A disclosure on the cutter head configuration has been written. This will be reviewed to determine if it contains any invention and patentable matter.

## REFERENCES

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