CONSTANT-DEPTH LINEAR CUTTING HEAD FOR CONTINUOUS MINING MACHINES

ENGINEERING AND ECONOMIC FEASIBILITY STUDY

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

FMC Corporation
Engineered Systems Division
328 Brokaw Road
Santa Clara, CA 95052

Final Report

on

Contract JO265010
Engineering and Economic Feasibility Study
Constant Depth Linear Cutting Head
... Continuous Mining Machines

March 1977

REPORT DOCUMENTATION PAGE

1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Engineering and Economic Feasibility Study of the Constant Depth Linear Cutting Head for Continuous Mining Machines		5. Report Date March 1977 6.
7. Author(s) A. Baldwin, J. Sutton		8. Performing Organization Report No. R-3599
9. Performing Organization Name and Address FMC Corporation, Engineered Systems Division 328 Brokaw Road, P. O. Box 450 Santa Clara, CA 95052		10. Project/Task/Work Unit No. 568 11. Contract or Grant No. J0265010
12. Sponsoring Organization Name and Address Office of the Assistant Director — Mining U. S. Department of the Interior, Bureau of Mines Washington, DC 20241		13. Type of Report Final 14.
15. Supplementary Notes		

16. Abstract

This report describes the engineering feasibility and economic advantages of a unique new mining machine using cutting bits that take a constant-depth linear cut in the coal face. The studies show that this innovative new cutting concept, being developed by the Bureau of Mines, can be designed into the basic continuous mining machine. The resulting miner would be attractive to mine owners because coal could be mined with minimum generation of airborne respirable dust, substantial increases in productivity, and elimination of methane ignition due to cutting.

USBM—OFR 95-77
NTIS # PB 267 927

17. Originator's Key Words	18. Availability Statement		
19. U. S. Security Classif. of the Report UNCLASSIFIED	20. U. S. Security Classif. of This Page UNCLASSIFIED	21. No. of Pages 197	22. Price

FOREWORD

This report was prepared by FMC Corporation, Engineered Systems Division, Santa Clara, California, under USBM Contract J0265010. The contract was initiated under the Coal Mine Health and Safety Act. It was administered under the technical direction of the Twin Cities Mining Research Center, with Mr. Wallace Roepke acting as the Technical Project Officer. Mr. William Case was the Contract Administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period April 1976 to March 1977. This report was submitted by the authors March 4, 1977.

CONTENTS

CONTENTS (continued)

ILLUSTRATIONS

ILLUSTRATIONS (continued)

ILLUSTRATIONS (continued)

ILLUSTRATIONS (continued)

I EXECUTIVE SUMMARY

The United Stated Federal Coal Mine Health and Safety Act of 1969 established strict limits on the amount of airborne respirable dust (ARD) permitted in underground coal mine environments. The Bureau of Mines, in response to the Act, implemented research programs to provide improved and/or new technology for control of dust. This contract report documents an engineering and economic feasibility study of new coal cutting concepts developed by the Bureau of Mines at the Twin Cities Mining Research Center. The results of the Bureau's Twin Cities work are reported in a Bureau Report of Investigation (RI 8185) titled "Reduction of of Dust and Energy During Coal Cutting Using Point-Attack Bits," with an analysis of rotary cutting and development of a new cutting concept, by Wallace W. Roepke, David P. Lindroth, and Theodore A. Myren; Patent Application 604,566, Method of Operating a Constant Depth Linear Cutter Head on a Retrofitted Continuous Mining Machine, by W. W. Roepke, K. C. Strebig, and B. V. Johnson; and Patent Application 702,373, Linear Cutting Rotary Head Continuous Mining Machine, by W. W. Roepke, D. P. Lindroth, and J. W. Rasmussen.

The new method of mining coal, being developed by the Bureau of Mines, is defined as the Constant-Depth Linear Cutter Head Concept. Constant depth means that the cutting bits are sumped straight into the coal to a depth greater than 1 inch and remain at this depth for the duration of the shearing process. Linear cutter head means that the shearing action of the bits is in a straight line as opposed to the circular path of the bits of a hard-head drum-type continuous miner.

The most comprehensive studies on deep cutting in coal are now evolving from the U.S. Bureau of Mines Research Center in Twin Cities, Minnesota. All other studies have underscored the benefits of deep cutting, through shallow cutting experiments that are extrapolated to deeper cuts. Through its research, the Bureau has concluded that the greatest generation of ARD occurs at cuts less than 1 inch deep so cutting should occur deeper than 1 inch.

The concepts evaluated during this study were based on the Bureau's Twin Cities Mining Research Center laboratory work. Continuous mining machines with hard-head drum cutting capabilities were analyzed as part of the Bureau's work, and some rather dramatic and pronounced inefficiencies were isolated as being characteristic of rotary cutting. In addition, the Bureau studies found many desirable characteristics and advantages of linear cutting over rotary cutting, such as reduced ARD generation and reduced specific energy requirements. Deep linear cutting is more than just a method of controlling dust. It limits the generation of dust at the source, the cutting action of the bit, before the dust can be be discharged into the mine environment.

During the initial stage of the study, many concepts and ideas were generated and evaluated in an attempt to develop a feasible CDLCH machine. Concept drawings, power requirements, component selection, and prouction analyses were accomplished for five concepts. Three concepts were rejected for various reasons, from low production potential to extreme complexity. The remaining two concepts, the linear cutting rotary head (LCRH) and the self-sumping head (SSH), show excellent promise for reducing dust, eliminating methane ignition at the face, and increasing productivity.

The linear cutting rotary head (LCRH) concept (Figure 1) dramatically increases productivity while reducing ARD generation. The geometry of the drive mechanism guides the bits in a square or box pattern. The deep linear cuts are made as the bits move across the top, front, and bottom edge of the box-cut path. Two versions of this concept have been considered, one that takes a 6-inch-deep cut and one that takes a 3-inch-deep cut. The philosophy behind the 6-inch version is simply that large increases in depth of cut optimize the decreases in specific energy and ARD generation with a corresponding increase in size and salability of the coal produced.

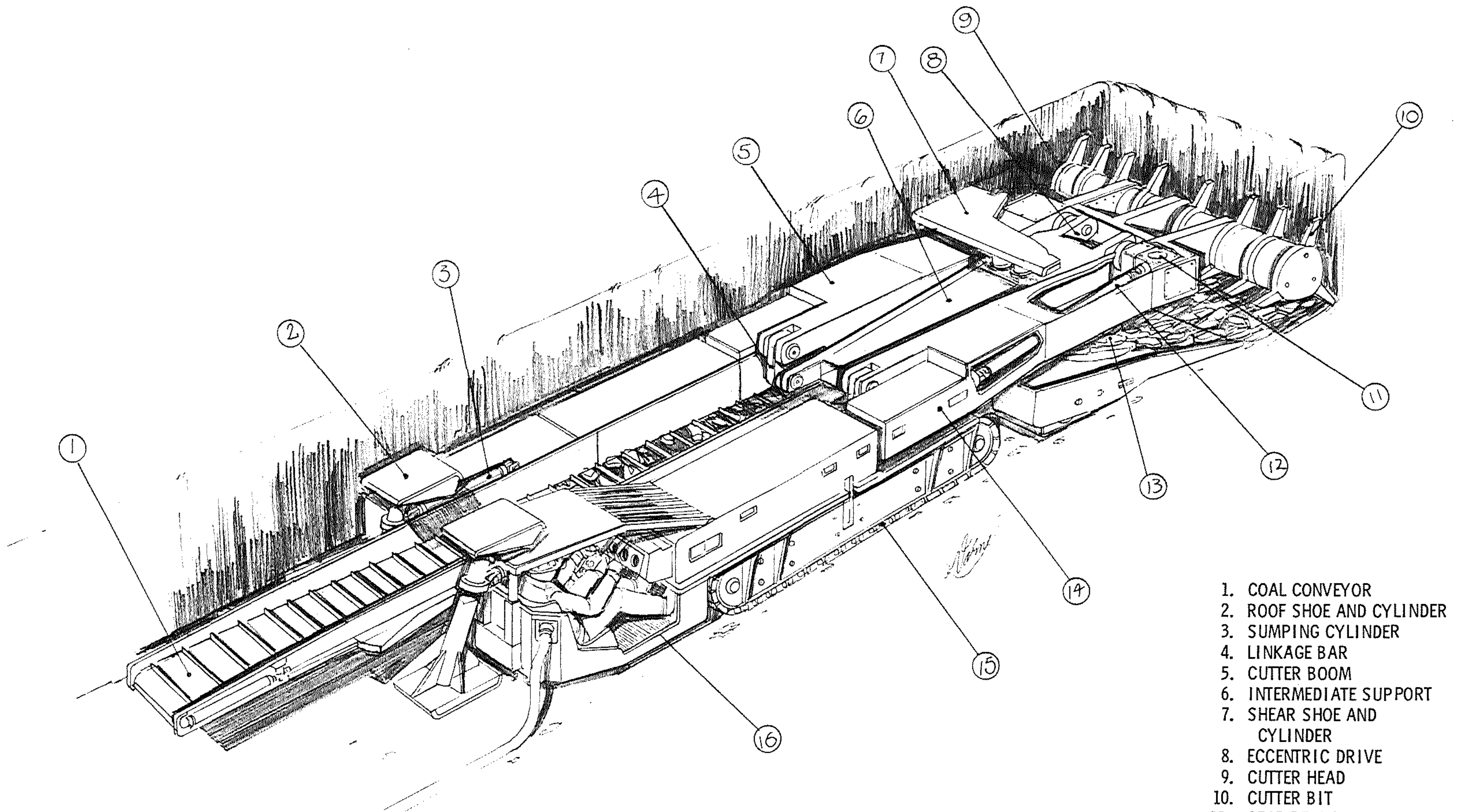


Figure 1 ARTIST'S DRAWING, LINEAR CUTTING ROTARY HEAD CONCEPT

The following significant features of this 6-inch-cut LCRH concept have evolved during this study:

- A 31-percent increase in productivity (tons per man-shift) when compared to a standard hard-head continuous mining machine developing a room and pillar mine plan in a 6-foot coal seam
- An 89-percent reduction of ARD (milligrams per ton) of coal mined, when compared to a hard-head continuous mining machine operating in the Illinois Number 6 coal seam
- Reduction or elimination of methane ignition due to cutting bits.

Although this concept exhibits outstanding potential, several questions remain unanswered, and several design features could prove troublesome, as a direct consequence of cutting to a 6-inch depth. Briefly, the following points should be considered when evaluating the 6-inch version of the LCRH:

- The forces involved in cutting to 6-inch depths have been extrapolated from shallower cuts. Continued testing must isolate the force range that will be encountered when cutting to a 6-inch depth.
- From initial evaluation, 600 horsepower is necessary to operate the head at 10 rpm. The largest continuous miner to date (a prototype still in the testing stage) produces 450 horsepower at the head. Most CMMs in use today produce 200 to 300 horsepower at the head.
- A large sumping rig located at the rear of the miner is necessary so that the machine will have a platform locked between the roof and floor in which to react the required sump forces. The sumping rig hinders maneuverability and production potential.
- The estimated weight of this concept is 130,000 pounds. Based on a $3.06-per-pound projected production cost, this machine would cost $398,000 as a production model.

These drawbacks led to consideration of the ramifications of designing the LCRH to cut at a 3-inch depth. The results of this analysis have been extremely encouraging and are beiefly summarized as follows:

- The sumping rig can be eliminated and the overall bulk of the machine can be reduced, giving this LCRH all the manueverability of existing CMMs.

- For any given head speed, the LCRH will cut approximately three times as much coal and reduce ARD by 33 percent over a CMM designed for 3-inch depth of cut.
- Again comparing a CMM cutting 3 inches deep to the LCRH, if both machines were designed for equal production rates, the CMM would use 33 to 67 percent more power and generate 200 to 300 percent more ARD.
- In comparing an LCRH at 3-inch depth of cut to an existing CMM cutting at 1 inch or less, for an equal production rate, the CMM would require 127 percent more power and generate 636 percent more ARD.
- Laboratory cutting tests have been conducted for 3-inch depth of cut; therefore, the necessary forces are known.
- The required head horsepower would range from 132 for a production rate of 6.6 tons per minute to 450 for a production rate of 22.7 tons per minute.
- ARD generation is dramatically reduced over that of existing CMMs and CMMs designed for deep cutting.
- Methane ignition due to cutting is eliminated because the bit velocity is always less than 250 feet per minute.
- The estimated weight of the 3-inch version of the LCRH is 100,000 pounds. This projects to a production cost of $306,000.

The self-sumping head (SSH) concept (Figure 2) has many desirable features and shows promise for use in a specific and difficult mining environment. The following list summarizes the characteristics of this concept and the reasons that it is retained as a recommended concept:

- The new cutter boom can be retrofitted to most existing CMMs.
- No chock system or sumping rig is necessary; the SSH retains the manueverability of existing CMMs.
- Large coal size is produced by deep linear cutting bits.
- Production in tons per shift is equal to that of existing CMMs.
- A 93-percent reduction of ARD (milligrams per ton of coal mined) is realized when compared to an existing continuous mining machine operating in the Illinois Number 6 coal seam.

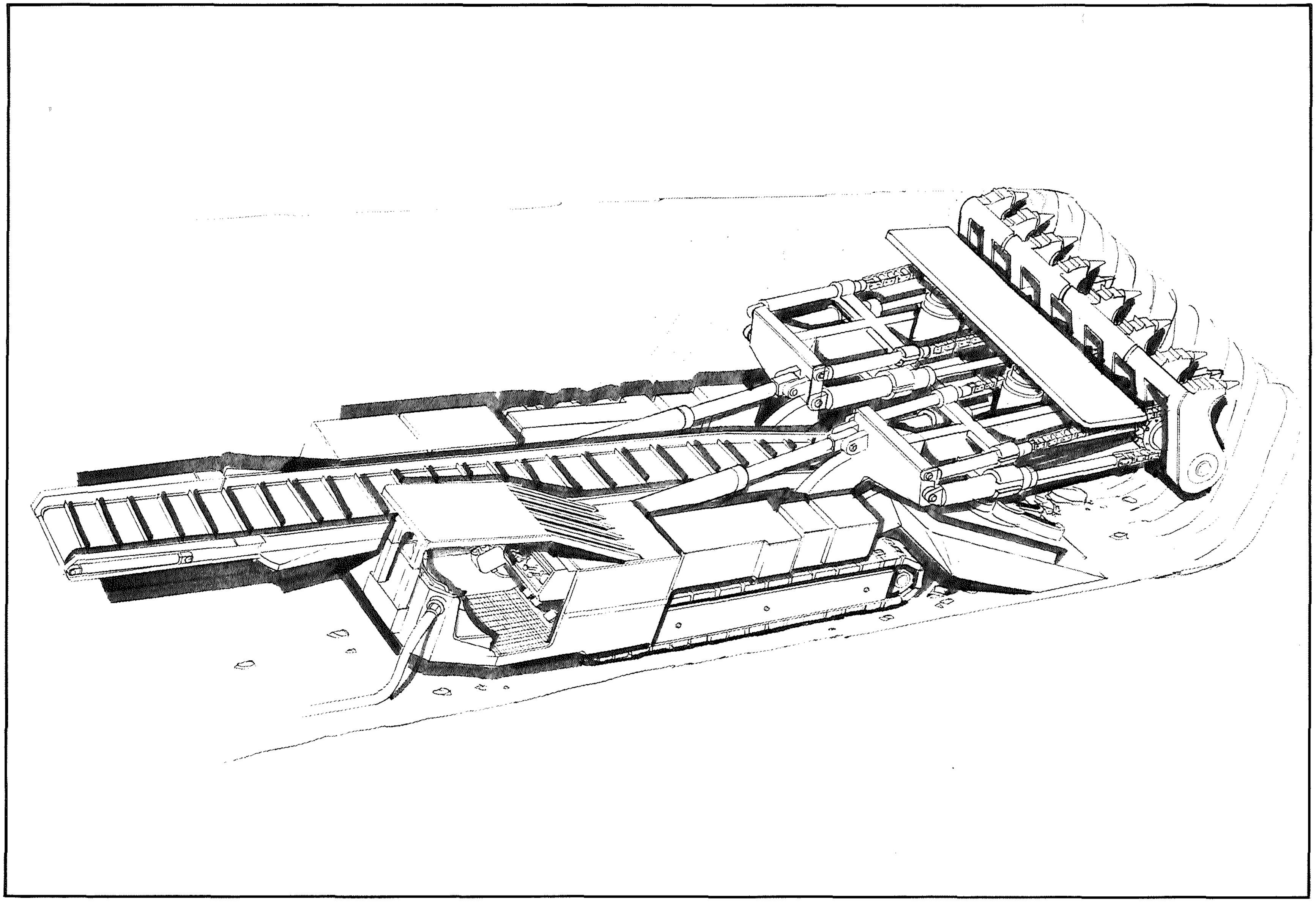


Figure 2 ARTIST'S DRAWING, SELF-SUMPING HEAD CONCEPT

- Methane ignition due to cutting bits is eliminated.
- Some coal seams such as the Upper Freeport are so friable and dusty that standard CMMs produce a large volume of fines that are not marketable. The SSH cutter boom could be retrofitted to existing machinery in such a mine, thus eliminating the dust problem as well as improving the size and salablity of the final product.

This study has concluded that the method of cutting coal by constant-depth linear cutting is a feasible engineering and economic alternative to existing rotary drum cutting in both underground and surface mining. The 3-inch version of the LCRH can boost productivity, reduce airborne respirable dust generation, and be constructed using off-the-shelf components. The SSH concept can match existing CMMs in productivity and reduce the generation of airborne respirable dust. It is important to note that the cutter boom design of the SSH can be retrofitted to existing CMMs working in dusty friable seams, and greatly improve the quantity of marketable coal and the quality of the working environment.

It is recommended that further in-situ testing of the coal cutting parameters of deep cutting be investigated so that a firm design basis can be established. When this information becomes available, and if it is still considered favorable, a full-scale prototype LCRH should be built, and an existing CMM should be retrofitted with an SSH boom for evaluation.

The Bureau of Mines has applied for patent of the constant-depth linear cutter head design. No additional subject inventions resulted from this study.

II INTRODUCTION

This report presents the results of an engineering study conducted by the Advanced Mining Systems Group, Engineered Systems Division, FMC Corporation. The project was conducted under U.S. Bureau of Mines Contract JO265010, titled "Feasibility Study of the Constant Depth Linear Head for Continuous Mining Machines."

The U.S. Federal Coal Mine Health and Safety ACt of 1969 established strict limits on the amount of airborne respirable dust permitted in the underground coal mine environment. The Bureau of Mines, in response to the Act, implemented research programs to provide improved or new technology for the control of dust. One of these programs, an investigation of the reduction of dust and energy during coal cutting, is being conducted by the Twin Cities Mining Research Center. Some of the results of the Twin Cities studies are included in Report of Investigations 8185, "Reduction of Dust and Energy During Coal Cutting Using Point-Attack Bits," with an analysis of rotary cutting and development of a new cutting concept, by Wallace W. Roepke, David P. Lindroth, and Theodore A. Myren.

The purpose of this contract was to investigate the engineering and economic feasibility of the new cutting concepts resulting from the Twin Cities studies. Two of the Bureau's concepts that led to this investigation are shown in Figures 3 and 4. The new techniques use a constant-depth linear cutter head (CDLCH) in place of the traditional rotary hard-head drum cutter. CDLCH cutting reduces the airborne respirable dust released when the bits cut through the coal. The Bureau's tests showed that shallow cutting (less than 1 inch) is a very inefficient, high-energy, dusty method of mining coal. Rotary-head miners and European shearers cut at a depth of 1 inch or less.

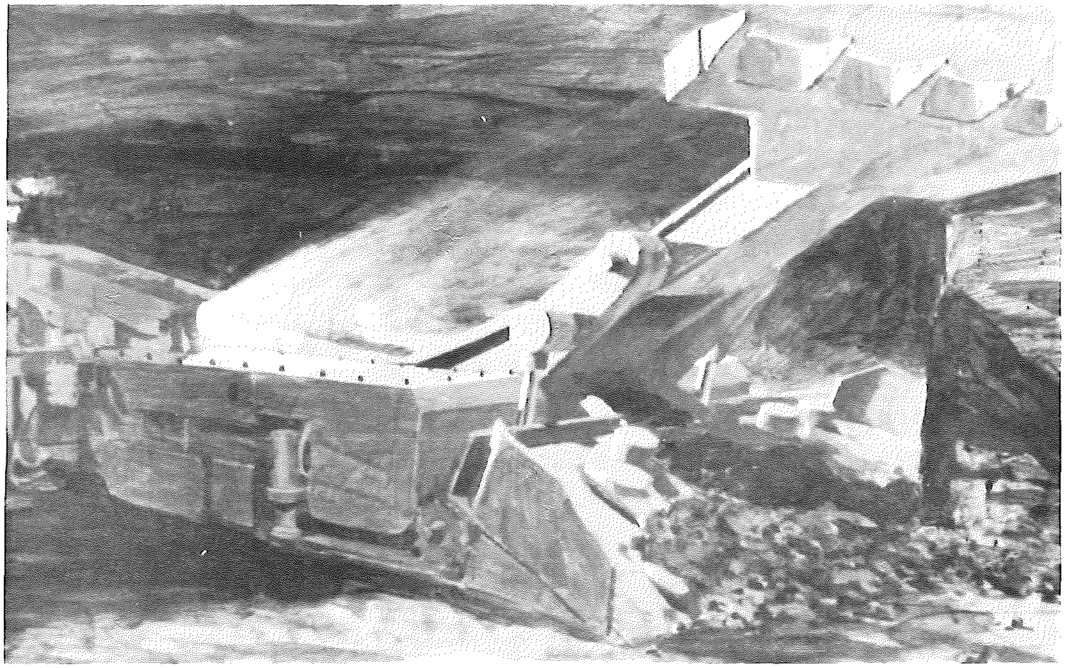


Figure 3 ARTIST'S CONCEPT — USBM FIRST-GENERATION CONSTANT-DEPTH LINEAR CUTTER DESIGN

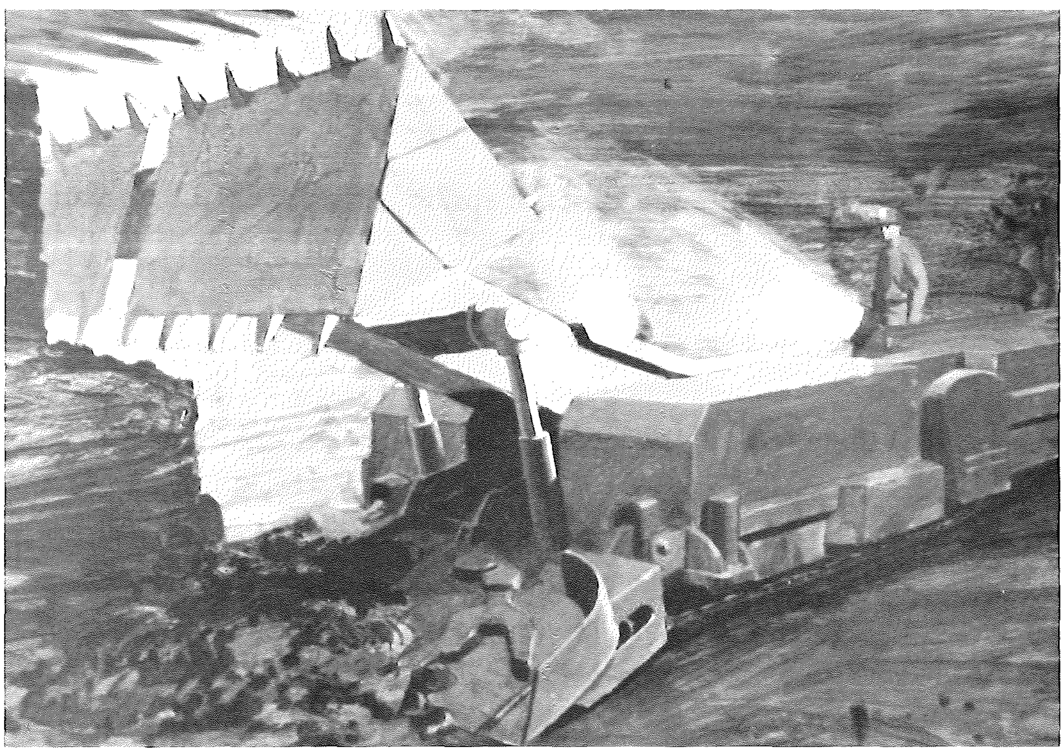


Figure 4 ARTIST'S CONCEPT — USBM SECOND-GENERATION CONSTANT-DEPTH LINEAR CUTTER DESIGN

In addition, an energy relationship exists between depth of cut and bit spacing. It was found that the optimum value for bit spacing is two to three times the depth of cut. This spacing allows the minimum energy input per volume of coal extracted (specific energy).

The CDLCH methods use fewer, deeper-cutting bits, and constant-depth bits that result in reductions in the dust generated. This report describes the reduction of the total airborne resirable dust at the face that can be attributed to CDLCH concepts and the corresponding effect on productivity.

The theory and design parameters were furnished to FMC by the Bureau in the form of R. I. 8185 and Patent Application 604,566, "Method of Operating a Constant Depth Linear Cutting Head on a Retrofitted Continuous Mining Machine," by W. W. Roepke, K. C. Strebig, and B. V. Johnson. Concepts generated under the principles of this patent included the V face, the articulated head, the chain ripper, and the self-sumping head.

The contract was subsequently modified to include a specific concept described in Patent Application 702,373, "Linear Cutting Rotary Head Continuous MIning Machine," by W. W. Roepke, D. P. Lindroth, and J. W. Rasmussen. This concept is known as the linear cutting rotary head (LCRH) concept. Three rows of linear cutting bits are equally spaced around a rotating head. As the head rotates, its centerline is oscillated in a motion that is synchronized with the rotating bits, causing them to cut a square linear pattern in the coal face.

The main goals of this study project were to provide answers in the following areas:

- It is feasible to engineer and build a production CDLCH mining machine that is acceptable to the industry?
- Is a production machine economically feasible and can an existing hard-head continuous miner be retrofitted to the CDLCH configuration?
- Will the production rate or productivity of the CDLCH concepts be competitive with those of existing continuous mining machines?

- Can airborne respirable dust generation be reduced and how does this reduced dust level compare to the dust levels associated with existing hard-head drum-type continuous miners?
- What relation do CDLCH concepts have to health and safety factors such as methane ignition potential, noise, and ventilation?
- Would a mechanized scale model of the LCRH concept be benificial to demonstrate its unique cutter head motion?
- What recommendations can be made for future development of the new CDLCH method of cutting coal?

The studies that provided the answers to these questions are described in this final report. The resulting recommended concepts offer an innovative new method of mining coal.

III CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

The concepts designed during this study were based on the Bureau's Twin Cities laboratory research. Continuous mining machines with hard-head drum cutting capabilities were analyzed as part of the Bureaus work and the results were as follow:

- The cutter bit space-depth ratio varies continuously during rotary cutting.
- Bit angle of attack relative to horizontal bedding plane varies continuously during rotary cutting.
- Specific airborne respirable dust generated from the rotary cut is greater than that from the linear cut.
- The greatest generation of airborne respirable dust occurs at cuts less than 1 inch deep so mining should be done at cutting depth greater than 1 inch.
- Constantly changing bit depth during rotary cutting produces an inherent bit-spacing problem that precludes optimum spacing.
- Rotary cutting results in an inherently poor volume recovery per bit per rotation relative to the linear distance cut because only 10 percent of the total volume is removed when the depth of cut reaches 60 percent of the advance distance.
- Data collected in the field on the airborne respirable dust generated by continuous mining machines varied to such a great degree that meaningful conclusions could not be made.

The data from the Bureau's linear cutting experiments led to the following conclusions:

- Both specific airborne respirable dust and specific nonairborne respirable dust are monotonically increasing functions of specific energy.
- The amount of nonairborne respirable dust ranges from 100 to 1,000 times that of the airborne dust.
- Specific dust and specific energy decrease as the depth of cut increases.

- An optimum value for the space-depth ratio is 2 to 3 for linear cutting.
- The force required to sump bits 6 inches into coal and shear at this depth is approximately 12, 000 pounds per bit in Pittsburgh and Illinois Number 6 coal.
- The force required to sump bits 3 inches into coal and shear at this depth is approximately 2, 700 pounds per bit in coal from the Wyoming seam.

Two CDLCH concepts evolved from the Bureau of Mines study of a new mining method, the self-sumping head (SSH) and the linear cutting rotary head (LCRH) concept. The SSH concept is of simple construction, easily maintained, and retrofittable to most existing continuous miners. The concept requires no auxiliary support system and no additional ancillary equipment, and can replace a hard-head drum miner in performing two-pass mining functions.

The second concept is the linear cutting rotary head (LCRH) miner. This machine is the result of engineering design based on the Bureau's Patent Application 702, 373 involving rotary CDLCH principles. The cutter drum comprises three rows of bits spaced 120 degrees apart that cut 3 to 6 inches deep while traveling in a square path. The square cutting pattern is created by mechanically driving the centerline of the cutter drum in an elliptical path as bits rotate around it. The high production rate of the LCRH makes it necessary to redesign the gathering head and main conveyor to move the coal away from the face as fast as it is cut. The main conveyor must be widened to handle more coal; therefore, a new machine frame must be designed.

During the early stages of the CDLCH feasibility studies, all concepts were designed to withstand the forces or stresses from constant-depth cuts 6 inches deep. The first linear cutting rotary head (LCRH) concept was designed to cut 6 inches deep, and the resulting machine was equipped with some specially designed subsystems such as the following:

- Special 300-horsepower electric cutter head motors.
- A power train that will deliver 160, 000 foot-pounds torque to the cutter head.
- A special sump rig jack system that is hydraulically raised to the roof from a floor skid plate. This provides the reaction point for the cylinders that push against the rig to sump the entire machine into the face.

The final version of the LCRH concept eliminated the areas of special design by changing the bit cutting depth from 6 to 3 inches. This meant that the mean force required to sump or shear the bits through the coal dropped from 12,000 pounds to 2,700 pounds. This large drop required a corresponding reduction in the total LCRH output horsepower and a mining machine that now can comprise off-the-shelf or existing components.

The productive capabilities of the LCRH miner with 3-inch-deep cuts continued to be high. Studies described in this report showed its performance exceeded that of a deep-cutting drum-type CMM that is designed to make the same 3-inch-deep cuts. The LCRH concept calculated performance surpassed that of an equivalent CMM in the following areas:

- More tons of coal were cut per horsepower input (specific energy).
- For equal peak cutting rates (tons per minute), the deep-cutting CMM generates approximately four times more ARD than the LCRH.

It is possible to design and build an LCRH concept that cuts 3 inches deep with existing components. Further in-situ testing of deep-cutting constant-depth bits will provide the data necessary to complete the evaluation of CDLCH concepts that cut 6 inches deep.

Additional features of these concepts are discussed as the advantages of constant-depth linear cutting are presented in the following subsections.

3.1.1 Mining With Deep Linear Cuts

If a coal mine operator were given the opportunity to specify the criteria for a mining machine that would best meet his needs, the specification sheet for the cutting device would call for a system that produced substantially more coal than that produced by existing continuous miners, and features that would ensure compliance with legal environmental requirements and salability of his product. The list would include the following requirements:

- High productivity or tons per man-shift
- Quality coal with no fines
- Cutting that generates a minimum of dust
- No methane ignition
- Low-maintenance mining with decrease in downtime

- Reduction of noise level
- Machine operator acceptance.

Results of the CDLCH feasibility study show that this new method of mining coal will yield many of these desired features directly and will more nearly approach the remaining features than any other existing hard-head or drum-type mining machine.

3.1.1.1 Productivity

When the 6-inch version of the LCRH concept was compared to an existing continuous mining machine (CMM) cutting at 1 inch by a Gantt chart time study, increase in the amount of coal cut per shift resulted. Both machines were working in identical room and pillar mine plans, in a 6-foot seam, and the two machines used similar haulage systems. Cut coal tonnage results shown in Table 1, are based on existing mine plans; and the total tonnage is restricted by the haulage, ventilation, bolting, and lift distance of the mine plan.

Table 1 CUT COAL TONNAGE RESULTS

	Total lifts	Lift time	Tons per shift
CMM	6.73	38.1	646
LCRH	8.43	25.0	849

A 31-percent increase from the LCRH is due to faster lifts that result in more lifts per shift. There would be no change in the section crew size, so productivity would increase correspondingly. The Gantt chart study for each system was conducted under ideal (no downtime) conditions, and actual production figures would be lower than those shown by some derating percentage.

This productivity study was made prior to consideration of an LCRH miner with a 3-inch depth of cut. However, the 3-inch LCRH machine will meet the production rate of the deeper-cutting LCRH if the cutter head speed is increased. The self-sumping head concept would show the same tons-per-shift output as the CMM. This miner could not increase productivity, but other features of the system are important in other areas.

3.1.1.2 Coal Without Fines and Respirable Dust

The ideal mining system would yield only coal in the coarse, less-expensive-to-process range. Fines, small coal particles that are expensive to process and outside the coal size limits specified by the customer, would be eliminated. In particularly friable coal seams, such as the Upper Freeport, appreciable coal has been so fine there is no market for it.

Deep-cutting CDLCH miners can potentially solve this problem. The coal is broken out in 3- to 6-inch-deep cuts with about a 140-degree included angle of breakout at each bit. This breakout pattern uses fewer bits and produces chunks of coal much larger than those produced by a hard-head continuous miner.

The bits of both the CMM and the CDLCH machines produce fines in a crushing zone at the tip of the bit, but each CDLCH bit produces a greater volume of coal for each foot of travel, or a greater percentage of large coal chunks for each pound of crushed coal from the tip zone of the bit.

The CMM cutter drum and bits make very shallow cuts which produce small coal particles but as the coal is cut it must travel along between the face and the drum before falling to the floor and gathering head. Secondary breakage of the coal due to this regrinding not only further reduces the coal size but is one of the prime sources of dust.

3.1.1.3 Reduction of Airborne Respirable Dust

The work done by the Bureau of Mines Twin Cities Mining Research Center originated as an investigation of methods of reducing the airborne respirable dust (ARD) produced as a bit cuts through the coal face. This laboratory study showed that it is possible to drastically reduce the amount of ARD released for every ton of coal cut. One goal of this project became use of the data from investigations of the dust caused by CMM cutting methods to design a CDLCH miner that would result in drastic reduction of primary ARD generated during cutting. Two new mining machine concepts, the SSH and the LCRH, were compared to the continuous mining machine (CMM). The results for a 6-inch machine are shown in Table 2.

Table 2 ARD ELEVATION RESULTS

	CMM	SSH	LCRH
Total ARD generated (milligrams per ton)	886	50	100
Percent reduction	--	93	89
ARD at peak (milligrams per minute)	3,030	204	900
Percent reduction	--	93	70

The first line in Table 2 shows the total ARD generated for every ton of coal cut; the third line shows the dust produced per minute at peak points in the cutting cycle. For the self-sumping head concepts, 93 percent is consistent in both areas, but the LCRH does not produce the large reductions in peak ARD levels because great volumes of coal are being sheared from the face so rapidly that a corresponding jump in the momentary release of dust results.

The charted ARD numbers represent the amount of dust from all sources at the face. For a CMM, this figure includes the following activities:

- Sump cutting
- Shear cutting
- Loading.

Study of past reports on CMMs revealed that 70 percent of ARD is generated during sump, 20 percent during shear, and the remaining 10 percent during loading onto the miner conveyor. The self-sumping head and LCRH concepts were able to cut much more cleanly than the CMM but still produced the ARD caused during loading. Continuing CDLCH work at the Twin Cities Mining Research Center has considered gathering and loading methods that would decrease the production of ARD well above the 93-percent level.

Although improved loading methods were not part of this contract, the Bureau of Mines has continued to work in this area and has identified a CDLCH cutting method that will collect the coal as it is cut and deliver it directly to the miner conveyor system. This third-generation CDLCH concept is described in Patent Application 732,676, Automatic Face Transfer by Linear Cutting Rotary Heads. ARD studies concluded that CDLCH concepts can reduce dust to levels not obtainable with existing CMM methods.

In later studies, the LCRH concept that cuts 3 inch deep was compared to a deep-cutting CMM capable of 3-inch cuts. As indicated earlier in this section, the 3-inch CMM was approximately four times as dusty as the 3-inch LCRH when both machines were cutting at the same peak cutting rate (tons per minute).

An added benefit of lower dust levels is that secondary ventilation systems or dust scrubbers should not be required. The normal face ventilation air will keep the dust level at the operator's station below the legal 2-milligrams-per-cubic-meter range and also maintain excellent visibility of the face. Mining will not be interrupted while the miner operator waits for the ventilation system to clear the face so he can check the cutting process.

3.1.1.4 No Methane Ignition

Because the bit speed of both the SSH and LCRH concepts is 250 feet per minute or less, or well below the point where bit-to-hard-band impact will cause methane ignition, methane ignition will be eliminated. This enhancement of safety is a direct result of CDLCH methods.

3.1.1.5 Reduced Downtime

A CMM is out of operation an average of 15 minutes a shift to allow time to replace broken or worn bits. Because the CDLCH concepts use fewer bits than a CMM and the bits do not hit hard bands with as high a velocity, the downtime for bit maintenance is reduced.

With the self-sumping head concepts, actual available productive mining time would be increased about 12 minutes per shift because of reduced bit maintenance. The productive mining time increase for the LCRH would be less because three rows of bits are used, but should show an increase of about 10 minutes per shift.

The self-sumping head miner develops cutting power through hydraulic cylinders. No high-maintenance electric or hydraulic motors or complicated gearboxes are incorporated in the head. Maintenance should be greatly reduced by elimination of these components. Total power requirements are equivalent to those of many existing CMMs at 480 horsepower.

3.1.1.6 Reduced Noise Level

The mechanical machinery of the CDLCH miners will be no quieter than that of the CMM. However, when the hard head of a CMM is sumped into the face, the noise generation from the cutting teeth adds to the total noise level. This noise generation from moving bits will be reduced when CDLCH designs are shearing coal from the face, because of reduction of the number of bits and slower bit travel.

3.1.1.7 Machine Operator Acceptance

Many CDLCH features should contribute to excellent operator acceptance, and this acceptance will contribute to better productivity:

- Controls that parallel existing miners such as sump, shear, and cleanup maneuvers
- Less visible airborne respirable dust improving visibility of the face
- Control of a machine that boosts section production rates
- Reduced noise level
- No methane ignition hazard during cutting.

3.1.2 Mining Rock With CDLCH

The CDLCH feasibility study did not produce any data, backed up by testing, that would predict the exact performance of these deep-cutting bits when they encounter rock partings or other hard material within the coal seam. However, several features of the design lead to the conclusion that this new cutting method should perform as well as or somewhat better than existing CMMs.

Because the maximum force available per bit is higher than that of the CMM, bits should penetrate rock more readily because the rock will fail as the bit forces exceed the compressive strength. After penetration, the higher bit forces will develop shear forces that should break out comparatively large chunks of rock.

The CDLCH bits travel through the face at lower velocities than those of the CMM. Impact on contact with rock will be reduced, and bit wear and breakage rates should also be reduced. As in the case of CMMs, partings will slow down the mining process during CDLCH coal mining but to no greater extent than that encountered with existing machines.

3.1.3 Surface Mine Application

Consideration is now being given to developing very large deep-cutting continuous miners that will mine thick-seam surface coal. This is an ideal application for the LCRH concept and in particular the third-generation version described in Patent Application 732,626, Automatic Face Transfer by Linear Cutting Rotary Heads. This version is identical to the LCRH concept described in this study, except the head is rotated in the opposite direction (counterclockwise) and is used as the primary gathering system. As the head rotates, the broken coal is caught by the specially shaped head (much like a bucket wheel excavator) and transferred to a conveyor system. The CDLCH principals allow optimum bit spacing, thus reduced specific energy; therefore, this concept, used as a surface miner, would cut more coal per energy input and load this coal faster, with less generation of dust than would be possible with a deep-cutting rotary-drum continuous miner.

3.1.4 Shear Cut Direction

Deep-cutting bits must travel in a vertical direction up or down through the face to be effective. If the bits were driven horizontally or parallel to the bedding planes, the breakout angle of the coal would be small, and it would be necessary to place the bits closer together than bits that shear vertically. Bits produce ARD; therefore, the bit spacing must be kept as large as possible to reduce dust generated during cutting. Laboratory tests conducted at the Twin Cities Mining Research Center indicate that bits should be spaced at a distance two to three times the depth of cut or from 12 to 18 inches apart when 6-inch cuts are made. The coal breakout angle for each bit would be about 140 degrees included angle.

During the early project design phase, attempts were made to design a machine with two cutting heads, each head with a single row of bits. One head would sump in at the roof and shear down to meet the second head that had been sumped in at the floor and sheared up. This idea did not result in a final concept because of the following deficiencies:

- Large forces required to sump in two rows of bits at the same time
- Crowded structure and mechanisms, interfering with the falling coal.

3.2 RECOMMENDATIONS

This unique new linear deep cutting method of mining coal, being developed by the Bureau of Mines, is recommended for continued development because of the potential to increase productivity and at the same time substantially reduce health and safety problems at the face. The coal mining machine would be designed around the constant-depth linear cutting principles and would provide the coal mine operator a way to meet the demands of the energy crisis and at the same time more easily comply with the Federal dust regulations.

Two concepts emerged as a result of this feasibility study of a new method for cutting coal, the self-sumping head (SSH) and the linear cutting rotary head (LCRH). The LCRH is recommended for further development because of design performance. This concept is recommended for detail design, construction, and in-mine testing because our studies and analysis have shown that the LCRH is more productive than standard continuous mining machines now in use. Gantt chart studies have shown that the use of this miner will increase productivity 31 percent over existing continuous mining machines. In addition, this deep linear cutting method will generate 89-percent less airborne respirable dust per ton of coal mined and eliminate methane ignition at the face. This new concept offers a clean way to increase productivity in underground coal mines.

The LCRH concept must be equipped with a redesigned higher-capacity coal gathering and main conveyor system to load the increased coal yield; therefore, we recommend this machine be built from the ground up rather than attempting to retrofit an existing CMM. This procedure will allow for design of a conveyor wider than presently possible, and make it possible to incorporate changes that will increase the capacity of the gathering head.

This engineering feasibility study has resulted in two LCRH design concepts. The first evolved was a machine with capabilities of cutting 6 inches deep, followed by a second concept with a 3-inch depth-of-cut capability. The LCRH miner that cuts 3 inches deep should be the first prototype built because, as pointed out in the conclusions section, this concept is less complex and uses more off-the-shelf conponents, thus has a greater chance of trouble-free operation.

The 3-inch prototype LCRH would supply answers that will make it possible to evaluate further the development of a 6-inch LCRH. The 6-inch machine should continue to be considered in future development because:

- The deepest possible cuts are desirable from a specific energy standpoint.
- Less airborne respirable dust per ton of coal is generated.
- A more salable final product size results from deeper cutting.

At the present stage of development, however, the 3-inch LCRH is the most feasible and the recommended version of the LCRH.

Actual LCRH design and fabrication phases must be preceded by an underground test program that will provide the data on the characteristics of multiple linear cutting bits that shear coal in 3- and 6-inch-deep passes. The data on 3-inch cutting will provide design criteria for the first LCRH prototype, and the 6-inch cutting would supply comparative data to reevaluate the feasibility of this deeper-cutting machine. The underground in-situ test will yield the following information necessary for successful design:

- Check of the forces required to sump bits 3 and 6 inches into the coal
- Check of the shear forces for 3- and 6-inch cuts
- Study of the coal breakout angle
- Bit action at the roof, floor, and rib line
- Bit angle of attack sutdy
- Effect of overburden loads on bit action
- Optimum bit spacing
- Check of ARD generation in relocation to depth of cut and other cutting parameters.

The Bureau's Twin Cities Mining Research Center is fabricating a test rig to study in-situ characteristics of linear cutting bits with 3-inch-deep cutting capabilities. These tests should be followed by the testing of 6-inch-deep cutting. The deeper test could be run by designing a bolt-on or weld-on fixture to be attached to the drum of a continuous mining machine already working underground. The fixture would hold three or four bits that could be manually repositioned for various test stages. These later tests would provide the data necessary to make the decision to proceed with an LCRH with 6-inch cutting capabilities.

The self-sumping head concept has been mentioned in the recommendation sectin because several features of this concept are attractive for mining in very dusty, friable coal seams. Mining in seams such as the Upper Freeport, with continuous mining machines, produces coal that is as high as 60-percent fines 1/2 inch or smaller. The self-sumping head miner would shear out coal in 6-inch-deep cuts. The result would be larger-size coal from a seam that had previously represented a problem. The productivity of this concept would equal that of existing continuous mining machines, and the cutter boom could be retrofitted to existing miners. Not only would coal size be improved, but the airborne respirable dust per ton of coal mined with this new machine would be 93 percent less than that resulting from existing continuous mining machines. A mine could retrofit hard-head drum miner during rebuild. The resulting machine would increase the particle size or value of the coal by increasing the salable portion of cut coal recovered per shift.

Existing hard-head drum-type continuous miners have exhibited disadvantages in the increase of coal mined per man-shift or productivity, reduction of airborne respirable dust levels, and elimination of methane ignition. Constant-depth linear cutter head concepts have the potential to solve these problems, and investigation should move forward into the prototype phases.

IV ENGINEERING FEASIBILITY

4.1 PREVIOUS STUDIES

The most recent research on the physical parameters of the coal cutting process is being done by the Bureau of Mines at the Twin Cities Mining Research Center. Most prior studies of this nature were done by the British using chisel-or wedge-type cutting bits. Since little published data was available on point-attack bits and nearly all coal cutting in the United States is done with point-attack bits, the Bureau's investigations were made to evaluate this style bit. The Bureau is conducting laboratory tests that will be followed with in-situ tests at the coal face to study the following factors:

- Point-attack bit forces required to sump and shear various bit configurations into or through coal
- Airborne respirable dust generated during cutting
- Variations in forces and generated dust as the coal type and depth of cut vary
- Optimum bit spacing in relation to depth of cut
- Specific energy changes resulting from cutting depth variations.

Research linking dust generation and efficiency to the coal-cutting process is described in the literature as early as 1956. Much research has also been conducted on cutting bit parameters such as shape, rake angle, clearance angle, spacing, cutting speed, and depth of cut. Forces related to depth of cut are well documented for cuts as deep as 1 inch. However, hard data on deeper cuts is almost nonexistent. In fact, most research on coal cutting has been conducted for shallow cutting and directed for application to rotary-drum-type miners and shearers.

This section reviews the early British work and the Bureau's Twin Cities Mining Research laboratory results.

4.1.1 Coal Properties

Because mechanical properties of coal are so diverse, very few generalizations can be made. Even coal samples taken within the same seam have demonstrated widely varying characteristics within a short distance. Most coal testing is not in-situ but rather laboratory investigation which adds to the complexity of the research. Once a specimen of coal is removed from the parent block, moisture content is altered as well as effects from overburden pressure and other innate characteristics of the block. Regardless of the inadequacies of laboratory testing, it provides a powerful tool for the scientific investigation of coal properties.

Compressive and tensile strengths of coal are common properties both analytically and experimentally investigated.[5, 6] The Impact Strength Index (ISI) is another measurement of coal strength which is ascertained by crushing a sample of coal with a hammer. Correlation of the ISI number with the compressive strength of coal results in a linear relation.

With the information obtained from laboratory investigation, mathematical relations are formulated in an attempt to predict the behavior of coal under the influence of cutting bits. However, much of this information is misleading when direct application is initiated. For example, extraction of a coal with a high compressive strength in a relatively cleat-free bed will be much more difficult than extraction of a coal of similar compressive strength lying in a bed with a dominant family of cleats. Cleats, therefore, are an important factor in studying the behavior of coal in relationship to mechanical extraction.

Cleats are cracks or planes of weakness running in a coal bed. Generally, there are two main sets of cleats in a bed, running perpendicular to one another. The more predominant of these sets are known as face cleats, or main cleats, and the less predominant are secondary or butt cleats. Fortunately for the coal miner, these cleat planes generally run perpendicular and parallel to the coal bed or bedding planes. Much research has been conducted in an effort to relate cleat frequency and orientation to coal cutting; this research is discussed in Section 4.1.3.1, Forces in Coal Cutting.

---

*Reference numbers refer to numbered items in the Bibliography, Section VI.

4.1.2 Cutting Tool Parameters

4.1.2.1 Clearance and Rake Angles

Figure 5 is a schematic diagram of a cutting tool. The rake angle α is defined as the angle made by the front face of the pick with respect to the normal to the direction of the cut.

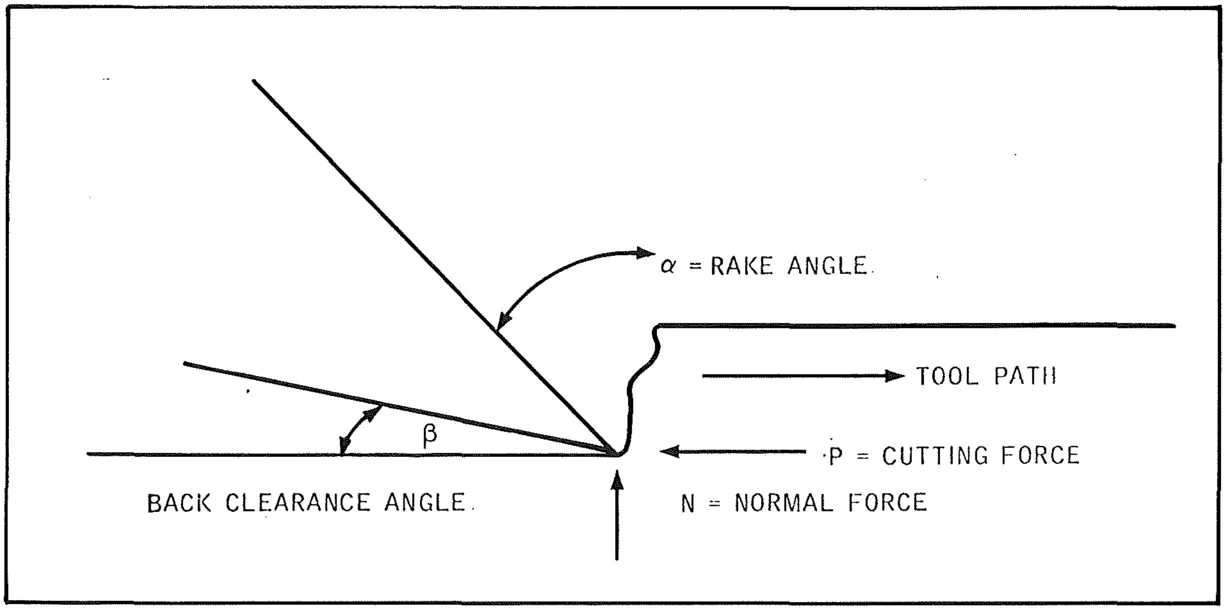


Figure 5 CUTTING TOOL SCHEMATIC

The clearance angle (β) is the angle made by the back face of the pick with respect to direction of cut. Cutting force is the force acting in the direction of cut. The normal force is the force acting at right angles to the direction of cut.

Analysis of the back clearance angle is straightforward. If the angle is zero, the cutting forces are not significantly affected; however, British research shows that the normal forces grow very large, as shown in Figure 6,[2] and are comparable to the cutting forces. As the clearance angle is increased from 0 to 5 degrees, the cutting and normal forces significantly decrease. Increasing this angle above 5 degrees has little effect on normal and cutting forces as shown in Figures 7 and 8[2] (d is depth of cut in Figures 6 through 10).

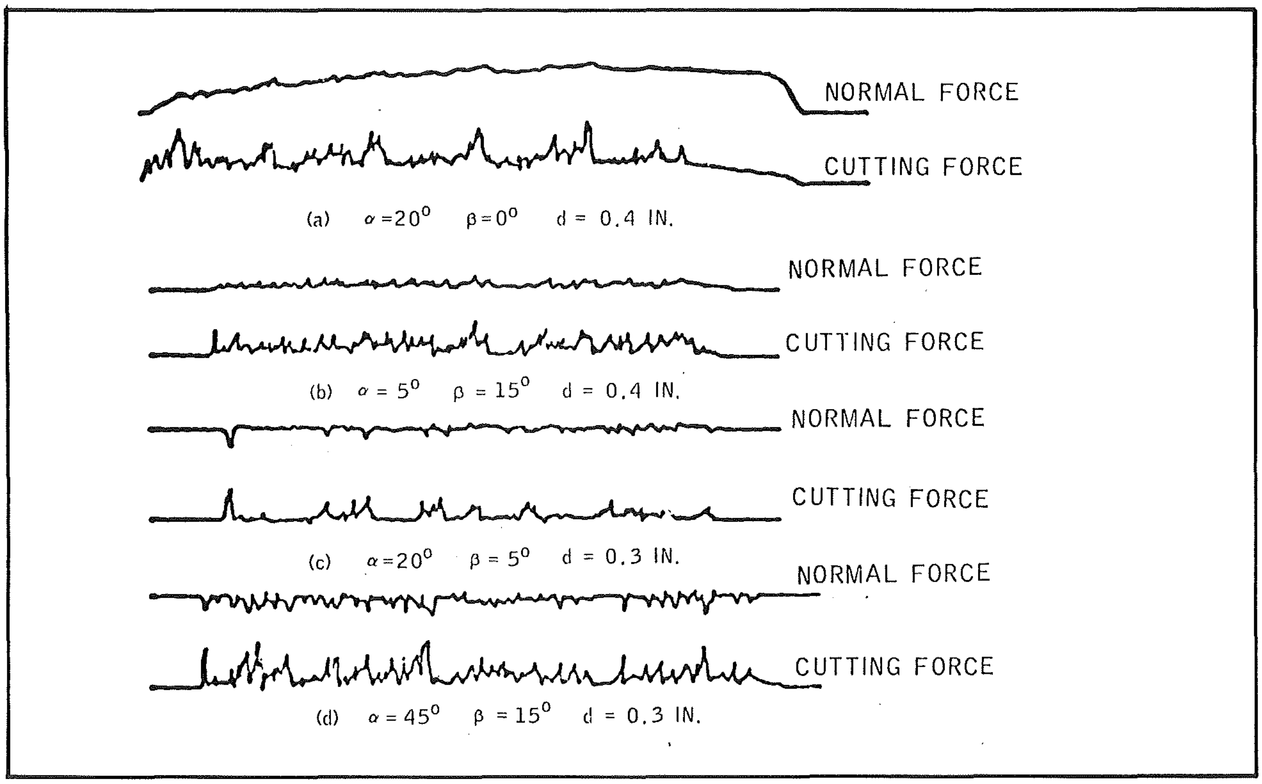
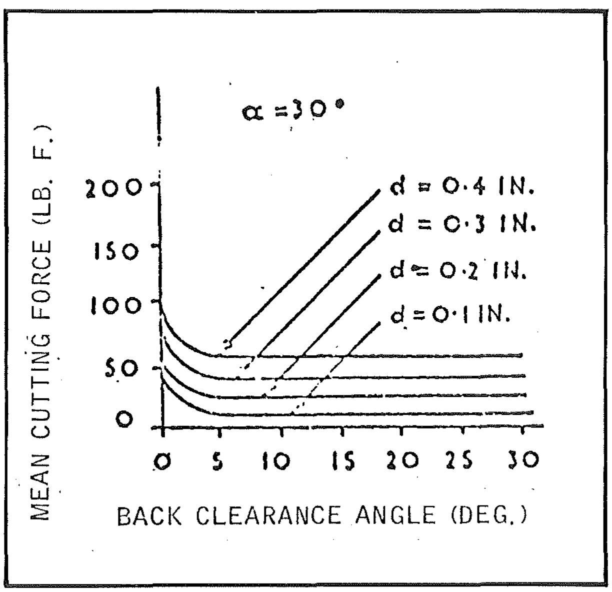


Figure 6 TYPICAL FORCE RECORDS



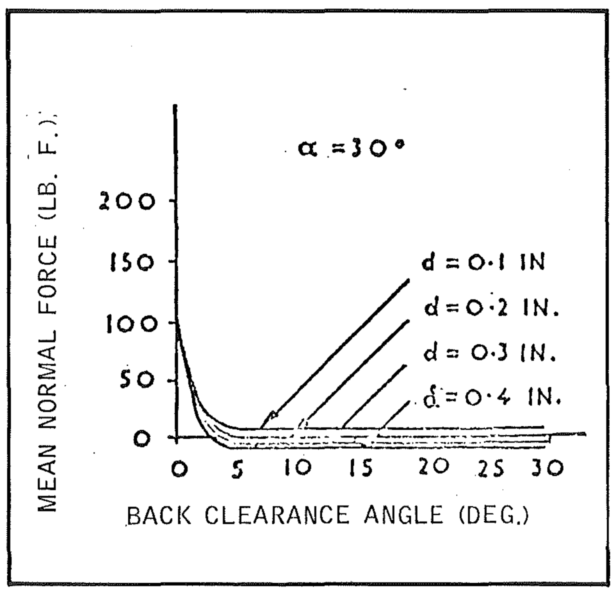


Figure 7 MEAN CUTTING FORCE
VERSUS
CLEARANCE ANGLE

Figure 8 MEAN NORMAL FORCE
VERSUS
CLEARANCE ANGLE

Both the mean normal force and the mean cutting force decrease with increased rake angle as shown in Figures 9 and 10.

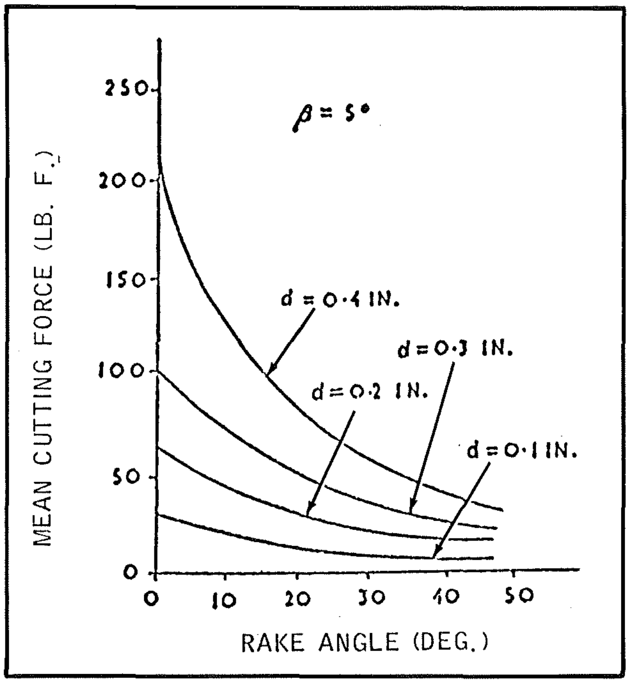


Figure 9 MEAN CUTTING FORCE VERSUS RAKE ANGLE

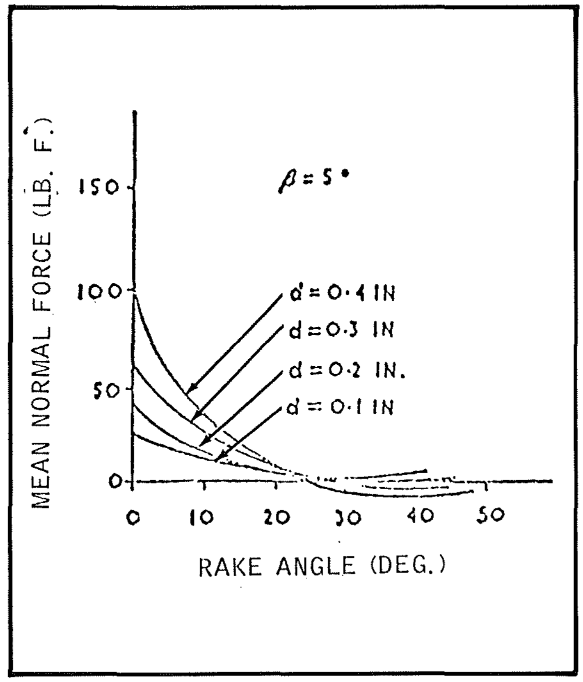


Figure 10 MEAN NORMAL FORCE VERSUS RAKE ANGLE

It is interesting to note that the mean normal force is approximately zero at rake angles above 25 degrees. If the cutting tool is sharp, in some cases the normal force becomes negative for rake angles above 25 degrees, indicating a self-penetrating action of the bit.

4.1.2.2 Pick Width (Tool Shape)

As would be expected, force increases linearly with pick width. Pomeroy[6] points out that two important components should be considered when analyzing pick width in coal cutting, the volume swept by the wedge and the side splay (breakout of coal to either side of cutting tool). Increasing the width of the wedge increases the volume swept and proportionately the side splay. Even though force increases with width of bit, volume also increases, thus decreasing specific energy (energy input per volume cut). Most bits used in the United States are of the point-attack type, such as the plumb bob and the pencil-type bit. These bits have been shown very inefficient compared with chisel-type bits.

In testing both hard and friable coal, Pomeroy[6] summarizes, "In hard coal, the benefits of large cutting tools are reduced specific energy and increased product size, whilst in a friable coal, large cutting tools will certainly be as good as small ones and there is some evidence that they may be better."

4.1.2.3 Bit Shape

A bit can be evaluated not only on ability to cut, but on efficiency in cutting. British Research has shown[4, 2, 7] that the efficiency of a bit increases as the angle on the face increases to 180 degrees. Certainly, different mining applications will require different and sometimes unique cutting tools, but generally the British research has found that the chisel bit is a more efficient cutting tool than are the pointattack bits.

4.1.2.4 Bit Speed

Bit speed within the limits of present-day mining machines appears to have little influence on the cutting process. Both British and U.S. Investigations have not verified any correlation involving bit speed. This may be explained by the crack propagation speed in coal. If the speed of crack propagation is much greater than the pick speed, it is reasonable to expect that changes in pick speed would have little influence on the cutting process. It is estimated that the crack propagation speed of coal may be in excess of 500 meters per second.

In a drum-type miner, however, increased drum speed can cause windage problems and scattering of dust. This high-rpm drum rotations has, in fact, been isolated as a significant factor in the distribution of dust.

4.1.3 Depth of Cut

Following is a summary of investigations concerned with depth of cut and related variables in the coal-cutting process. Of major concern to the CDLCH project are forces involved in deep cuts, spacing of the bits, dust generation, size distribution of the broken coal, and specific energy.

4.1.3.1 Forces

As previously mentioned, information on the forces involved in cutting coal to a depth of 0 to 1 inch is readily available. The research has been conducted on British as well as U.S. coals. Information on cuts greater than 1 inch is very limited at this time; however, research is now being conducted at the USBM facility in Twin Cities, Minnesota.

Generally, in both British and U.S. laboratory investigations concerned with forces related to depth of cut, a single pick is employed in cutting coal at various depths. All tests show that the forces involved in cutting coal, normal and cutting, vary in a sawtooth fashion over a given specimen of coal. The peaks of the sawtooth are referred to as peak forces. Usually, a group of peak forces are calculated so that a mean peak force can be determined. Once data for a particular test is collected, a mathematical and statistical analysis is performed.

The end result is an equation describing the behavior of forces as a function of depth, and correlation is very good within the limitations of the experiment. However, the tests to date have been conducted at depths less than 2 inches, in most cases less than 1 inch, and using the experimental equations for depths greater than the scope of the experiment gives unreliable information.

Attempts have been made at purely theoretical derivation of equations. These derivations are usually identified by use of the compressive and/or tensile strength of coal. For example, I. Evans[5] formulates equations with respect to coal ploughing using the tensile breakage theory of coal. He derives an equation describing the cutting forces as a function of blade geometry and the tensile strength of coal. The expression for cutting force for a sharp wedge is

$$P = 2td \frac{\sin(\theta + \phi)}{1 - \sin(\theta + \phi)}$$

where P = peak cutting force per unit width of wedge

t = tensile strength of coal

d = depth of cut

θ = semiangle of wedge

ϕ = clearance angle.

In addition, the normal force is expressed in the following manner:

$$Q = P + \tan(\phi - \alpha)$$

Q = normal force

α = rake angle.

In conjunction with the equation for cutting force, this gives a correct form for normal force, falling to zero for ϕ = a and becoming negative for greater values of α. Again, these equations generally agree well with experimental results, although at times they deviate widely.

The nature of the foregoing discussion is to emphasize that the information available to us from previous research is insufficient to make an accurate evaluation of the forces involved in sumping and shearing coal to a depth of 6 inches. However, more recent research conducted by the U.S. Bureau of Mines in deep cutting has given the necessary information for initial evaluation of the forces required to sump into and shear coal to a depth of 6 inches. Following is a brief summary of USBM research into cutting forces.

From a test performed on Illinois Number 6 coal, an extrapolation was projected that suggested 12,000 pounds per bit was an approximate force requirement to sump 6 inches. The bit used in this projection is a 1/2- to 1-1/2-inch pointed-face-shape bit.

Actual penetration or sump tests conducted by the Bureau used six 1-inch-diameter bits, with cone angles varying in 30 degree increments from 30 degrees to 180 degrees (flat face). Sumping 4 inches into coal produced a mean force of 11,500 pounds ± 1,500 pounds. These tests were conducted on Illinois Number 6 and Pittsburgh Seam coal. The shape of the cone angle on the cutter face had no effect on the force requirement.

In addition, the Bureau found that in shear tests using a 4-inch bit, 2-inch-diameter shank, 60-degree tip, and 45-degree rake angle, the following forces were recorded:

- Maximum force: 8,800 pounds
- Mean force: 3,300 pounds.

Another important point determined in previous investigations and confirmed by recent Bureau work involves shear forces connected with groove spacing. (Groove spacing or bit spacing is the distance between cutting paths generated by adjacent bits.) If groove spacing in a material is such that neighboring grooves do not interact, the cutting force increases in proportion to the depth of cut. However, for spacing where neighboring grooves interact, the cutting force decreases after reaching a maximum. Spacing is further discussed in Subsection 4.1.3.3.

4.1.3.2 Specific Energy

In coal-cutting genre, specific energy is defined as energy input per unit mass removed. Evidence [11, 1, 9, 2, 20] has been gathered indicating that as depth of cut increases specific energy decreases. Also, as bit spacing tends toward an optimum, specific energy decreases (Figure 11).[20] In addition, the production of fines (Figure 12)[8] is accompanied by the expenditure of more energy in their production.

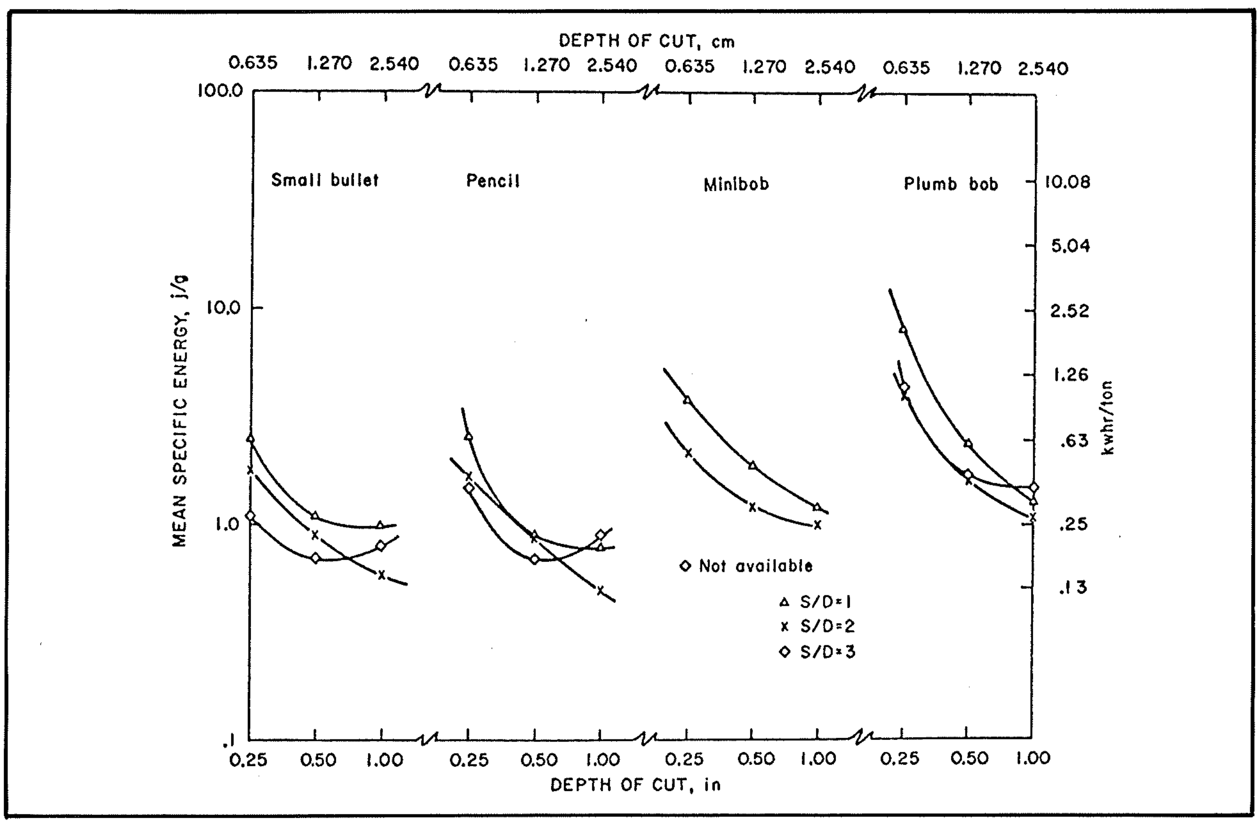


Figure 11 VARIATION OF SPECIFIC ENERGY WITH COAL LINE SPACING AND DEPTH OF CUT, ILLINOIS NUMBER 6 COAL

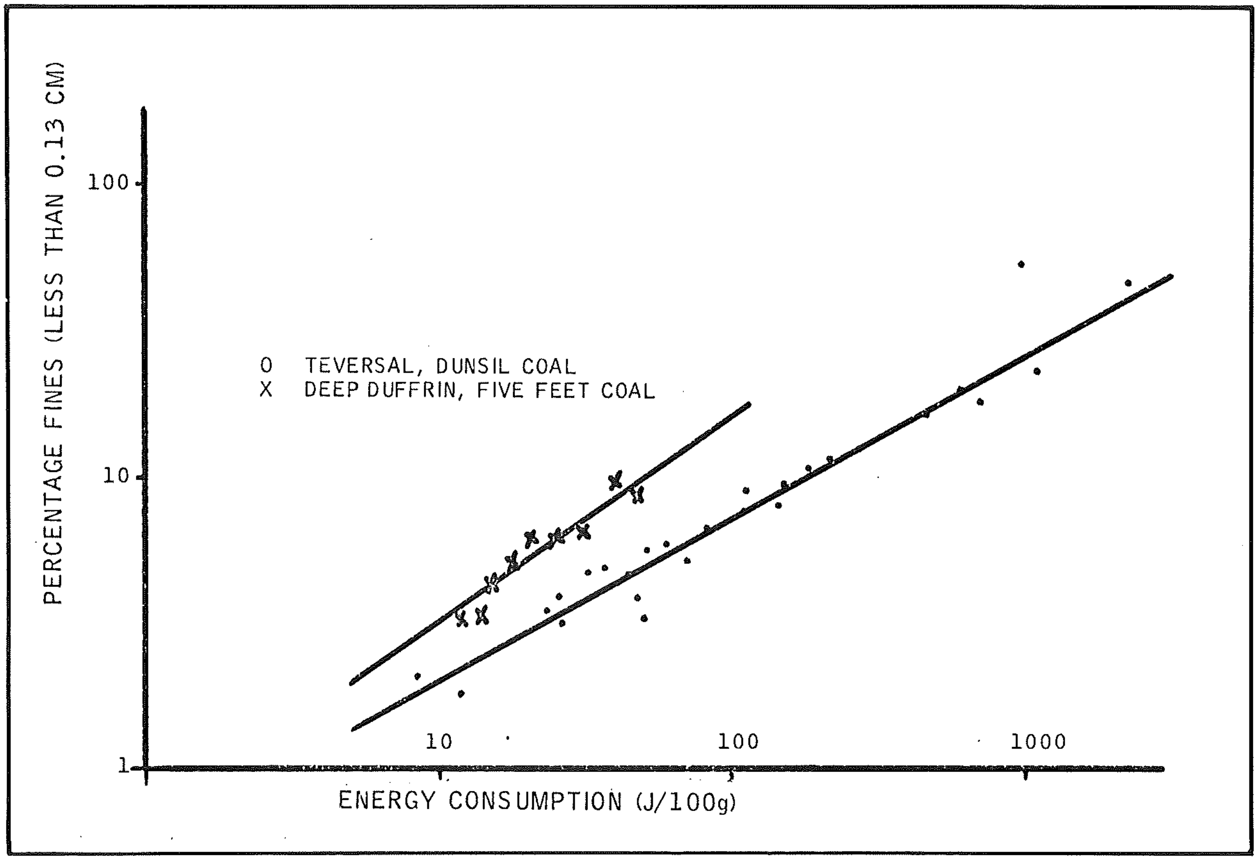


Figure 12 RELATIONSHIP BETWEEN FORMATION OF FINE COAL AND ENERGY CONSUMPTION

Concerning machine design and specific energy, Pomeroy[8] states, "The general principle that cutting efficiency is highest for deep cuts with widely spaced tools is true even when the tools are substantially blunted. A further relevant factor that must be mentioned is the ideal tool width. It has been shown that the breakout to each side of a chisel shaped tool is controlled primarily by the depth of cut and not by tool width. Deep cuts will inevitably demand high forces that fluctuate between wide limits but these can be contained within machine design, provided this fact is properly considered in the design of a complete cutting system on the machine."

4.1.3.3 Line Spacing

When two grooves are channeled parallel to one another, the interaction between the grooves is a function of the distance between bits and the depth of the groove (Figure 19).[12]

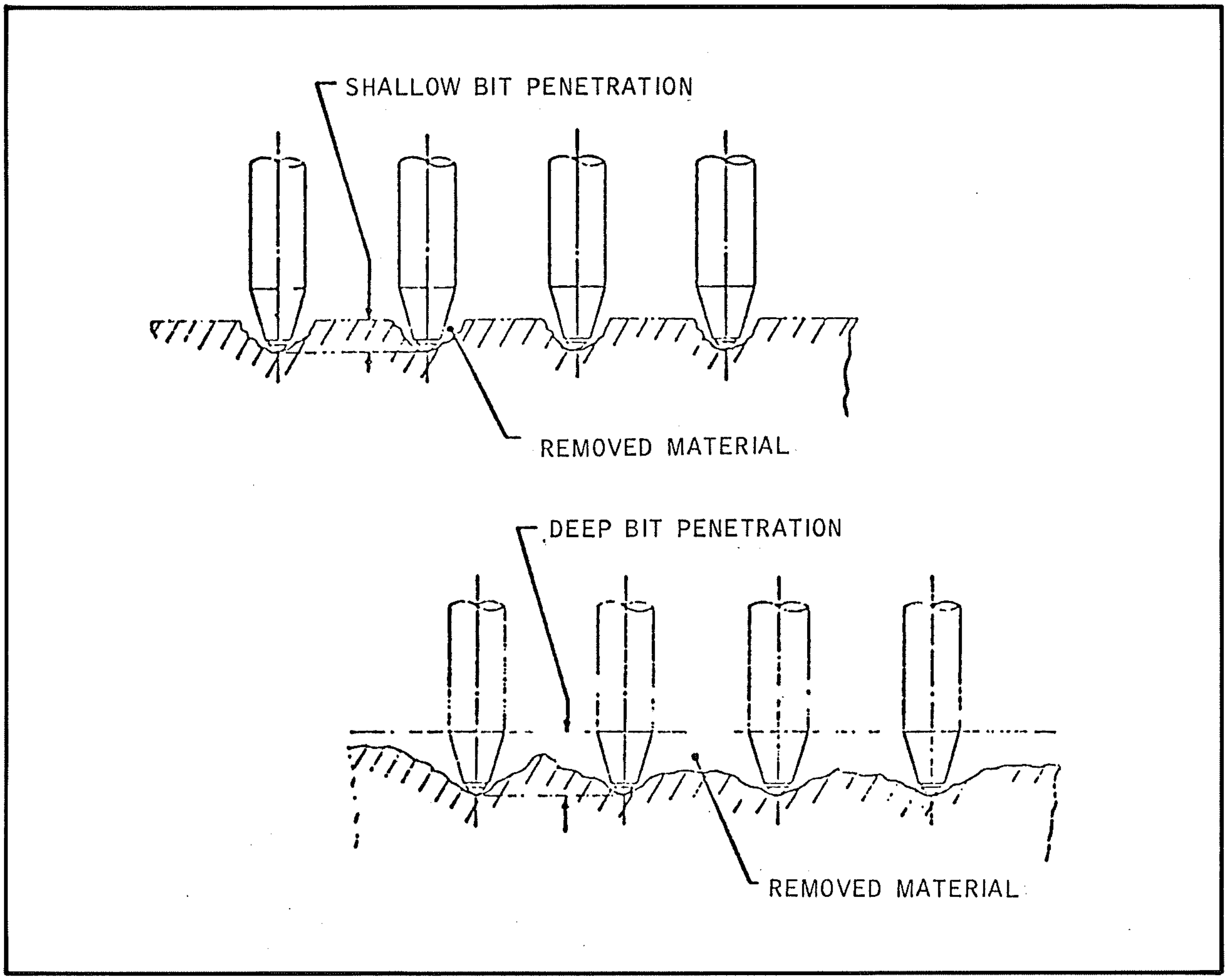


Figure 13 COMPARISON OF REMOVED MATERIAL

I. Evans[13] best sums up the importance of spacing, stating, "If picks are well positioned, relative to one another, the machine stands a good chance of cutting efficiently. That is producing material in a desirable size range, with economic use of power and minimum fines; if badly positioned, an excessive amount of power will be used and a super abundance of fines produced." Empirical[7] and theoretical[13] researchers have reached similar conclusions involving optimum line spacing. Although the actual coal to be cut will determine bit spacing, it is generally agreed that the optimum bit spacing is within a range of two to three times the depth of cut. I. Evans[13] developed a theoretical model for chisel-type bits that exhibited good agreement with experimental results when the width of the tool to depth of cut ratio is between 0.5 and 2. His model is based on the tensile strength theory of coal, and predicts optimum line spacing and splay angle.

For splay angle the following expression is used:

$$\tan a = 1/5 \left[k + (k^2 + 20)\ 1/2\right]$$

where a = splay angle
w = width of tool
d = depth of cut
k = w/d.

Furthermore, line spacing (s) is described by

$$s/w = \left[1/2 + \left(1 + \frac{20}{k^2}\right) 1/2\right]$$

where s = line spacing.

4.1.3.4 Dust and Related Parameters

Existing continuous miners generate large quantities of airborne and non-airborne respirable dust. Not only are the economic repercussions of this problem of great concern, but because of the health hazard alone elimination of the problem is of paramount importance. In the past, concentration has been on suppression rather than prevention. Extensive studies have been conducted on water sprays and configuration in an attempt to wet down and suppress dust at the major generation points. The optimization of ventilation systems has been examined in an effort to effectively control dust.

In actual experiments, the following dramatic findings have surfaced concerning dust generation in the coal extraction process:

- Percentage fines increase with specific energy (Figure 14).[8]
- Respirable specific dust decreases with depth of cut (Figure 15).[14]
- The greatest dust generation per ton of coal mined occurs at cuts less than 1 inch deep.
- Specific energy decreases with increased depth of cut.

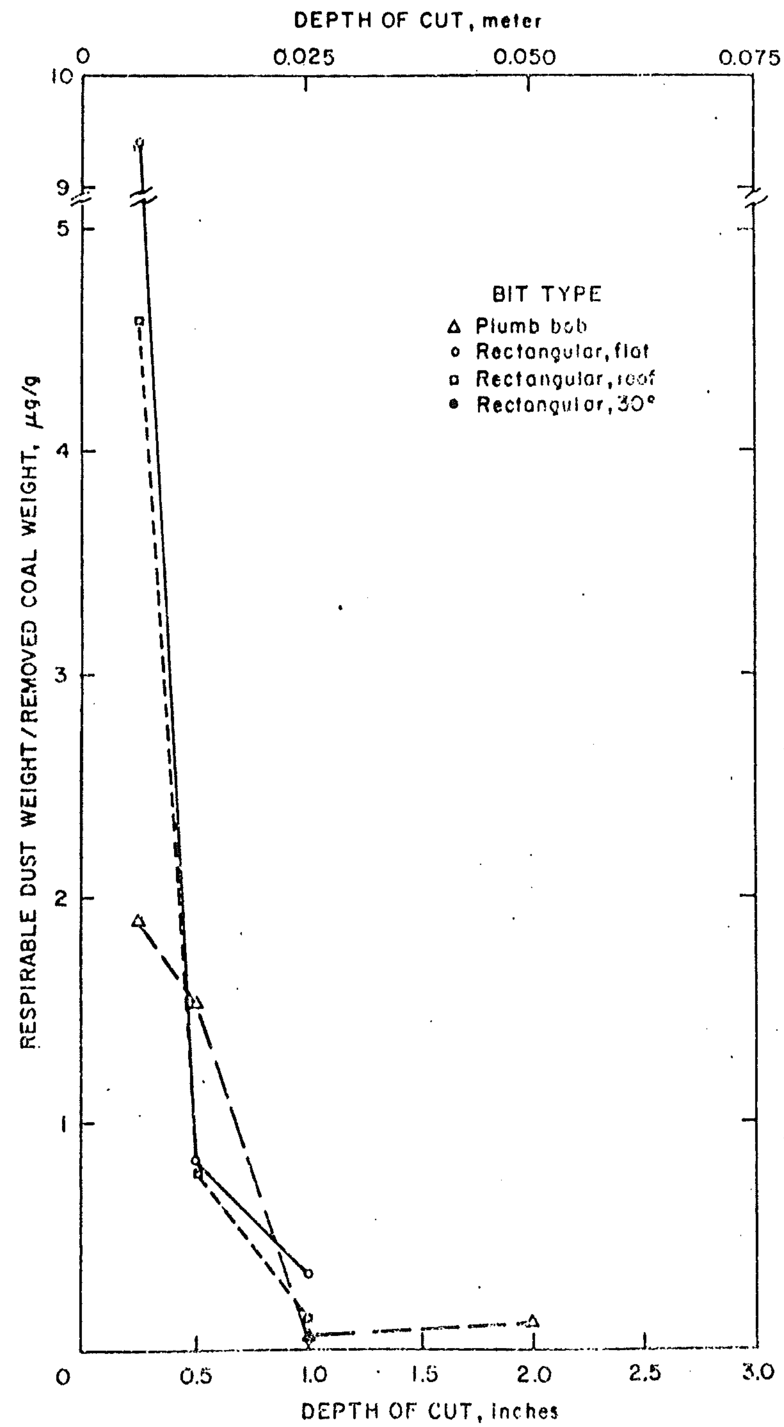


Figure 14 EFFECT OF CUT DEPTH ON AIRBORNE DUST GENERATED BY FIRST CUTS IN PITTSBURGH COAL

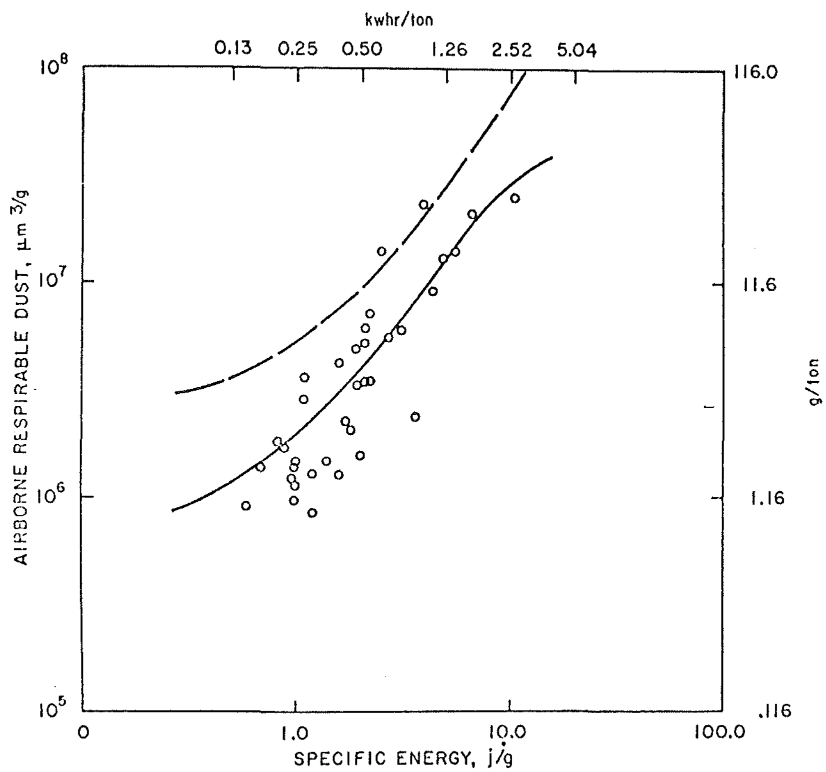
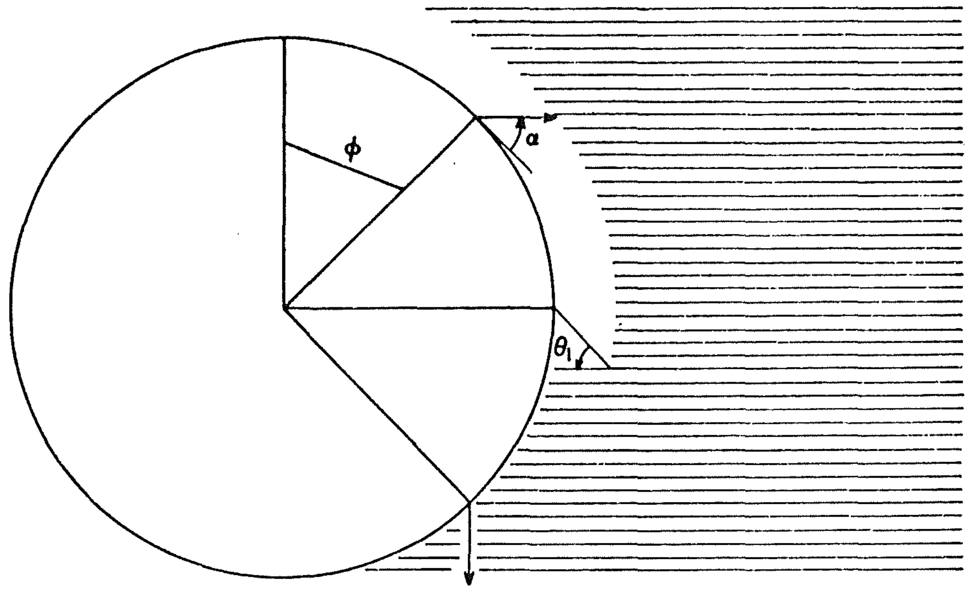


Figure 15 ARD FOR PITTSBURGH SEAM COAL

4.1.3.5 Characteristics of the Rotary Cut

As part of the study of deep, constant-depth cutting, the Bureau's Twin Cities Mining Research Center analyzed the characteristics of existing rotary-cutting continuous mining machines (CMM). The bits on the drum of a CMM are fixed at some angle of attack (α) relative to the drum. During a 180-degree rotation of the drum, the actual angle of attack (θ_1) relative to the bedding plane of the coal continuously changes as shown in Figure 16.[20] For a fixed angle of attack α = 45 degrees, θ_1 would range from -45 degrees (entry) to +135 degrees (exit) during 180-degree rotation of the head. This shows clearly that α is equal to θ_1 at 90 degrees rotation, thus limiting the optimum angle of attack to only one point during rotation.

In addition, the depth of cut is a continually changing function of rotational angle ϕ. Figure 17 shows that the depth of cut at ϕ = 0 is zero (entry) and the depth increases to a maximum at ϕ = 90 degrees. The depth of cut from 90 degrees to 180 degrees is a mirror image of the graph in Figure 17,



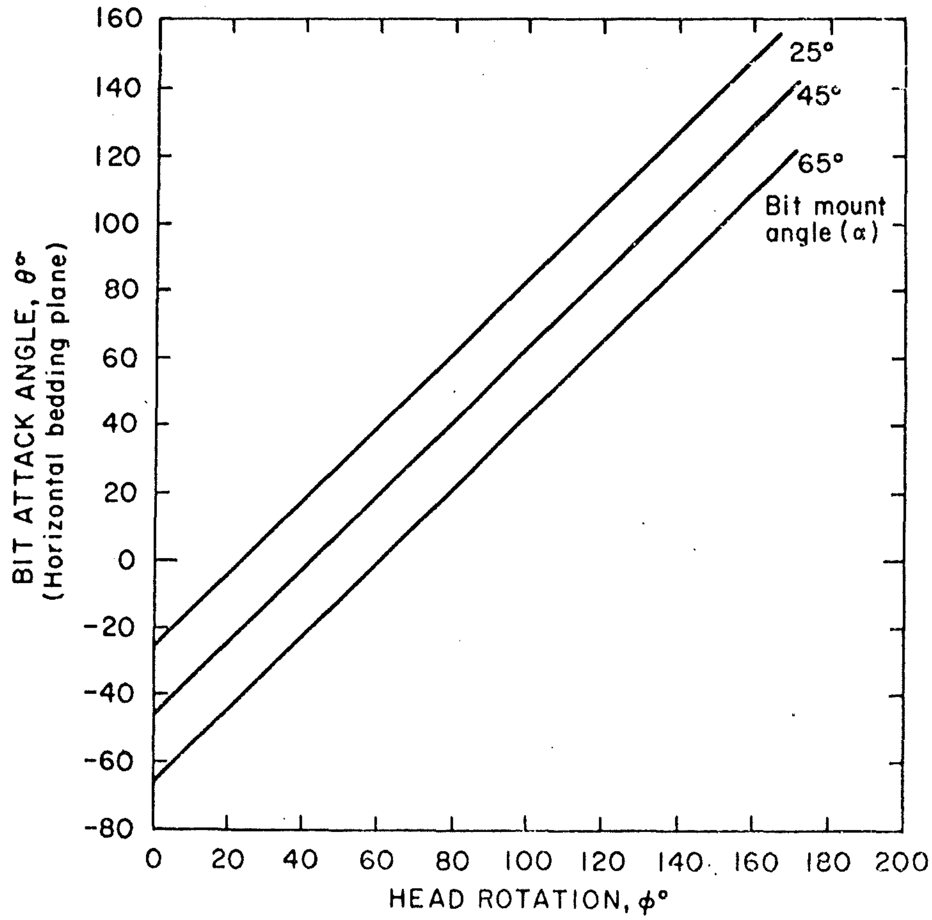


Figure 16 BIT ATTACK ANGLE AS A FUNCTION OF HEAD ROTATION

and shows the decreasing depth of cut from 90 degrees to the exit at 180 degrees. As with angle of attack, the maximum or optimum depth of cut is obtained only during one brief point in the rotation.

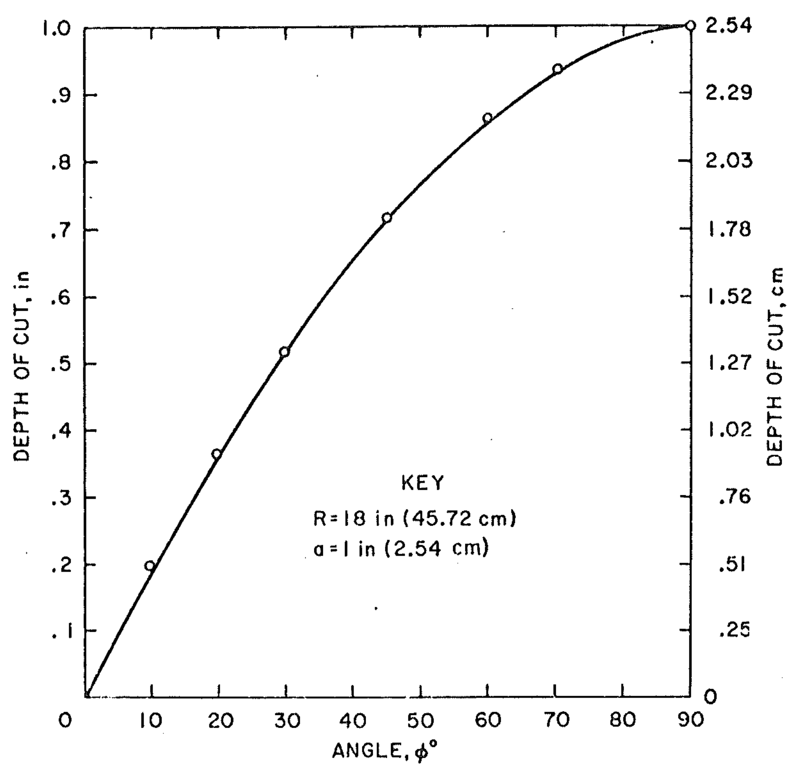


Figure 17 DEPTH OF CUT AS A FUNCTION OF ROTATION

4.1.4 Cleats and Angle of Attack

As previously discussed, cleat effects play a major role in the cutting of coal. To test the effect of cleats, researchers have built experimental models so that various angles of attack with respect to the cleat planes can be evaluated. The results of these tests indicate that cutting 90 degrees to the main cleat (i.e., "on end") is most difficult, and that cutting "on board" (0 degrees) or at an angle of 45 degrees to the main cleat requires the lowest forces. The explanation of cleat effects is probably best explained by Pomeroy:

> It can be seen why cutting at 45 degrees to the main cleat results in a larger product yield than for the other orientations. Moreover, as the initial crack from the wedge tip runs down into the coal along a cleat a low force is needed to start it. Breakage finally results in transverse bending of the "beams" of coal defined by the cleats.

In the 90 degree direction there are no existing cleats in the coal to assist crack formation (unless there is a marked cross cleat) and the cracks from the wedge run downwards into the coal until a gross main cleat is interesected, when a fragment breaks away. As the cracks are formed in solid coal the cutting forces are high, and unless the main cleats are widely spaced the product yield will be low and consist of relatively small fragments.

Cutting in the other two directions is self-explanatory. At 0 degrees the cleats are oriented in a way that encourages cracks to run along the path of the wedge tip and so breakage forces and coal yield are both low, whilst at 135 degrees a sequence of cracks runs from the wedge to the surface of the coal with very few excursions into the bulk of the coal. In this case the forces are again relatively low but the product is small in size and in quantity.

4.2 DESIGN CONSTRAINTS

The design constraints dictated by the contract are straightforward with regard to the project goals. The means and conditions for obtaining these goals, however, are generally left to the discretion and judgment of the contractor based on conclusions resulting from the problem analysis. Specifically, the contract calls for accomplishing the tasks of an existing continuous miner by means of retrofitting such a miner with a constant-depth linear cutting device as discussed in RFP JO265010. If a retrofit is not possible, then the contractor is directed to look at total machine design to accomplish the contract requirements.

4.2.1 Bit Type

The type of bit used will be dictated by the individual concept. Standard off-the-shelf bits will be specified when possible, but generally the bits will be unique to the concept.

4.2.2 Bit Spacing

As discussed in Section 4.1, Previous Studies, the general consensus of the research indicates that bit spacing can be related to depth of cut and that, generally, a spacing of two to three times the depth of cut will assure sufficient breakout. This assumption will be used in developing concepts for this study. However, only an in-situ test at the coal face can determine the correct bit spacing.

4.2.3 Sump and Shear Forces

Determination of the forces to sump and shear coal to a depth of 6 inches must also be determined by a comprehensive test program. Most of the British work has involved shallow cutting, primarily at depths less than 1 inch. This work cannot be applied or extrapolated to deeper cuts. Recently, the USBM Twin Cities Research Center has made laboratory cuts and recorded the forces for the cuts to a depth of 4 inches.

From the Illinois Number 6 coal and the Pittsburgh coal, the Bureau has extrapolated (for a 6-inch cut) a force of 12,000 pounds as a probable sump force. This force is considered a mean force for a 6-inch depth of cut. In addition, based on the Bureau's research, the shear force will be equal to or less than the sump force.

For the purposes of this study, the concepts are designed for a 15,000-pound sump and shear force, at a 6-inch depth of cut. When actual forces are determined, the machine components can be scaled up or down as the case dictates. Consideration was also given to designing LCRH for a 3-inch depth of cut (see the conclusions and recommendations section). The forces used for this 3-inch cutting depth are based on actual forces measured during cutting tests of Wyoming coal at the Bureau's Twin Cities laboratory. The mean cutting force was found to be 2,700 pounds.

4.2.4 Seam Height

The seam height will not be a specific value, but rather will be dictated by the machine chosen for retrofit.

4.2.5 Sump and Shear Rates

The sump and shear rates will certainly be dictated by the individual concept and the components involved. However, where applicable, the following rates will be specified:

- Sump rate: 1 inch per second
- Shear rate: 1 foot per second.

4.3 CONCEPT DESCRIPTION

During the course of the contract, five concepts were considered sufficiently significant to develop layout drawings and perform preliminary calculations for power, production, and component sizing. Table 3 is a summary of these concepts, location in the text, characteristics such as production potential and horsepower, and some remarks about the advantages and disadvantages of each concept. The linear cutting rotary head (LCRH) and the self-sumping head (SSH) concepts are recommended in this report. They have been developed to a much greater extent than the other three concepts, and are fully discussed in this section. The remaining three concepts, the chain ripper, the articulated head, and the V-face concept, although not recommended, are described in the appendix, because they were important parts in the total study.

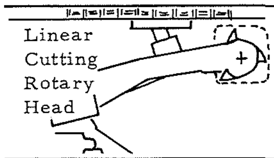
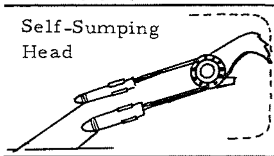
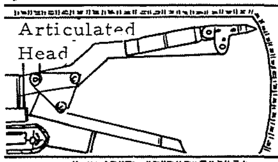
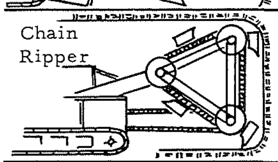
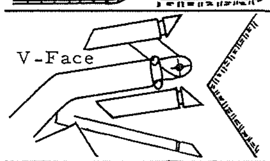
4.3.1 Self-Sumping Head (SSH) Concept

4.3.1.1 General Description

Figure 18 is an artist's drawing of the self-sumping head concept. Figure 19 is a general arrangement drawing of the concept retrofitted to a Joy 12CM miner. Figures 20, 21, and 22 show the concept on a Jeffery 120 Heliminer, a Lee-Norse 455 hard-head miner, and a National Mine Service miner, respectively.

The concept features an eight-bit head driven by chains attached to cylinders. Each of four sump cylinders (1, Figure 20) across the head drives a segment of the head containing two bits. The bits can be rotated two at a time, thus reducing need for auxiliary support. In this mode of operation, only a stabilizer pad (13) located at the rear of the machine (Figures 19 and 20) will be necessary to react the cutting forces. Such stabilization mechanisms are frequently incorporated on standard continuous mining machines. As the head is sumped, the rotation action brushes the roof by means of a brushup bar (7). In addition, if rib brushing becomes necessary, small side bits (11) can be installed that would rotate with the head, facilitating rib cleanup. These rib brushing bits would be employed only when absolutely necessary, as more bits generate more dust. The cutting bits are equipped with standard carbide tips (8) and a special carbide insert (9) for the shearing process.

Table 3 CONCEPT SUMMARY

Concept Description	Location in Text		HP for 6" Depth of Cut	HP for 3" Depth of Cut	Total Weight (Lbs)	Calculated Tons Per Shift	Retrofit To Existing CMM	Remarks
	Engineering Feasibility	Economic Factors						
Linear Cutting Rotary Head 	4.3.2	4.5.5 4.6 4.7.2	600	450	130,000	1314 849	No	High production Low airborne respirable dust
Self-Sumping Head 	4.3.1	4.5.4 4.7.1	300	NC	88,000	505	Yes	Production matching existing CMM Simple, reliable head mechanism No sump rig jacks required
Articulated Head 	A	A	300	NC	NC	549	Yes	Good production but requires sump rig jacks and head is complex
Chain Ripper 	A	A	300	NC	NC	671	Yes	Good production but chains are a high maintenance item Large head hard to maneuver and limits visibility of face
V-Face 	A	A	400	NC	NC	303	Yes	Complex cycle, thus long cycle time yields low production.

NC = Not Calculated A = Appendix

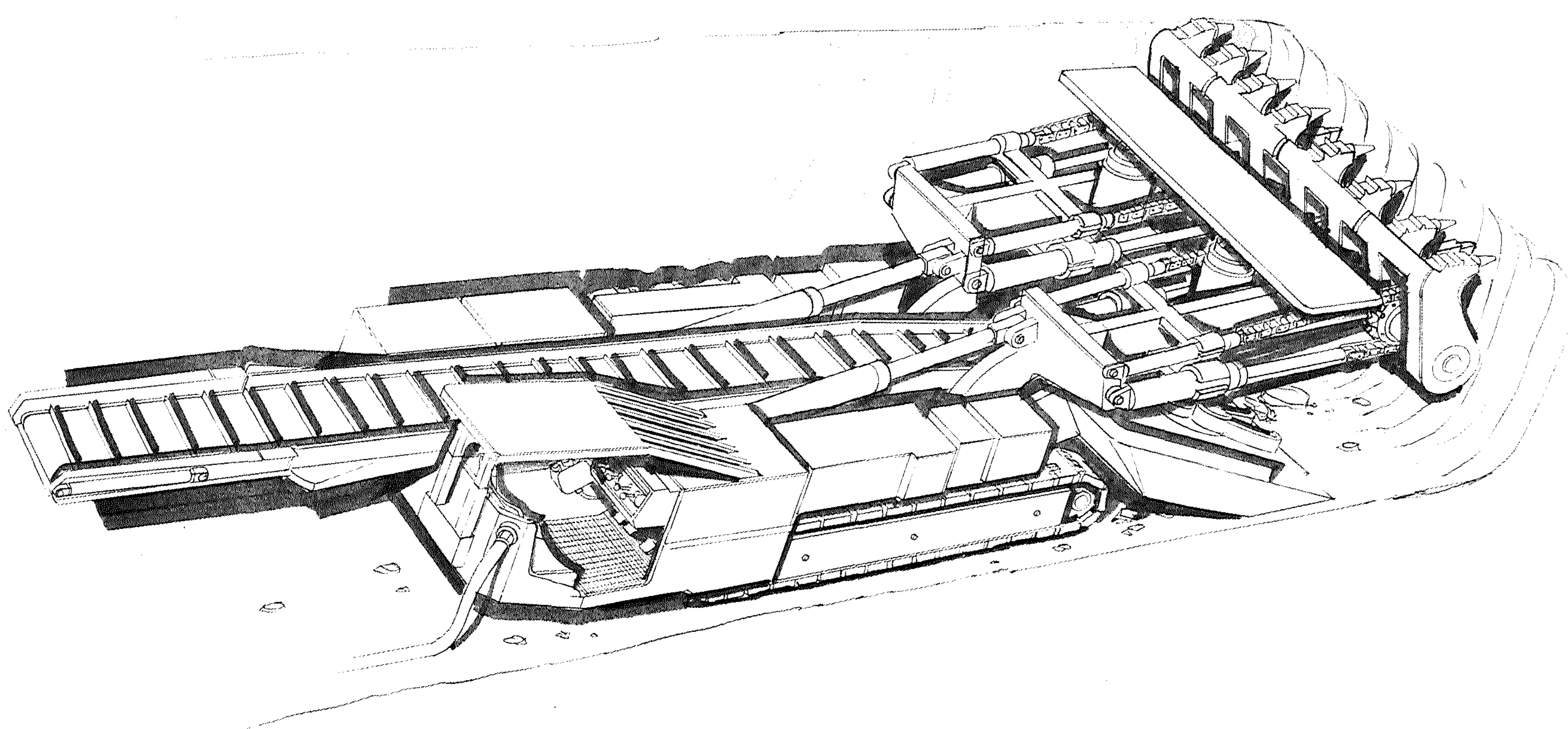


Figure 18 ARTIST'S DRAWING, SELF-SUMPING HEAD CONCEPT

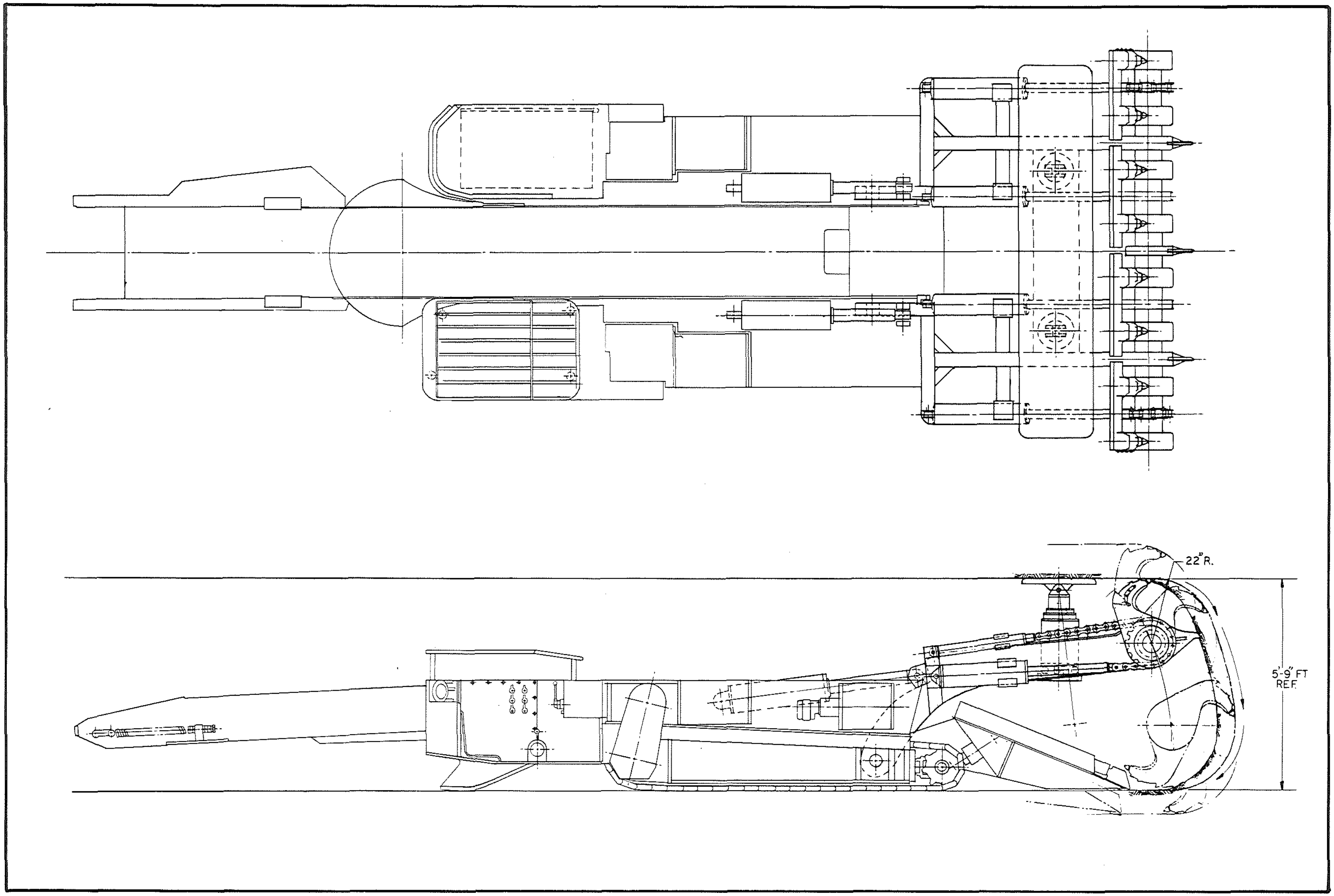


Figure 19 LAYOUT DRAWING, SELF-SUMPING HEAD CONCEPT SHOWN ON JOY 12CM MINER

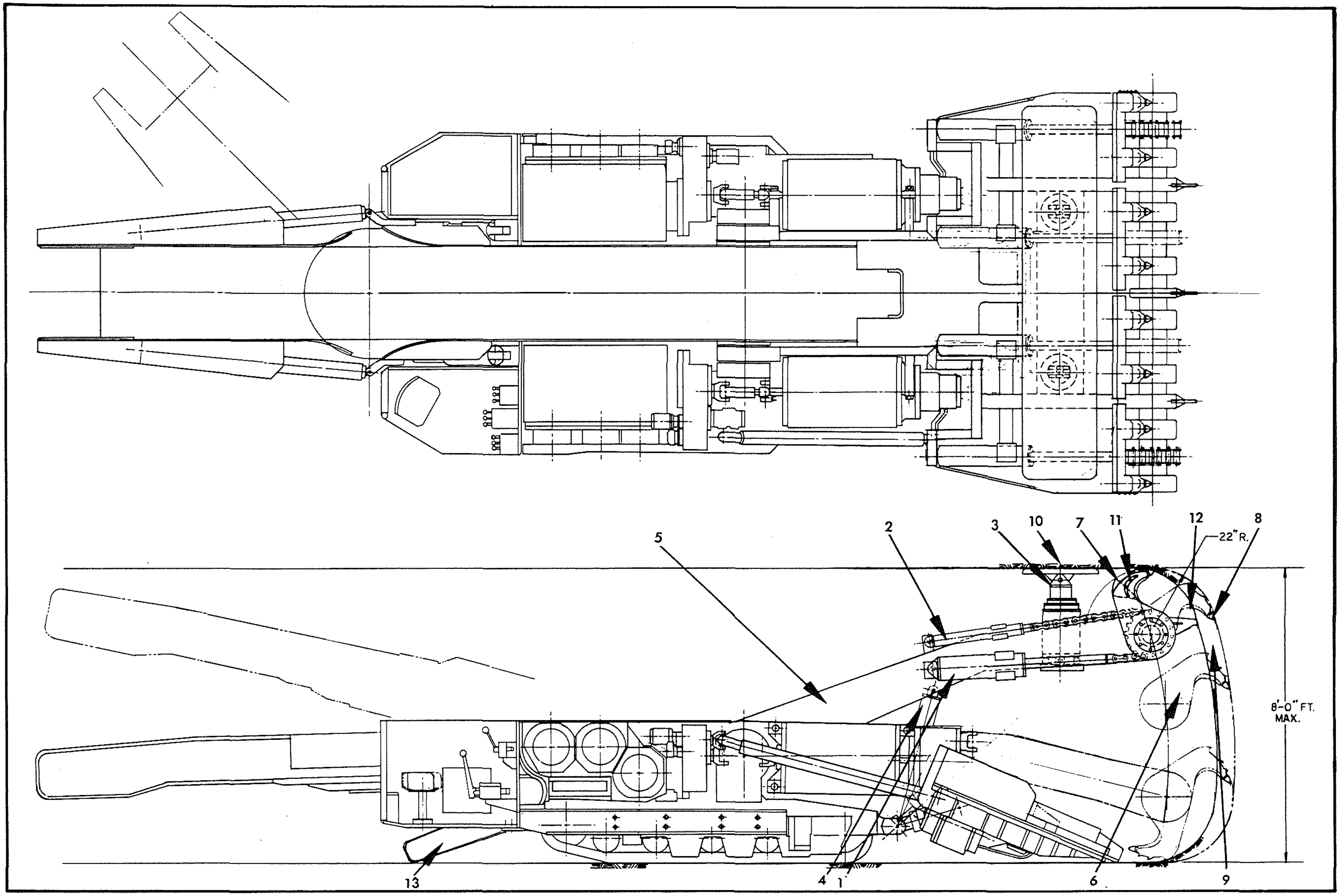


Figure 20 LAYOUT DRAWING, SELF-SUMPING HEAD CONCEPT SHOWN ON JEFFREY 120 HELIMINER

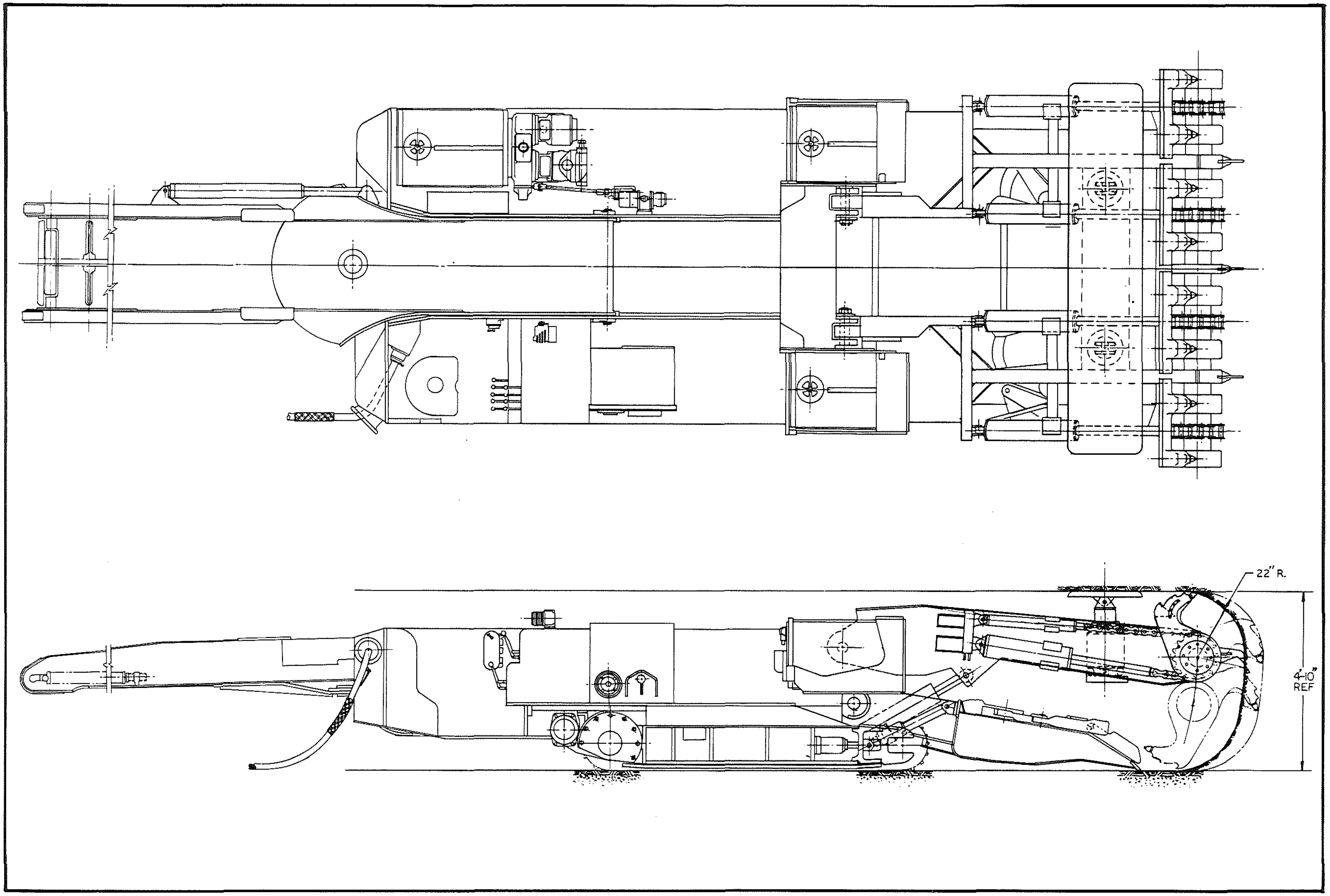


Figure 21 LAYOUT DRAWING, SELF-SUMPING HEAD CONCEPT SHOWN ON LEE-NORSE 455 MINER

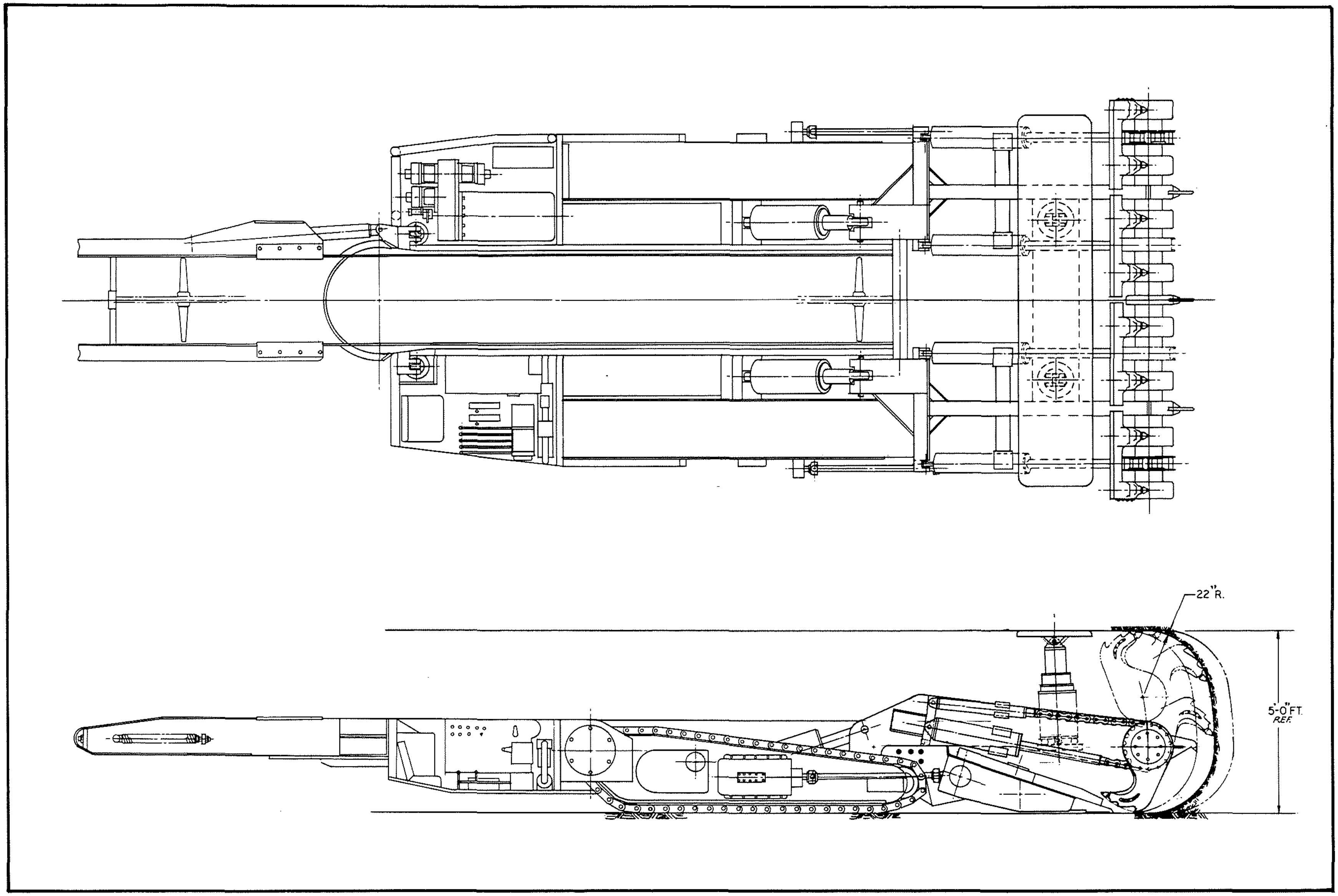


Figure 22 LAYOUT DRAWING, SELF-SUMPING HEAD CONCEPT
SHOWN ON NATIONAL MINE SERVICE 3080 MINER

With the head (6) positioned at an efficient shearing angle (approximately 45 degrees to the bedding planes), shear cylinders (3) push the entire cutting boom (5) down through the coal a preset distance. At this time the sump cylinders (1) are activated, rotating the head the remaining distance through the coal and out as shown in Figure 19. Again the brushup bar is employed, this time brushing the floor as it is rotated out of the coal. The head is capable of rotating 240 degrees. Three bumpers (12) along the front of the head position the miner so that the appropriate sump will be achieved. Four return cylinders (2) return the head to its maximum drawnback position (ready to sump). The top plate (10) of the shear cylinders (3) has a roof contact area that gives about 30 psi pressure against the roof during shear-down. The entire boom assembly is pivoted at the same point as the original rotary head and is maneuvered by cylinders (4) using the original pivot points.

4.3.1.2 Mining Sequence

The following mining sequence is anticipated for the self-sumping head concept (see Figure 23):

- The miner trams forward until the bumpers engage the face.
- The boom is positioned so that the desired seam height will be achieved.
- The shear jack cylinders raise the roof plate to the roof.
- The head cylinders are activated and the bits are sequentially sumped to a preset position.
- The shear cylinders then push the head assembly through the coal to a preset position.
- The bits then sequentially finish the sump and clear the coal.
- The head assembly is then returned to the initial position and the miner is trammed forward for another cut.

The control system will be a manually operated semiautomatic hydraulic system that will be no more complicated than existing control systems for CCMs. This system allows full benefit of the operator's feel and vision during the cutting process. The sequencing of the head segments will be semiautomatic. They can be controlled in an automatic mode or the operator can control each segment individually.

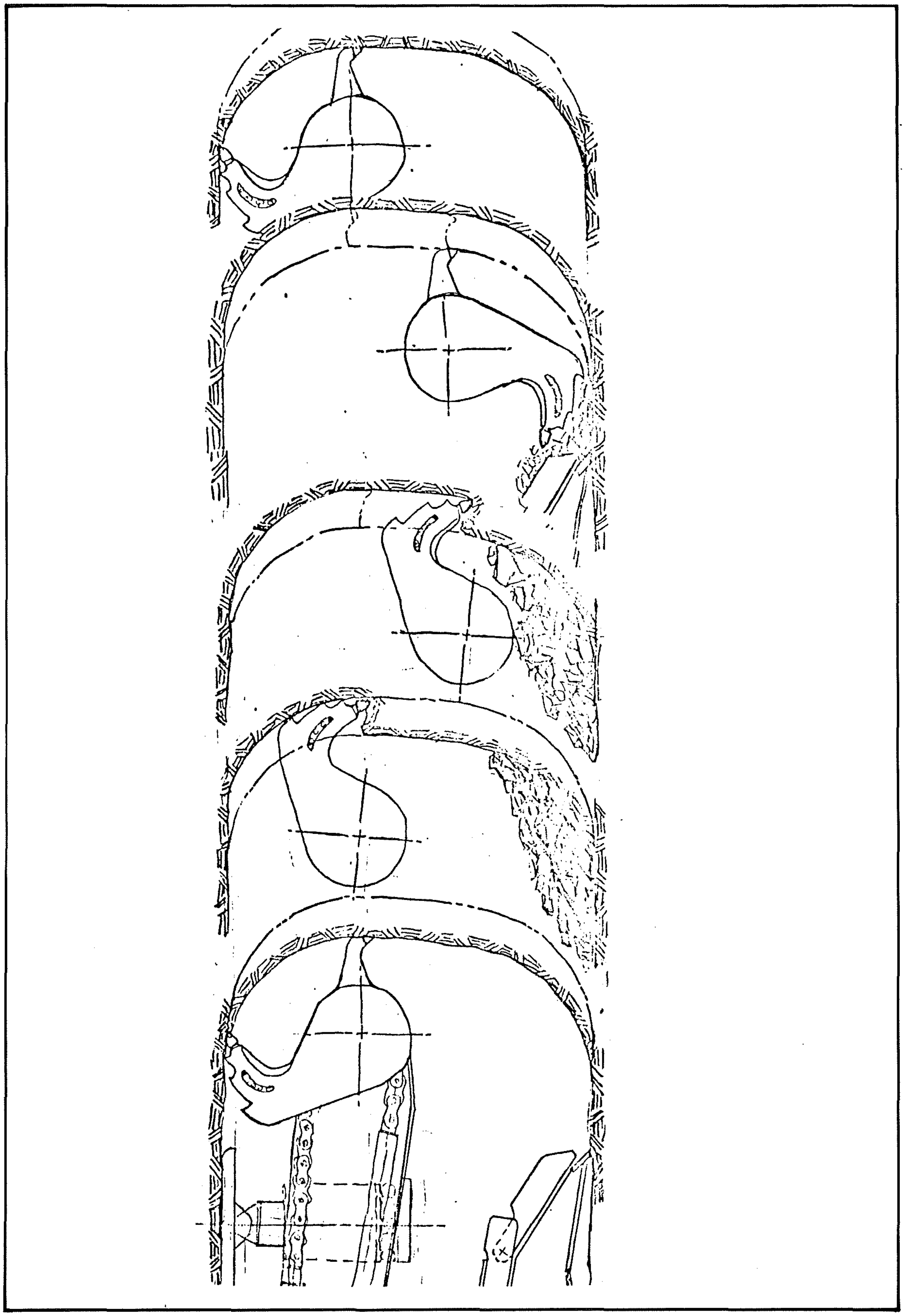


Figure 23 MINING SEQUENCE

4.3.1.3 Retrofit Components

The self-sumping head concept is shown in Figure 19, retrofitted to a Joy 12CM continuous miner. The chassis, basically unchanged, retains the standard gathering head, conveyor, tram system, and related components. The major modifications involve replacement of the standard hard head with an SSH boom and head. The boom, constructed of steel plates and members, is pivoted at the same location as the hard-head boom. The head contains four sets of cutters and related hydraulic cylinders. Two telescoping hydraulic cylinders are mounted directly on the boom for shearing the head down. It is anticipated that the original head motors will be replaced by two electric motors and pumps to power the head components. These electric motors will develop approximately 150 horsepower each.

The following major components and materials are required for retrofit; they replace the standard rotary head, boom, and related support components.

- Four 8-1/2-inch-diameter, 30-inch-stroke hydraulic cylinders with 3-inch-diameter rods
- Four 3-1/2-inch-diameter, 30-inch-stroke hydraulic cylinders with 2-inch-diameter shafts
- Two PMC 15,500 three-stage double-acting hydraulic shear cylinders
- Twenty-five feet RC 250S-2-double-strand Link-Belt chain
- Eight Acme 200 A24, 20.49-inch -diameter sprockets
- Steel plates and material necessary to construct boom and roof reaction plate
- Four specially designed head sections, each section containing two deep-cutting bits, two carbide inserts, brushing bits, and bars
- Two 150-hp electric motors
- Two 180-gpm hydraulic pumps
- Necessary electrical and hydraulic controls.

Horsepower is as follows:

- Head 300
- Gathering head and conveyer 60
- Tram 70
- Hydraulic pump 50.

Total horsepower is 480, approximately equal to that of an existing CMM.

4.3.1.4 Forces and Power

Each sump cylinder (Figure 24) sumps two bits, 15,000 pounds each, for a total reactive force of 30,000 pounds.

Using a 20-inch-diameter sprocket, the necessary cylinder force (F) is:

$$F = \frac{22}{10}(30,000)$$

$$= 66,000 \text{ pounds.}$$

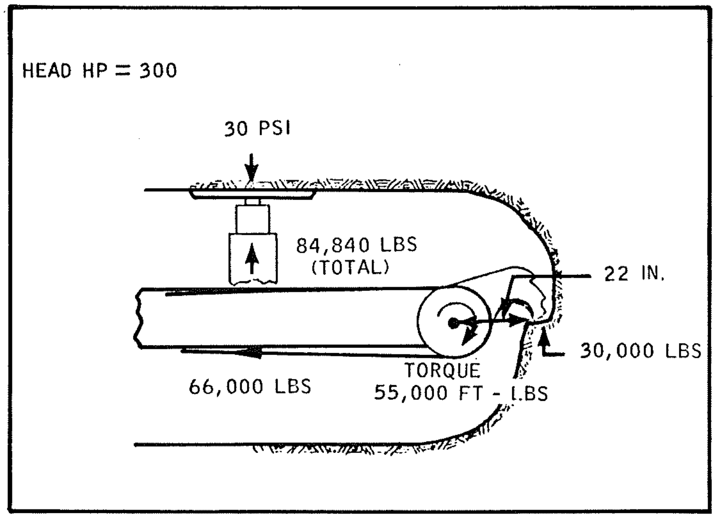


Figure 24 FORCE DIAGRAM, SELF-SUMPING HEAD

Cylinder force - chain pull = 66,000 pounds.

Assuming system hydraulic pressure = 1,500 psi, area sump

$$\text{cylinder } (A_s) = \frac{66,000 \text{ pounds}}{1,500 \text{ psi}} = 44 \text{ inches}^2.$$

For a 3-inch-diameter shaft:

$$\sigma_A = \text{axial stress} = \frac{66,000}{(3.1416)(1.5)^2} = 9,337 \text{ psi.}$$

$$\text{Diameter of cylinder (d)} = 2\sqrt{\frac{A_s}{\pi} + R^2}$$

$$= 2\sqrt{\frac{44}{\pi} + (1.5)^2}$$

$$= 8.06 \text{ inches.}$$

Let diameter = 8. 5 inches

Maximum rotation of head = 216 degrees

Circumference of sprocket = 62. 8 inches

$$\text{Cylinder stroke} = \frac{216}{360}(62.8) = 37.7 \text{ inches.}$$

For a cutting rate of 12 inches per second, the head must rotate 143 degrees in 2. 15 seconds. Therefore, cylinder stroke for 143 degrees rotation is:

$$\text{Cylinder stroke} = \frac{143}{216}\, 37.68 = 24.9 \text{ inches.}$$

$$\text{Cylinder speed} = \frac{24.9 \text{ inches}}{2.15 \text{ seconds}} = 11.6 \text{ inches per second}$$

Hydraulic flow:

$$\text{Rate } (Q) = \frac{\pi D^2 V}{4}$$

$$= \frac{(\pi)(8.5)^2(11.6)(60)}{(4)(231)}$$

$$= 171 \text{ gpm.}$$

$$\text{Working pressure} = \frac{66,000}{(\pi)(4.25)^2} = 1,163 \text{ psi.}$$

$$\text{Horsepower} = \frac{(171)(1.163)}{(1,714)} = 116 \text{ hp.}$$

Shear cylinder, roof, and reactive forces are shown in Figure 25.

W1 = 68, 000 pounds	Fx = FCOSθ
W2 = 20, 000 pounds	Fy = Fsinθ
F = 120, 000 pounds	For = θ = 45 degrees
	Fx = Fy = 84, 840 pounds.

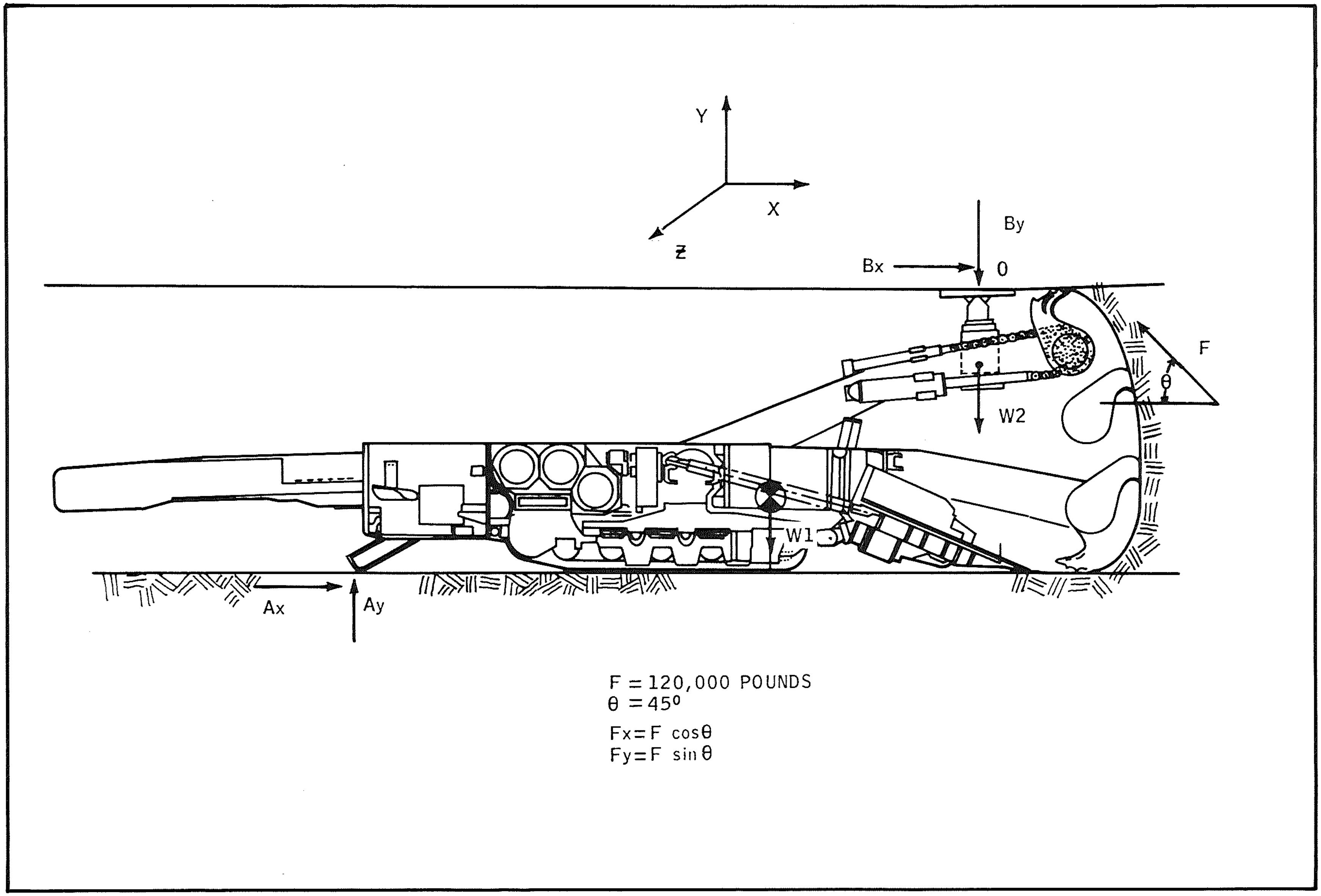


Figure 25 SHEAR CYLINDER, ROOF, AND REACTIVE FORCES

$Ay = W1 + W2,\ 68{,}000 + 20{,}000 = 88{,}000$ pounds.

$Ax =$ frictional force $= \mu Ay = (88{,}000)\ (0.5) = 44{,}000$ pounds.

$\Sigma Fy = 0, \quad Ay - W1 - W2 + Fy - By = 0$

$By = -W1 - W2 + Fy + Ay$

$\quad = -88{,}000 + 84{,}840 + 88{,}000 = 84{,}840$ pounds.

$\Sigma\ FX = 0,\ AX + BX - FX = 0$

$BX = 84{,}840 - 44{,}000 = 40{,}840$ pounds.

Shear cylinders must react 84,840 pounds. Using two cylinders, let force each cylinder reacts = 50,000 pounds.

$$A_c = \text{area cylinder} = \frac{50{,}000}{1{,}500} = 33.3 \text{ inches.}$$

$$\text{Diameter} = 2\sqrt{\frac{A_c}{\pi}} = 2\sqrt{\frac{33.3}{\pi}} = 6.5 \text{ inches.}$$

$$\text{Roof pressure} = \frac{84{,}840}{\text{area of top pad}} = \frac{84{,}840}{(10)(12)(2)(12)} = 30 \text{ psi.}$$

Let the shear speed equal 12 inches per second. For 6-foot seam, shear cylinders will be telescoping four-stage "Prince" cylinders with bores of 6, 7, 8.25, and 10 inches.

$$\text{Average diameter (DA)} = \frac{10 + 8.25 + 7 + 6}{4} = 7.81 \text{ inches.}$$

$$\text{Flow rate (Q)} = \frac{\pi(DA)^2 V}{4}$$

$$= \frac{(\pi)(12)(7.81)^2(60)}{(4)(231)} = 149 \text{ gpm.}$$

$$\text{Total shear hp} = \frac{(2)QP}{1{,}714}$$

$$\text{Pressure (P)} = \frac{50{,}000}{(\pi)\ (3.0)^2} = 1{,}768 \text{ psi}$$

$$\text{Total hp} = \frac{(2)(149)(1.768)}{1,714} = 307 \text{ hp.}$$

Root mean square hp is the sum of hp requirements times the time needed (t) divided by the total time in use.

$$\text{RMS (hp)} = \sqrt{\frac{\Sigma(\text{hp})^2(t)}{\text{total time}}}$$

$$\text{RMS (hp)} = \sqrt{\frac{[(307)^2(2.5)]}{20.31}} = 170 \text{ hp.}$$

Considering inefficiencies, an estimated 300 hp would be required to operate the head under maximum load.

Total power:

Head	300 hp
Gathering head-conveyor	60 hp
Tram	70 hp
Hydraulic pump	50 hp
Total	480 hp.

This approximately equals the power requirements of a standard CMM.

4.3.1.5 Cutting Bits

The main cutting bits for this concept will be standard plumb-bob-type bits with carbide tips. Each cutting section will also be equipped with specially designed inserts of carbide or other suitable material. These inserts will interact with the face during cutting. Figure 19 shows the location of these inserts (9). The cutter (7) located on top of the head will be a replaceable-type cutting device. Also included in the design are rib cleaning devices (11), small off-the-shelf bits or cutting teeth.

4.3.1.6 Auxiliary Support

As discussed in the SSH general description section, only a stabilizer pad, operated by a hydraulic cylinder, will be necessary to react sumping forces. The function of the pad (Figures 19 and 20) is to extend the pivot point from the rear of the tracks back to the stabilizer pad. Coupled with the shear pad, this system will assure machine stability while mining. The shear pad located on the boom reacts shear forces off of the roof. The shear pad will be large enough to assure minimum pressure against the roof (30 psi for ideal contact).

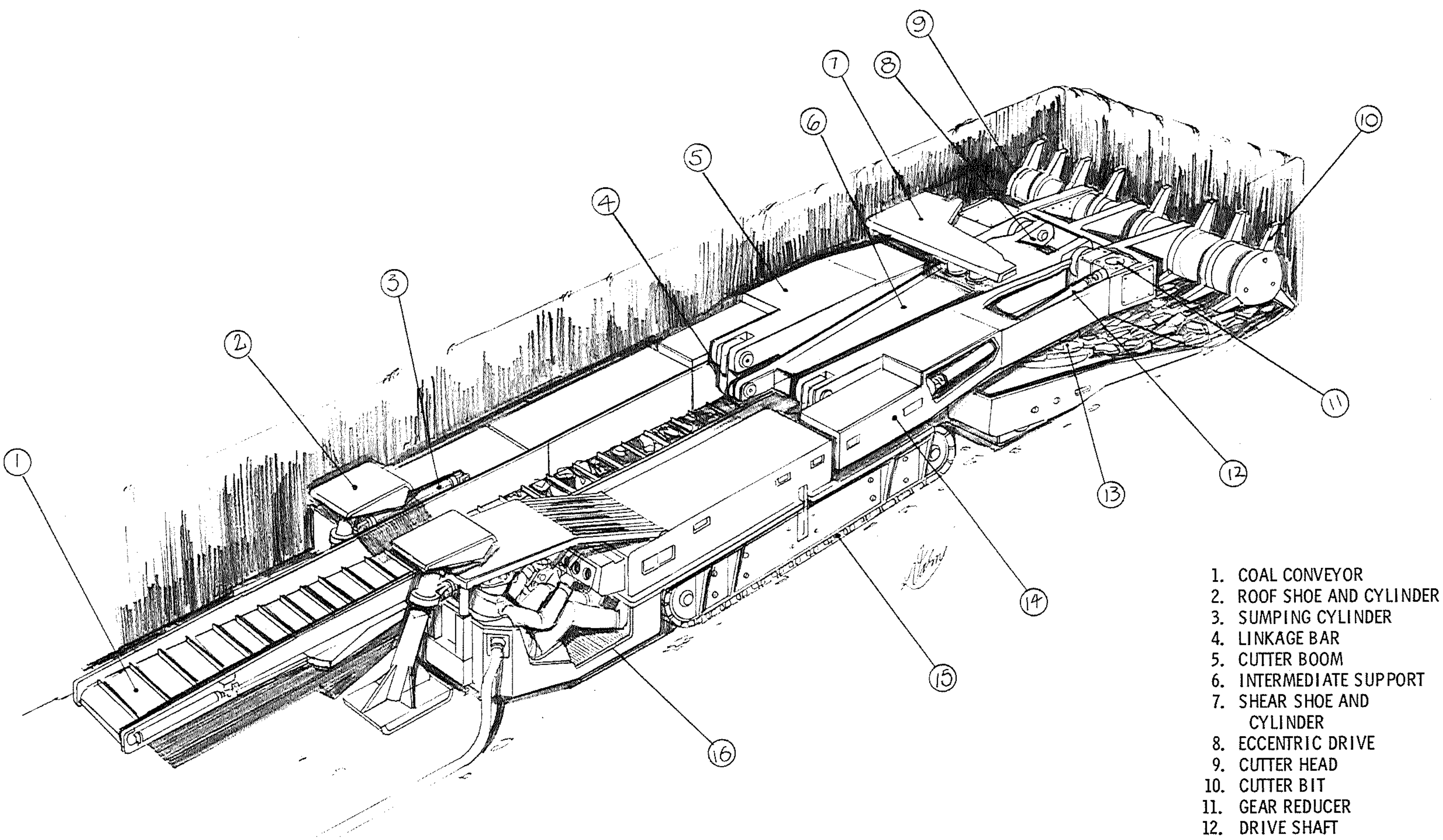
4.3.2 Linear Cutting Rotary Head Concept (LCRH)

4.3.2.1 General Description

Figure 26 is an artist's concept drawing, Figure 27 is a scale model picture, and Figure 28 is a general arrangement drawing of the LCRH concept. The head is essentially a crank-rocker arrangement that duplicates the motion of a Cardan generation mechanism. The triangular cross-sectional drum (13) is coupled via an offset crank (11) to the boom (9, Figure 29). With the intermediate support frame (16) rigidly fixed, the counterclockwise motion (10) of the crank coupled to the head (13) in a 3:1 speed ratio forces the cutter tip (15) to trace a nearly square path. Two 300-hp electric motors input a transmission that is coupled to the head and through the offset crank to the boom. A shear pad and cylinders attached to the intermediate support frame supply the reaction force for the shear cut. A sumping platform located at the rear conveyor of the machine supplies the reaction force via hydraulic cylinders to sump the machine. The sumping platform is designed to provide the forces necessary for 6-inch cuts. If 3-inch cuts were made, the platform would not be required because the vehicle tracks would provide sumping thrust.

4.3.2.2 Cardan Motion Mechanism and Eccentric Drive Crank Concept

Figure 29 and Patent Application 702,373, "Linear Cutting Rotary Head Continuous Mining Machine" describe triangular rotary head with cutting bits located 120 degrees apart driven by a pinion within a fixed internal gear. This generates a Cardan motion which causes each individual bit to follow an approximately square pattern. Such a cutting pattern would permit quick bit entrance and exit which will minimize the creation of dust. A deep constant-depth cut will maximize coal production and minimize coal dust.



1. COAL CONVEYOR
2. ROOF SHOE AND CYLINDER
3. SUMPING CYLINDER
4. LINKAGE BAR
5. CUTTER BOOM
6. INTERMEDIATE SUPPORT
7. SHEAR SHOE AND CYLINDER
8. ECCENTRIC DRIVE
9. CUTTER HEAD
10. CUTTER BIT
11. GEAR REDUCER
12. DRIVE SHAFT
13. GATHERING HEAD
14. MOTOR WITH ENCLOSURE
15. TREAD
16. OPERATOR'S CAB

Figure 26 ARTIST'S DRAWING, LINEAR CUTTING ROTARY HEAD CONCEPT

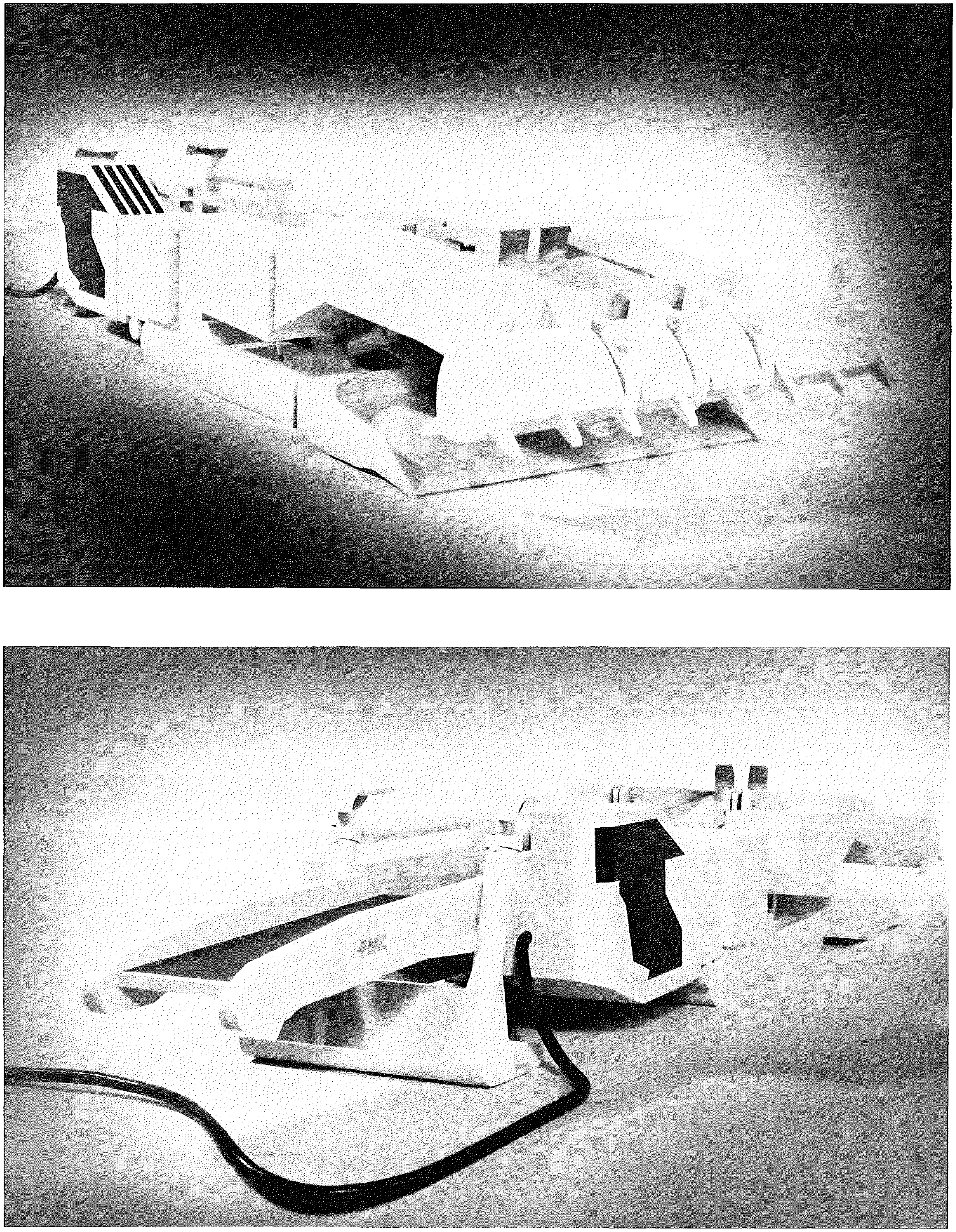


Figure 27 SCALE MODEL, LINEAR CUTTING ROTARY HEAD CONCEPT

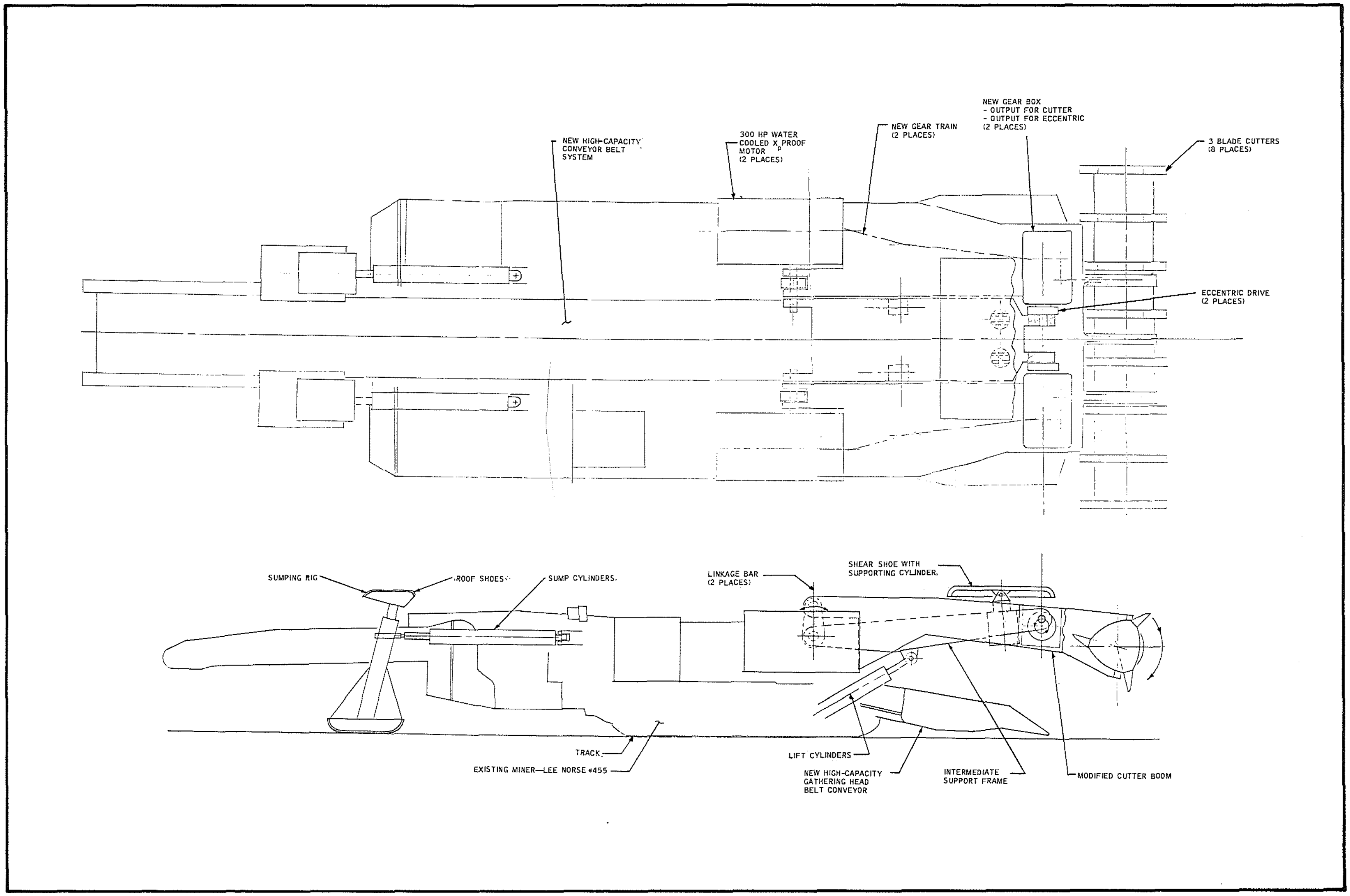


Figure 28 LAYOUT DRAWING, LINEAR CUTTING ROTARY HEAD CONCEPT

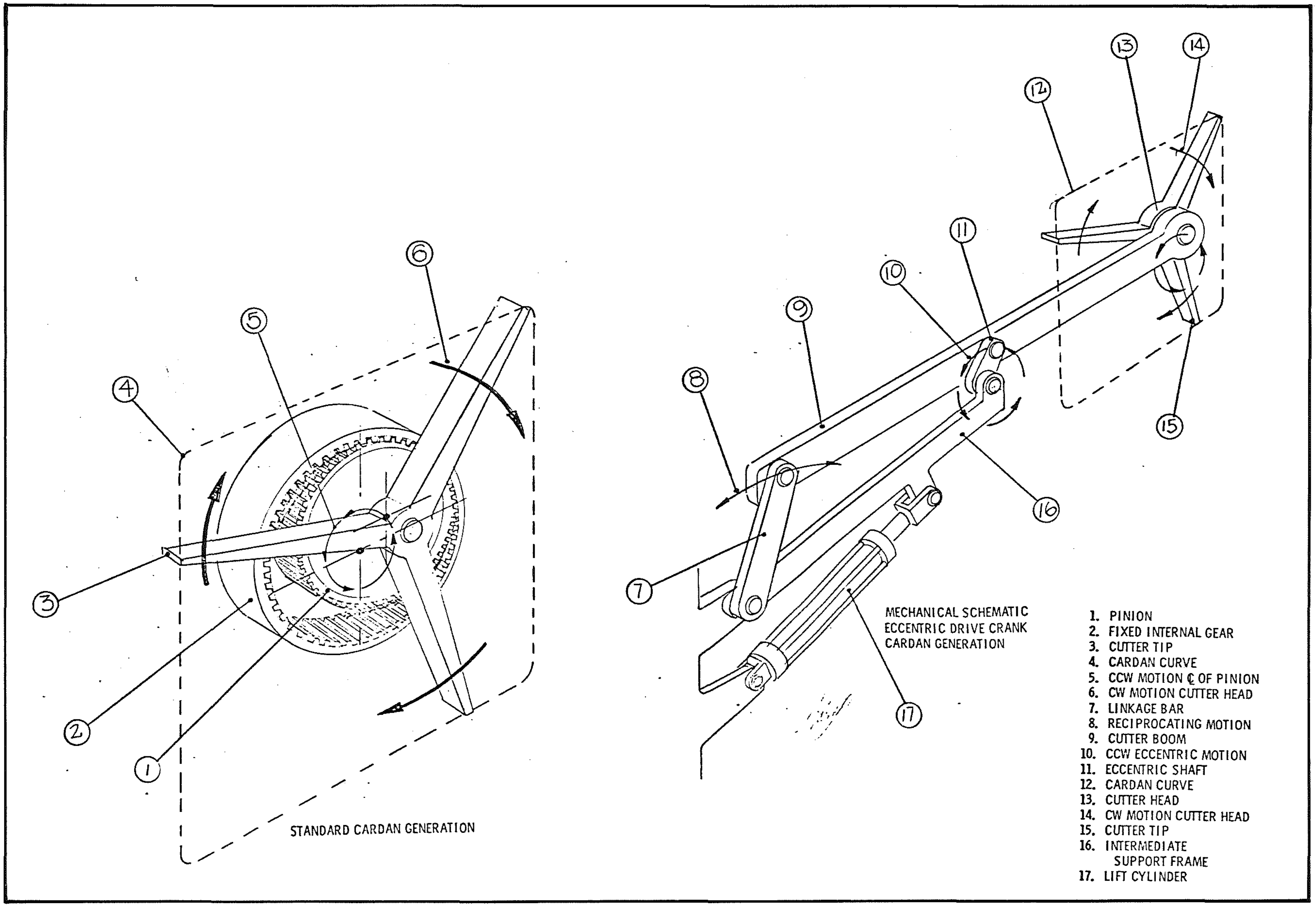


Figure 29 CARDAN GENERATOR AND ECCENTRIC DRIVE CRANK

For the following reasons an eccentric drive crank mechanism outside and behind the cutter head has been substituted for the pinion/internal gear Cardan motion mechanism described in the referenced patent application:

- A large cross-sectional area and volume is required to incorporate the mechanism within the cutting head. A Cardan motion with a 3-inch eccentric results in a head with a cutting circle of approximately 56 inches rather than the desired 36 inches.
- High gear loading.
- Difficulty of sealing mechanism against dust and moisture.
- Difficulty of maintaining and repairing, particularly in the field.

The cutting head subassembly specifications are as follow:

- Head rotational speed: 10 rpm
- Depth of cut: 6 inches
- Cut pattern: straight-line (part of Cardan curve)
- Load on an individual bit: 15,000 pounds
- Number of bits: 24
- Bit arrangement: three groups of eight bits located at 0 degrees, 120 degrees, and 240 degrees; bits located on 18-inch centers.

The eccentric drive crank concept simplifies the Cardan generating mechanism. Patent Application 702,373 specifies a pinion diameter to internal gear diameter ratio of 3:4. Figure 29 illustrates such a mechanism and shows that the Cardan motion can be broken down into a clockwise rotary motion of the cutting head and an eccentric counterclockwise rotary motion of the center location of the cutting head.

The eccentric drive speed is three times that of the cutter drum. The two motions are mechanically interconnected to ensure synchronization, as shown in Figure 30.

To reduce the amount of machinery within the cutting head and to simplify design, a four-bar linkage mechanism was considered; see Figure 31. Both alternates generate a "pure" Cardan motion.

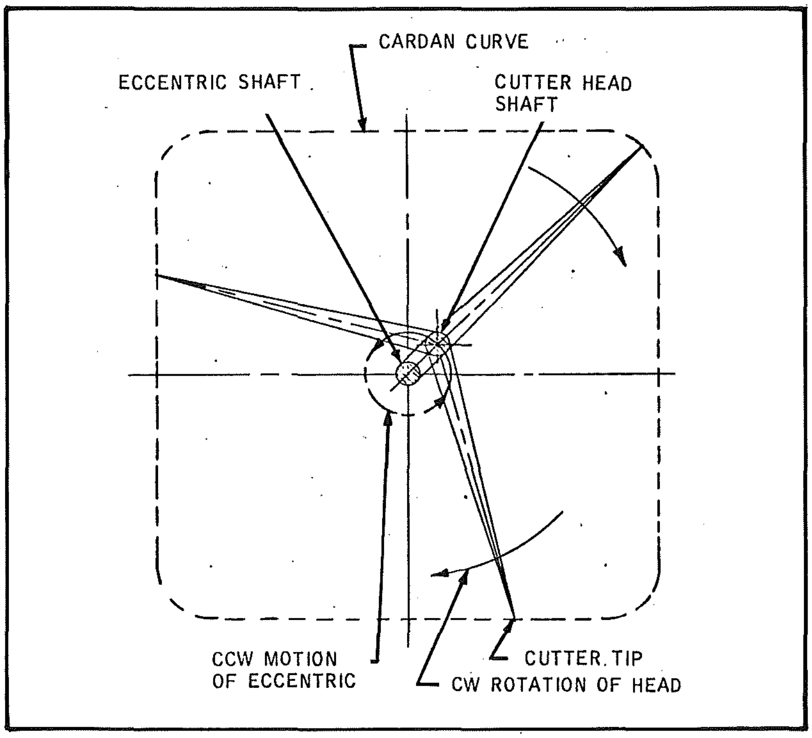


Figure 30 ALTERNATE CARDAN MECHANISM

To further simplify the design, one of the eccentric shaft mechanisms was replaced with a linkage bar that reciprocates back and forth (Figure 30). With this design, the counterclockwise motion of the center of the cutter head will follow an oval rather than a circular path.

The resulting modified Cardan rectangular curve is satisfactory for linear cutting. See Figure 29.

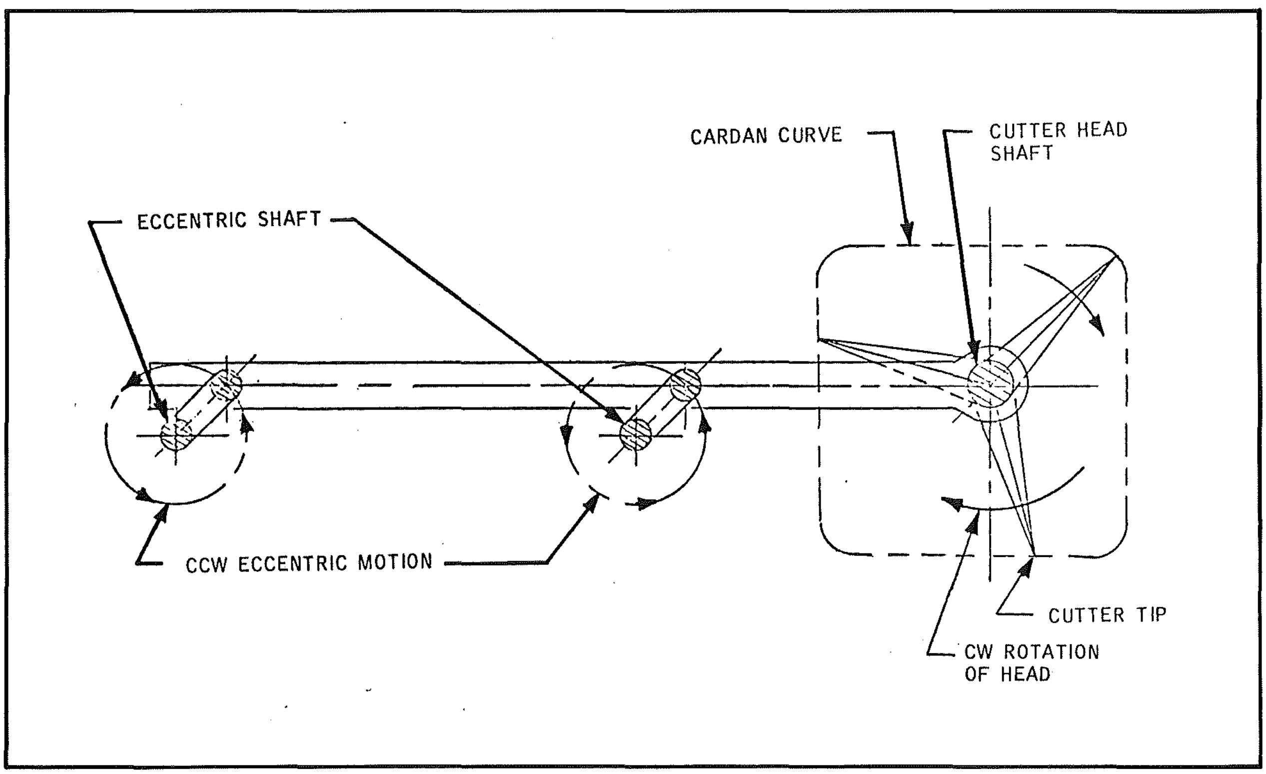


Figure 31 FOUR-BAR-LINKAGE CARDAN MECHANISM

4.3.2.3 Mining Sequence (6-inch cut)

Refer to Figure 32. The sequence is as follows:

- The shear shoe with supporting cylinder is retracted.
- The cutting head is raised to the roof by extending the two lift cylinders.
- The cutting head is rotated at 10 rpm.
- The sump cylinders push the cutting head forward at a rate of 15 feet per minute.
- After the head advances 30 inches (10-second time period), the motion of the sumping cylinders is stopped.
- The cylinders for the shear shoes are extended at the rate of 15 feet per minute. This pushes the cutting head down for the shearing operation.
- During the shearing operation, the sumping rig is disengaged from the mine roof and the sumping cylinders are retracted. This moves the sumping rig forward.
- When the shearing operation is completed, the roof shoes of the sumping rig are extended to the roof.
- The cycle is repeated.

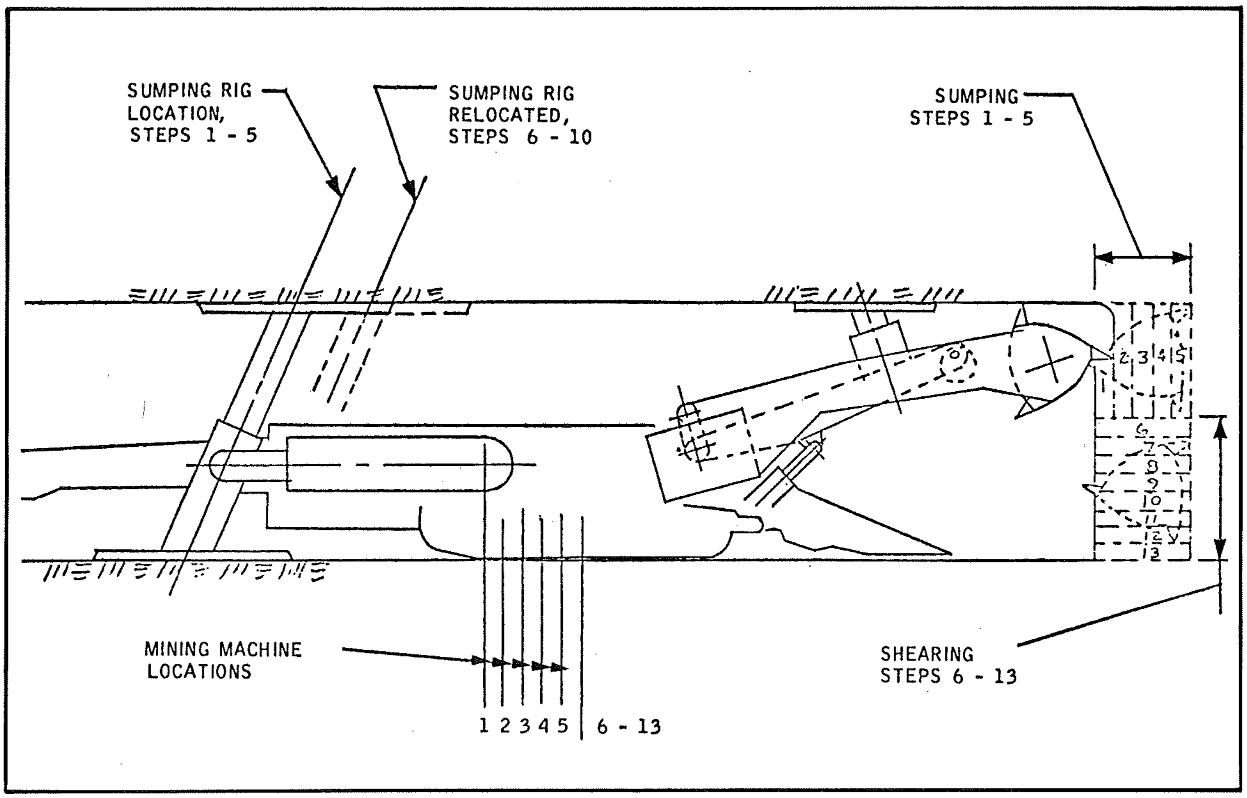


Figure 32 SUMPING AND SHEARING OPERATING SEQUENCES

It is likely that if the cutting depth was changed from 6 to 3 inches, the need for a sumping rig would be eliminated. The mining sequence would therefore be simplified and speeded up with elimination of sumping rigs for the 3-inch cut.

4.3.2.4 <u>Retrofit Components</u>

Following is a list of the major changes and components necessary to transform a CMM to the LCRH eccentric drive crank concept:

- <u>Drum Body</u>

  Design of the drum body is shown on Figure 28. The gear train driving the drum at 10 rpm will be built to accommodate the torque needed to drive eight cutting tools through the coal face at a depth of 6 inches.

- <u>Eccentric Drive</u>

  The eccentric drive, with a 3 inch throw, is driven at 30 rpm by a takeoff from the transmission train to the drum drive. See Figure 33.

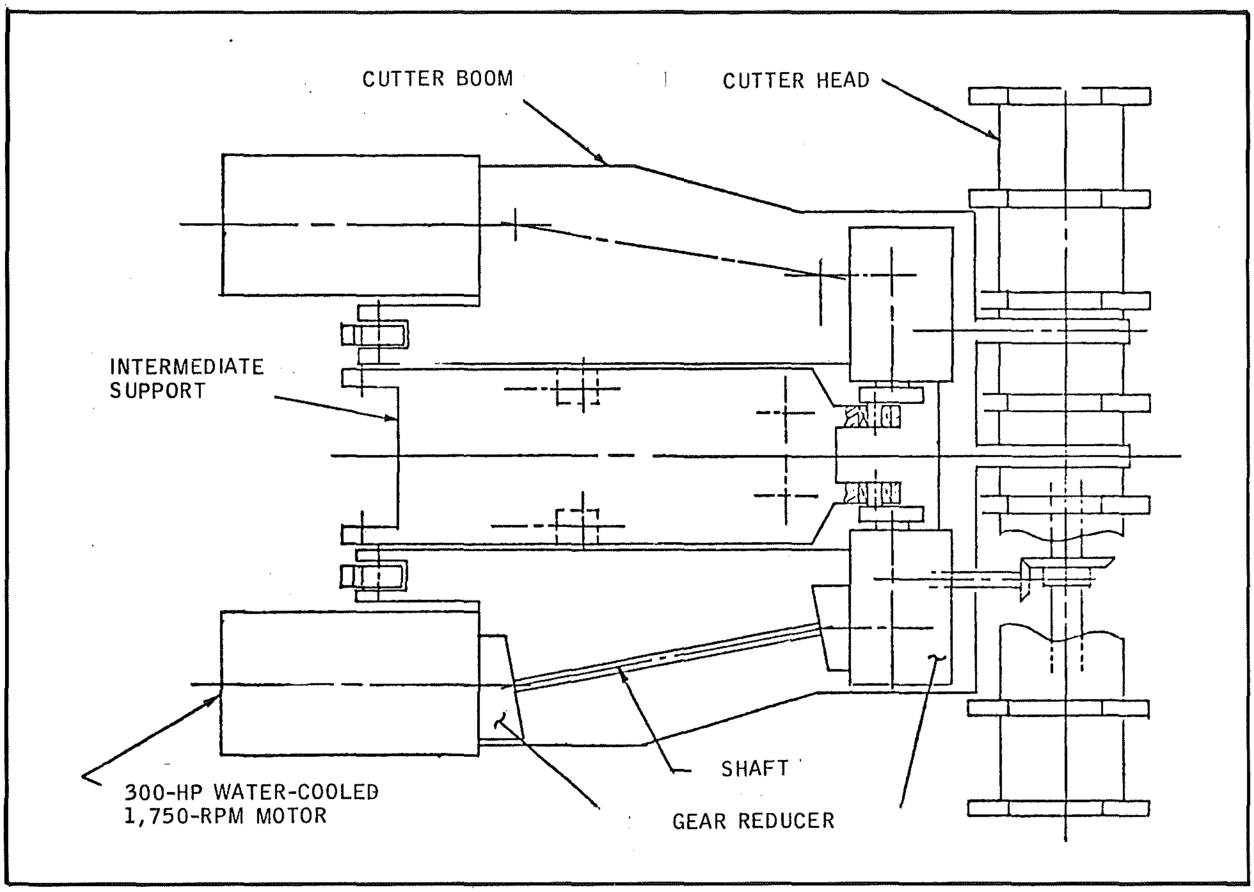


Figure 33 POWER TRAIN

- <u>Eccentric Drive Crank Cutter Head Power Train</u>

  Refer to Figure 33. The drive train is similar to that for a medium CCM except for the addition of the power takeoff for the eccentric drive. The proposed design is for illustrative purposes only.

- <u>Motor</u>

  The two motors are 300-hp water-cooled electric units suitable for coal mine use. See Figure 33 for location of motors on cutter boom.

- <u>Cutter Boom For Cutting Head</u>

  The cutter boom will be connected to the main frame via a 12-inch-long pivoted linkage bar (Figure 34). The cutter boom will be supported by eccentric drive mechanisms connected to the intermediate support frame.

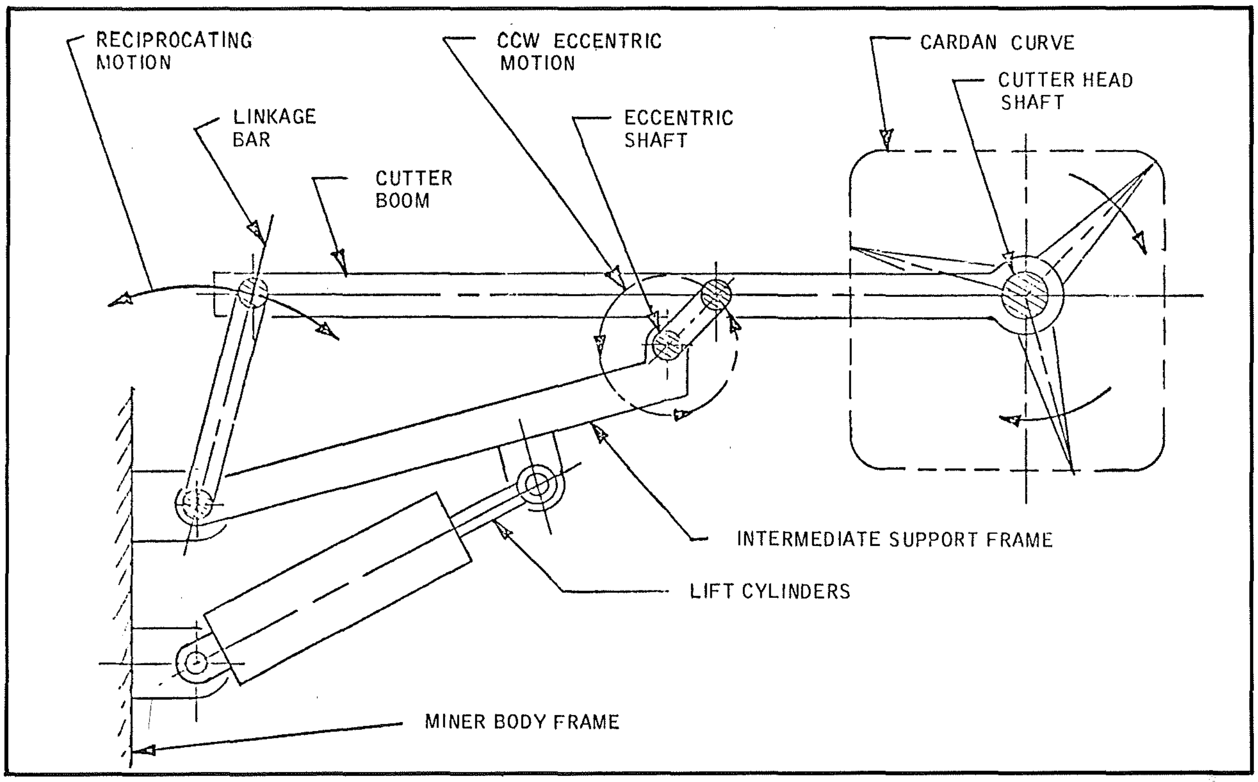


Figure 34 MECHANICAL SCHEMATIC

- <u>Intermediate Support Frame</u>

  Refer to Figure 34. The framework is hinged at a fixed point on the frame of the vehicle and is supported by two lift cylinders. This support is connected to the cutter boom by the two eccentric drives. In operation, the entire assembly can be raised and lowered by the lift cylinders. The Cardan motion is generated, independently of the lift cylinders, by the rotating cutting head and eccentric shafts.

- Shear Shoes With Supporting Cylinders

  During sumping and shearing operations, an 86,000-pound force is required to hold down the cutting head. Otherwise the cutting head would lift the mining machine off the floor. This force is obtained by the use of two shear shoes with individual telescopic cylinders mounted on the intermediate support frame; see Figure 35. Equipment required includes two fabricated shear shoes, two telescopic cylinders, and miscellaneous hardware.

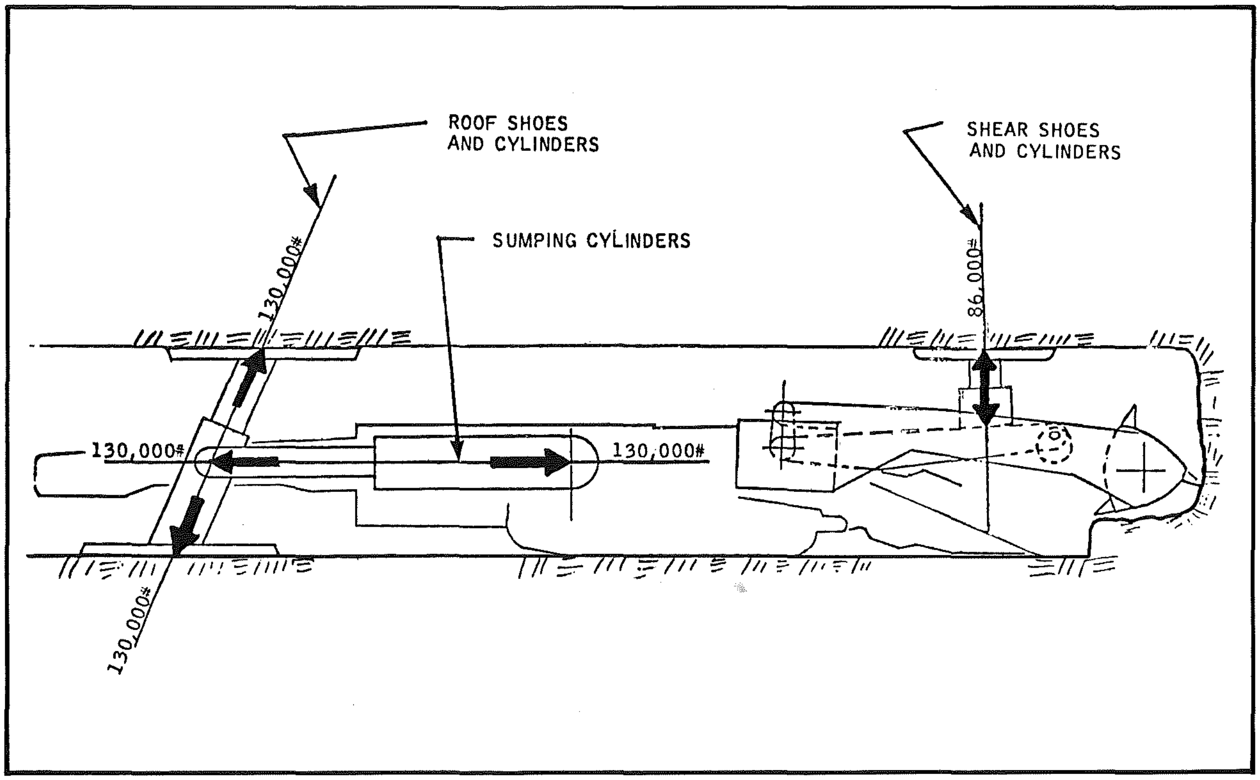


Figure 35 SUMP AND SHEAR FORCES

- Sumping Rig

  The sumping rig subsystem is required to advance the miner at a rate of 15 feet per minute during the sumping operation. A horizontal force of 130,000 pounds will be required. The sumping rig is anchored to the floor and ceiling by extending the two cylinders for the roof and floor with a force of 65,0000 pounds each. See Figure 35. Equipment required includes two fabricated roof shoes, two fabricated floor shoes, two hydraulic cylinders for roof shoes, two hydraulic cylinders for sump cylinders, and miscellaneous brackets, hardware, etc.

- High-Capacity Gathering Head and Conveyor Belt System

  The new LCRH design will have an average production rate of 540 tons per hour, with short peak loads approaching 1,000 tons per hour. The gathering head and conveyor system will be sized accordingly.

4.3.2.5 Forces and Power

Forces and power of the LCRH concept drive mechanisms and related components were determined for two depths of cut, 3 inches and 6 inches. Figures 35 and 36 are force diagrams (for 6-inch depth of cut).

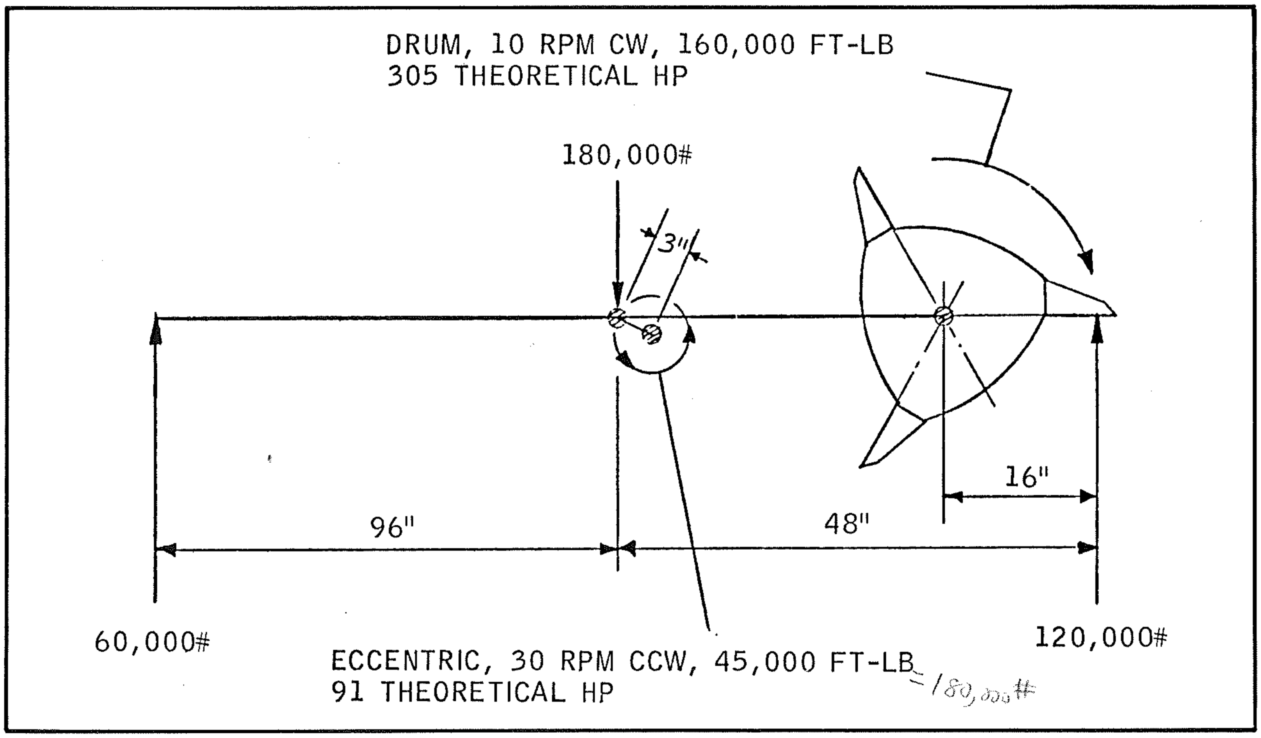


Figure 36 FORCES AND POWER REQUIRED

Forces and power for 6-inch depth of cut were determined from the following data:

- Force per bit = 15,000 pounds
- Number of bits = 24
- Number of bits simultaneously cutting = 8
- Bit spacing centerline to centerline = 16.2 inches
- Head rotational speed = 10 rpm
- Sump rate = 3 inches/second
- Shear rate = 3 inches/second.

The power requirements for the head to cut coal and operate the eccentric are:

- Head torque required: 160,000 foot-pounds
- Theoretical horsepower at the cutter head: 305
- Eccentric maximum torque required = 45,000 foot-pounds
- Theoretical power required to drive the eccentric mechanism: 91 horsepower.

Using electric motor drive to a gear reduction unit with two power takeoffs (one to the head, one to the eccentric), we have the following requirements:

- Total theoretical horsepower required: 396
- Estimated total cutter boom power required (66 percent efficiency): 600 horsepower
- With load divided between two motors, electric motor size: 300 horsepower.

Currently, Louis Allis Division of Litton Industrial Products, Inc., specially produces a 200-horsepower, 1,200 rpm water-cooled electric motor for mining applications. The power requirements of this motor can be increased to 300 hp by increasing the rotational speed to 1,800. The approximate package size would be 18 inches diameter by 32 inches long.

The gear reduction units would be custom-built items. The maximum torque requirement of the units would be 80,000 foot-pounds each. Although this requirement is high, it is not seen as a technical determent to the LCRH concept. The Deep Cutting Continuous Miner, U.S. BM contract HO122039, is capable of 116,000 foot-pounds at the head or 58,000 foot-pounds per reduction unit.

Additional power requirements are:

- Shear Shoe Cylinders (2)
  Total force required: 86,000 pounds
  Telescoping cylinder diameter, smallest cylinder (1,500 psi): 6 inches
  Hydraulic flow rate: 90 gpm
  Theoretical power required: 78 horsepower.

- Sumping Rig Roof Shoe Cylinders (2)
  Total vertical force required: 130,000 pounds
  Cylinder diameter: 12 inches.
- Sumping Cylinders (2)
  Total horizontal force required: 130,000 pounds
  Cylinder diameter: 7.5 inches
  Hydraulic flow rate: 70 gpm
  Theoretical power requirement: 60 horsepower.
- Tram
  Total power required: 70 horsepower.
- Conveyer and Gathering Head
  Total power required: 70 horsepower.
- Other Hydraulic Functions
  Total power required: 50 horsepower.

In summary, the total peak power requirements would occur during the sump cut and are:

- Head cutting: 600 horsepower
- Conveyor: 70 horsepower
- Sump cylinders: 60 horsepower.

The total power requirements of the LCRH are:

• Two 300-horsepower electric head morots:	600 horsepower
• One 200-horsepower electric motor to operate the hydraulic tram, hydraulic conveyor, sump rig, shear rig, head boom, tail boom swing and raise, and main conveyor raise:	150 horsepower
• Total	750 horsepower.

Forces and power for the 3-inch depth of cut are determined from the following data:

- Force per bit: 2,700 pounds (Wyoming Coal)
- Number of bits: 42
- Number of bits simultaneously cutting: 14
- Bit spacing, centerline to centerline: 8.85 inches

- Head rotational speed: 25 rpm
- Sump rate: 3.8 inches per second
- Shear rate: 3.8 inches per second.

The total power requirements are:

• Electric head motors, 2 to 225 horsepower	450 horsepower
• Electric hydraulic system, 200 horsepower	200 horsepower
• Total	650 horsepower.

4.3.2.6 Trailing Cable Requirements

A 950-volt power supply system is recommended for the LCRH concept. This would require a 1/0 awg or 4/0 awg cable.

A 1/0 awg cable is 1.86 inches in diameter and weighs 3 pounds per foot. A 4/0 awg cable is 2.31 inches in diameter and weighs 4 pounds per foot.

4.3.2.7 Cutting Bits

A detailed analysis, test, and development program is required to determine the optimum design.

Some design parameters to be considered are as follow:

- Depth of cut: 6 inches.
- Length of cutting tool: approximately 8 inches. This provides a 2-inch clearance between drum body and coal face.
- Angle of cutting tool in relationship to coal surface: +30 degrees to 90 degrees to -30 degrees. See Figure 37.
- Chisel bit cutter design: see Figure 38.
- Carbide bit holder design: see Figure 39.
- Force on individual cutting tool during a 6-inch cut: 15,000 pounds.
- Cutting tool is to be designed for easy replacement.

4.4 AIRBORNE RESPIRABLE DUST GENERATION

Overwhelming evidence from laboratory and in-mine testing is that dust can be reduced by optimizing machine parameters. The most significant parameters are depth of cut, bit spacing, and cutter head speed.

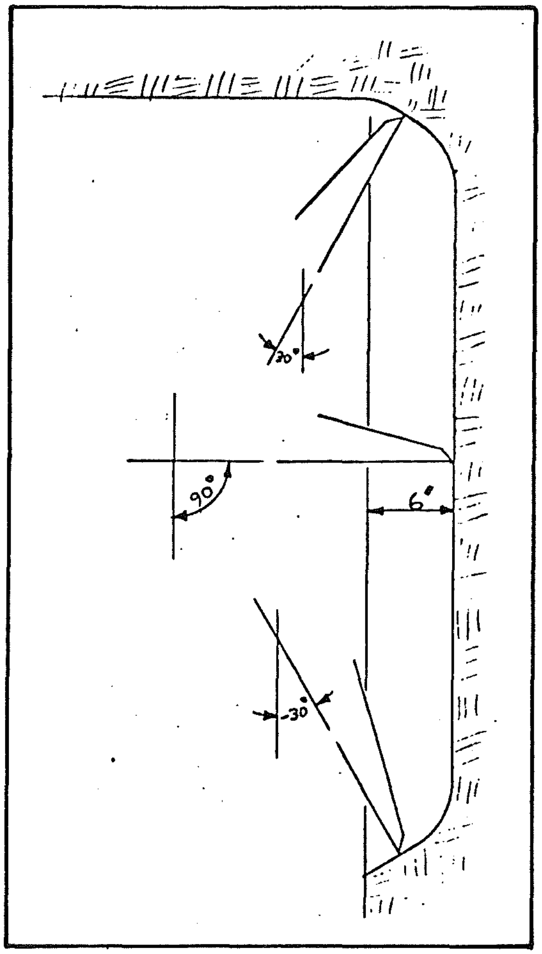


Figure 37 CUTTING ANGLES

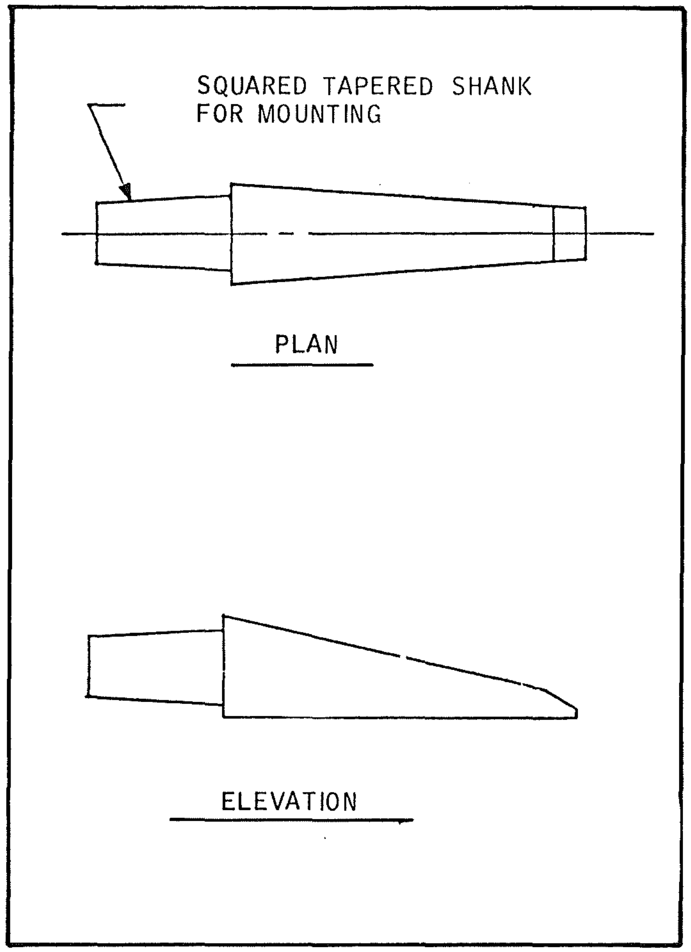


Figure 38 CHISEL-BIT CUTTER DESIGN

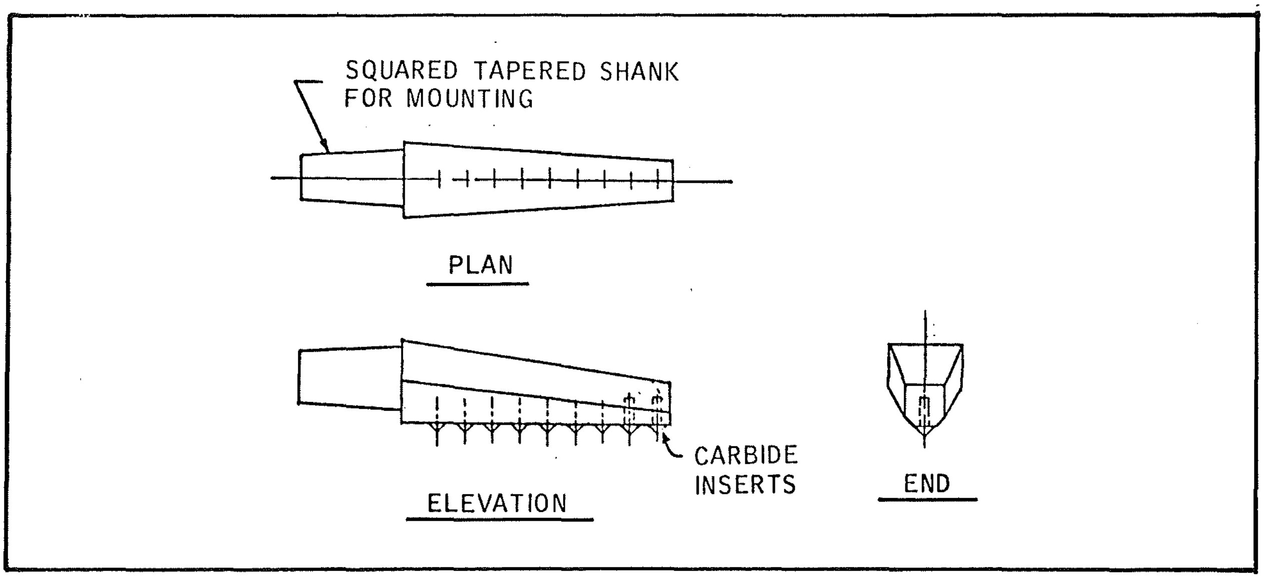


Figure 39 CARBIDE-BIT-HOLDER DESIGN

Following is a comparison of the airborne respirable dust (ARD) generation of a CMM and of two CDLCH concepts, the self-sumping head (SSH) and the linear cutting rotary head (LCRH). This study is based largely on linear cutting tests conducted by the USBM at the Twin Cities Mining Research Center.

From this data and by calculating the total linear distance all bits must travel to remove a given amount of coal, a value for ARD generation due to the cutting process can be established. Dust generated from the process of the bits cutting coal is referred to as primary dust. Additional dust is distributed into the mine environment by regrinding the broken coal between the rotary head and the face, windage due to the rotating drum, falling coal, and the loading process. Dust generated from these processes is called secondary dust. In analyzing the amount of dust due to secondary sources, several assumptions must be made, based on actual in-mine testing. Calculations based on these assumptions result in an approximation of the total dust generated by both secondary and primary sources.

In the process of conducting this study of airborne respirable dust and collecting data on the subject, the following observations were made:

- More data is needed which can associate actual numbers (i.e., total mass of respirable airborne dust per ton, or per minute) to a continuous mining machine.
- A correlation must be established that would relate the dustiness of different coal seams reactive to one another. Data for such a correlation does not now exist.
- The instrumentation, methods, and results of in-mine dust collection studies must be standardized so that reliable conclusions can be made.
- The most reliable information on dust generation to date is laboratory studies[20] using linear cuts and relating dust generation to depth of cut and linear distance of cut. The information from these studies can give theoretical dust generation values, for linear cuts as well as rotary cuts, for the cutting process <u>only</u>. Dust generation due to secondary breakage by falling, loading, regrinding, or fanning action is not accounted for in these studies.

To date, only a few in-mine tests to measure ARD generation of a CMM have been conducted. These tests were conducted in various coal seams under varying conditions and test procedures. Although collected data correlates well within individual tests, collectively it varies widely. For example, in five tests, the mean ARD generation is 5,160 milligrams per ton with a standard deviation of 4,320 milligrams per ton. Table 4 summarizes the results of the five mentioned tests and with some Twin Cities Mining Research Center laboratory and micro-miner data for comparison.

Table 4 SAMPLING CORRELATION

Source	Coal seam	Grinding index	Sampler type(s)	ARD, mg/meter^3	ARD, mg/ton	Type cut	Remarks
TCMRC laboratory data	Illinois Number 6 Pittsburgh	52 to 60 59	B&L optical sampler		176 to 812	Constant 1-inch depth	Calculated values which do not include falling coal, regrinding, gathering arms, or fanning action
	Illinois Number 6 Pittsburgh	52 to 60	B&L optical sampler		591 to 2,664	Calculated rotary	Includes regrinding only from above listing
TCMRC micro-miner	Pittsburgh	59	GCA, SRI		895 to 1,307	60 rpm at 1-inch depth	Short test cycles only may have influenced distribution on low side
TPR 96 Matta	Sewell	100	SRI		290	Rotary at 0.63 inch	Depth of cut calculated from sump rate and volume removed in cutting dry, i.e., no sprays
RRI HO-122039	Pittsburgh	59	Impingers		6,949 to 11,519	Rotary at 1-inch nominal	Nominal depth of cut varied for tests used from 0.83 inch to 1 inch at 51 rpm
RRI HO-122039	Pittsburgh	59	SRI impingers	1 to 3 44 to 60		N/A	Unreduced data; tons were not yet available; cuts were not less than 1 inch deep
CR HO-230031	Lower Freeport	89 to 99	MRE, MSA, impingers, MSA no cyclone		3,950 to 5,904	Rotary long-wall	
CR HO-232061	Upper Elkhorn Number 1	46 to 57	MRE, MSA, MSA + BC pump		512 to 597	Rotary	Depth unknown but would not exceed 1 inch maximum
Jeffrey HO-232060	Pratt	Unknown	MRE, MSA, UNICO		2,599 to 18,994	Rotary	Depth unknown but would not exceed 1 inch maximum

From analysis conducted using laboratory data, some in-mine data, and some assumptions, we calculated 886 milligrams per ton ARD generation for a CMM in Illinois Number 6 coal. This is obviously on the very low side of the in-mine mean. However, we felt that using the laboratory data, a more meaningful comparison can be made between existing machinery and proposed concepts. All comparisons are based on laboratory data and similar assumptions. If any conclusion can be drawn from a comparison of laboratory-based values and actual measured values, it would be that the laboratory values are very conservative approximations of ARD generation.

Table 5 and Figures 40 through 43 summarize the results of this ARD study. The following report sections provide a detailed explanation of how the results were obtained.

Table 5 RESULTS OF DUST STUDY

Factor	Concept		
	CMM	SSH	LCRH
Total ARD generation, mg/ton	886	60	100
Percent reduction	--	93	89
ARD generation, cutting only, mg/ton	798	16	56
Percent reduction	--	98	93
Return air concentration, * mg/meter^3	98.00	3.14	21.00
Theoretical room concentration, mg/meter^3	65.00	2.61	17.60
Average cutting rate, ** tons/minute	3.42	3.41	9.00
Average ARD generation, mg/minute	3,030	204	900
Percent reduction	--	93	70
Peak cutting rate, *** tons/minute	7.5	4.5	18.0
Peak ARD generation, mg/minute	6,679	267	1,800
Percent reduction	--	96	73

*3,000 cubic feet per minute return air flow, brattice 4 feet from rib, 6-foot seam.
**Average cutting rate of miner while performing cutting and noncutting functions.
***Peak cutting rate is rate of cutting only.

4.4.1 Existing CMM Dust Analysis

Because reduction of ARD is one important goal of constant-depth linear cutting, it was necessary to determine the amount of ARD generated by existing continuous mining machines and use this number as a baseline to determine the relative degree of dust generation of the CDLCH concepts.

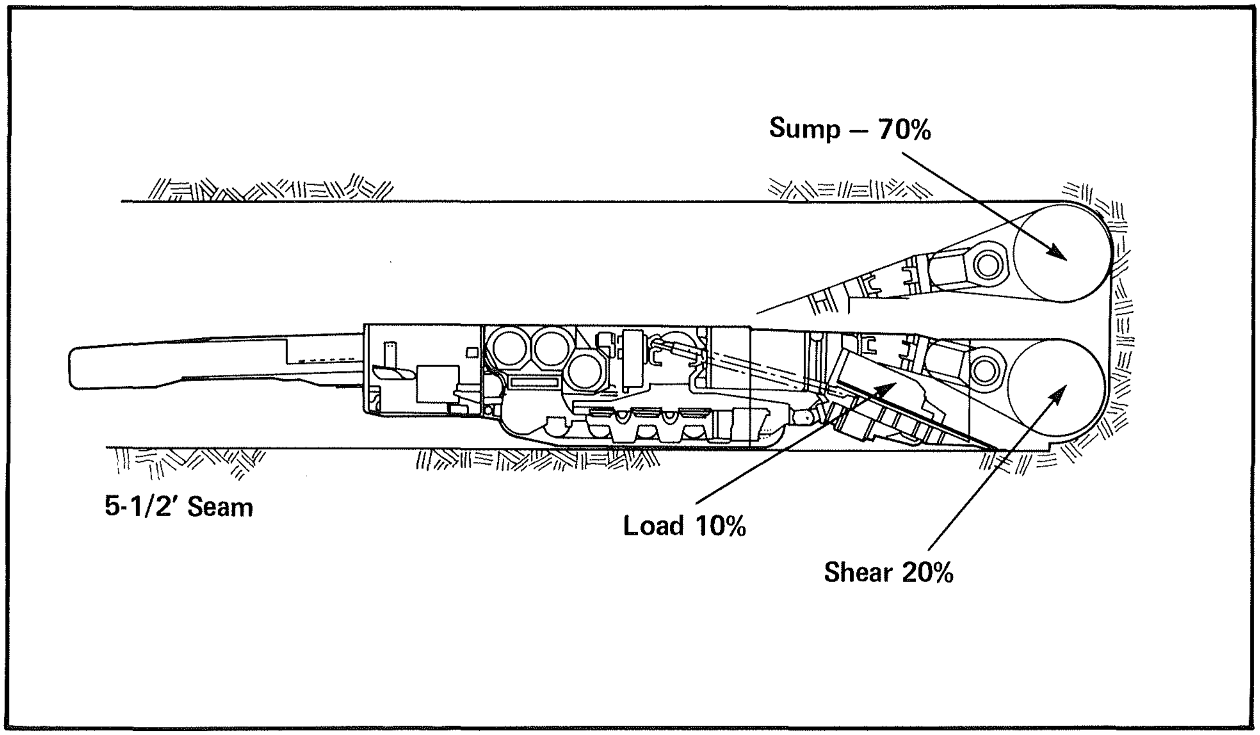


Figure 40 SOURCE OF DUST GENERATION DURING CONTINUOUS MINING MACHINE CUTTING CYCLE

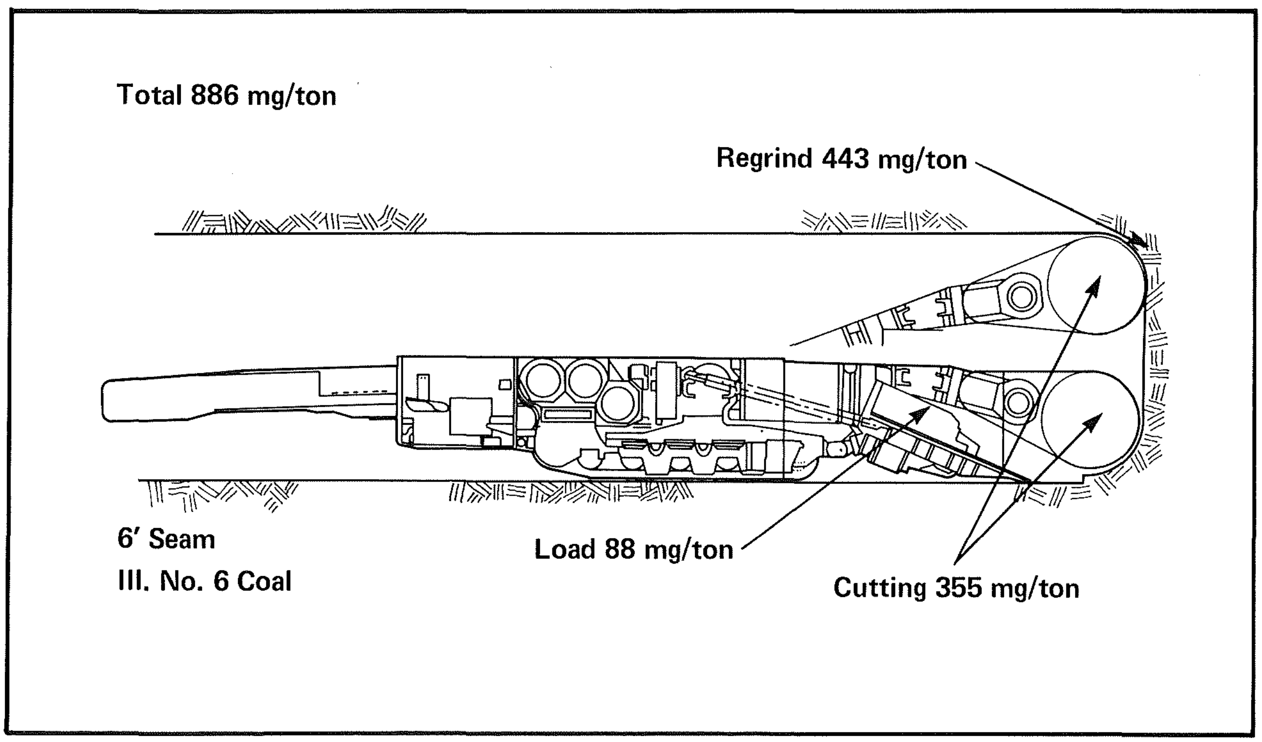


Figure 41 THEORETICAL CONTINUOUS MINING MACHINE DUST PRODUCTION

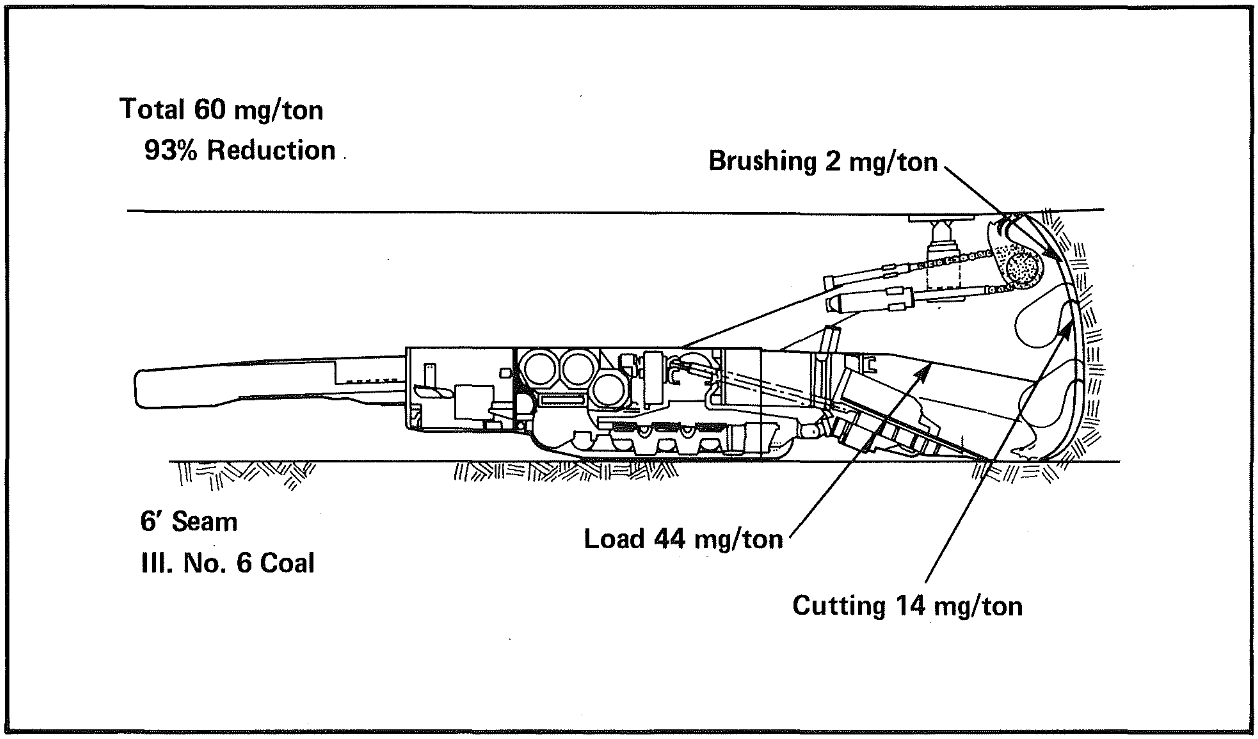


Figure 42 SELF-SUMPING HEAD DUST GENERATION

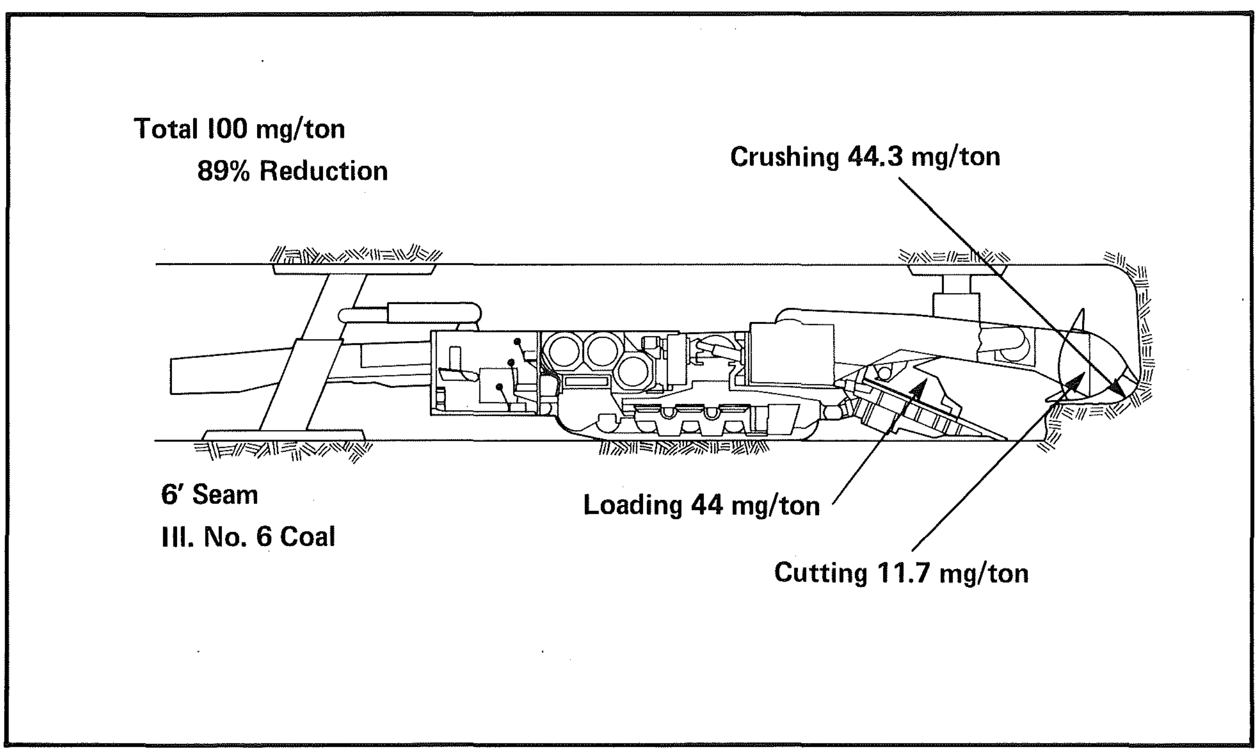


Figure 43 LINEAR CUTTING ROTARY HEAD DUST PRODUCTION

A description of the dust production due to regrinding, fanning, and loading is found in TPR 96.[18] The study found that in a 5 1/2-foot seam, 70 percent of the ARD was generated during sump, while 20 percent was generated during shear, and the remaining 10 percent resulted from loading, falling coal, and gathering.

Because approximately equal amounts of coal were cut in sump and shear, it is necessary to determine which factors contributed to the large difference in ARD production. During the sump cut, the drum comes into contact with the face at one point, and gradually increases the contact area until two entire quadrants of the head are inundated in the coal. That is, at a sump equal to one-half the diameter of the head, each bit must travel 180 degrees of head rotation from entrance to exit of the coal. This condition would certainly leave much time and area for abundant regrind of cut coal. Looking at the shear cut, it can be seen that only one quadrant of the head (90 degrees) would ever be in contact with the coal during a cut. This would leave less area and time for regrinding of broken coal.

Perhaps an even more important consideration is the actual methods of force application in sump and shear. In sumping, the weight of the miner is employed through the tracks to the head. The operator jogs the miner via the the tram controls to control sump. An experienced miner develops a feel for effective tram control during sump. If a CMM weighed 100,000 pounds, it is conceivable that 50,000 pounds of force or more could be applied to the head during sump. In contrast, the shear cut is controlled by the boom cylinders. A constant pressure and cylinder speed dictate the shear cut. Generally, little more than the head weight (say 25,000 pounds) is required to shear down.

In summary, it can be seen that more force is applied to the head, and more head area is in contact with the face during sump than during shear. Because the head rpm and the cutting characteristics of the bits are unchanged during the cutting methods, it is reasonable to conclude that at least a portion of the difference between sump and shear dust generation is due to regrind.

To pursue the regrind question further in an attempt to assign a number or percentage value, three semimathematical techniques are employed in the analysis, to determine how much ARD is generated from regrind and windage.

4.4.1.1 Technique 1

Dust generation breakdown:

- Sump = 70 percent
- Shear = 20 percent
- Load = 10 percent
- Total dust generated = 100 percent.

Assume that equal amounts of coal are cut in sump and shear. It is obvious that some regrind takes place during shear, but if we say that all dust generated in shear is due only to cutting, we can make the following statement:

Dust generation due to cutting only:

- Shear = 20 percent
- Sump = 20 percent
- Load = 10 percent
- Total = 50 percent.

Regrind = 100 percent - 50 percent = 50 percent.

4.4.1.2 Technique 2

The miner used in the TPR 96 study was a Lee-Norse 26H continuous miner. The cutting diameter of the head is 31 inches, and the head speed is 90 rpm. It was calculated that the distance one bit travels while actually cutting sump is 643 inches. In shear this distance is 907 inches. Again assuming that all dust generated in shear is due to cutting only (a conservative assumption), we can create the following expression:

$$\frac{\text{shear cut}}{\text{shear distance}} \qquad \frac{\text{20 percent}}{\text{907 inches}} \qquad \frac{\text{0.022 percent}}{\text{inch}}$$

percentage of dust generated due to cutting only, per inch of cut.

For sump, then:

$$\frac{(0.022)\ \text{percent}}{\text{inches}}$$

= 14.15 percent of total dust generated is due to cutting.

Therefore, 70 percent - 14.15 percent = 55.85 percent of total ARD is due to regrind and windage.

4.4.1.3 Technique 3

Total dust (TD) = 100 percent = sump percentage (PS) + shear percentage (PSH) + load percentage (PL)

TD = 0.7 + 0.2 + 0.1 = 100 percent.

Bit cutting distance percentage:

Length sump = 42 percent = ls

Length shear = 58 percent = lsh.

Regrind = 100 percent - PL - lsPS - lsh PSH

= 100 percent - 10 percent - 42 percent (70 percent) - 58 percent (20 percent)

= 1.0 - 0.1 - 0.42(.7) - 0.58 (0.2) = 0.49

= 49 percent.

The three techniques examined resulted in 50 percent, 55.85 percent, and 49 percent as values for dust generated due to regrind. In continuing this analysis, we will assume that 50 percent of respirable airborne dust genrated during the cutting process is due to regrind. With this established, calculation of the total ARD generated by the CMM can be made with the following laboratory data and assumptions.

Data from the Bureau's Twin Cities linear cutting laboratory test:

- Seam: Illinois Number 6
- Dust production: $1.05 \times 10^8 \mu^3$ of respirable airborne dust per linear cut foot, increasing 17 percent per inch with depth regardless of bit type, angle of attack, space to depth ratio, or volume of coal removed.

Assumptions for a continuous mining machine:

- Number of bits: 88
- Head speed: 60 rpm
- Depth of cut: 1 inch or less
- With a 10-foot head, 3 feet in diameter, double laced with 88 bits and cutting 1-inch maximum depth, the total linear distance traveled by the bits to remove 1 ton of coal will be 2,700 feet.
- Coal mass: 80 pounds per foot.[3]

Multiplying the laboratory dust production rate by the distance the bits travel to cut a ton of coal gives the dust generated by the cutting process only.

$$\text{Dust production} = (2,700)(1.05 \times 10^{8}\mu^{3})$$

$$= 2.83 \times 10 \text{ inches } \frac{\mu^{3}}{\text{ton}} = 355 \text{ milligrams per ton.}$$

As stated earlier in this section and as established by TPR 96, the dust generation distribution when cutting a 5-1/2-foot seam is:

- Sump = 70 percent
- Shear = 20 percent
- Load = 10 percent.

From previous analysis of CMM using linear cutting laboratory data for the Illinois Number 6 coal, we determined that 355 milligrams per ton of ARD would be generated due to cutting. Dust generation breakdown is as follows, on a per-ton basis:

- Cutting = 40 percent = 355 milligrams per ton
- Regrind = 50 percent = 443 milligrams per ton
- Loading = 10 percent = 88 milligrams per ton
- Total = 100 percent = 886 milligrams per ton.

The spread on the results of in-mine dust studies is too great to draw any specific conclusions; however, a comparison can be made. Table 4 is a summary of previous in-mine dust studies involving mining machines.

The generation of ARD varies from a low of 290 milligram per ton to a high of 18,894 milligrams per ton; the mean value is on the high side of the scale. From these initial studies, it would seem that 886 milligrams per ton is a conservative value.

4.4.2 Self-Sumping Head Concept Dust Analysis

The SSH concept can be analyzed in a similar manner, by isolating the individual ARD generators. Because of the nature of the design, regrind does not occur. However, roof, floor, and rib brushing is accomplished by secondary cutting; therefore, a factor of 10 percent is used for ARD production due to brushing. The SSH produces much less ARD due to cutting than a CMM; therefore, less ARD is entrained in the broken coal. A 50-percent reduction in ARD due to loading can be expected for the SSH. Therefore:

- Cutting = 14.0 milligrams per ton
- Brushing = 2.0 milligrams per ton
- Total = 60.0 milligrams per ton.

The reduction of ARD generation, when compared to the CCM, becomes:

$$\text{percentage change} = \frac{886 - 60}{886} \times 100 = 93 \text{ percent.}$$

The conclusions listed above are based on the following assumptions and calculations for the self-sumping head:

- $1.05 \times 10^{8}\ ^{3}$respirable dust is produced at 1-inch depth of cut per linear foot cut (from previously mentioned Bureau laboratory tests).
- The above dust level increases 17 percent per inch depth of cut (established by Bureau laboratory tests).
- Face: 10 feet wide by 6 feet high.

The cutting path is not strictly a straight-box linear cut, but rather an elongated crescent-shaped cut: therefore, the 6-inch path is divided into three sections and analyzed graphically:

Cutting distance per bit = 7.62 feet

For eight bits, total distance = 61 feet.

Figure 44 shows the SSH cutting path, Table 6 lists SSH parameters.

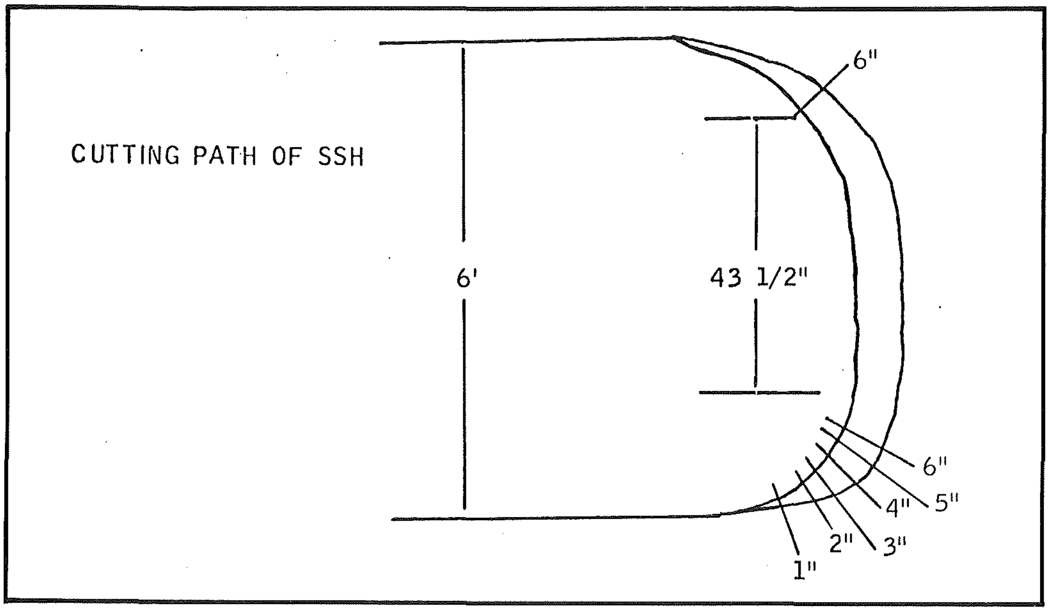


Figure 44 CUTTING PATH OF SELF-SUMPING HEAD CONCEPT

Table 6 SELF-SUMPING HEAD PARAMETERS

Depth of cut, inches	Distance cut, inches	Total distance (8 bits), feet	Dust, μ^3/foot	Total dust, μ^3	Coal cut, tons
0-1	9.0	6.0	1.05×10^8	6.3×10^8	
1-2	4.5	3.0	1.2×10^8	3.7×10^8	
2-3	6.6	4.4	1.4×10^8	6.2×10^8	
3-4	12.0	8.0	1.6×10^8	1.3×10^9	
4-5	9.0	6.0	1.9×10^8	1.1×10^9	
5-6	12.6	8.4	2.2×10^8	1.8×10^9	
6	45.0	30.0	2.3×10^8	6.9×10^9	
Total				1.3×10^{10}	1.15

$1.3 \times 10^{10} \mu^3$ respirable dust per cut = $\frac{.014 \text{ gram}}{\text{ton}}$ = 14 milligrams per ton, cutting only.

4.4.3 <u>LCRH Concept Dust Analysis</u>

No analytical or experimental method is available to determine the secondary dust generation that may exist with the LCRH concept. Only an intuitive approach can be used, and such an attempt will be geared toward presenting the most conservative approximation that is close to the in-mine conditions. In the CMM theoretical case, it was determined that regrind was responsible for 50 percent of the dust generation during cutting, or 433 milligrams per ton for Illinois No. 6 coal. We intuitively tried to explain the regrind phenomenon by examining the cutting action of a rotary head. Regrind as such does not occur with this concept, but some crushing is evident.

Figure 45 shows the cutting sequence of the proposed LCRH concept. Number 1 is the first cut and so on to Number 12, the final cut.

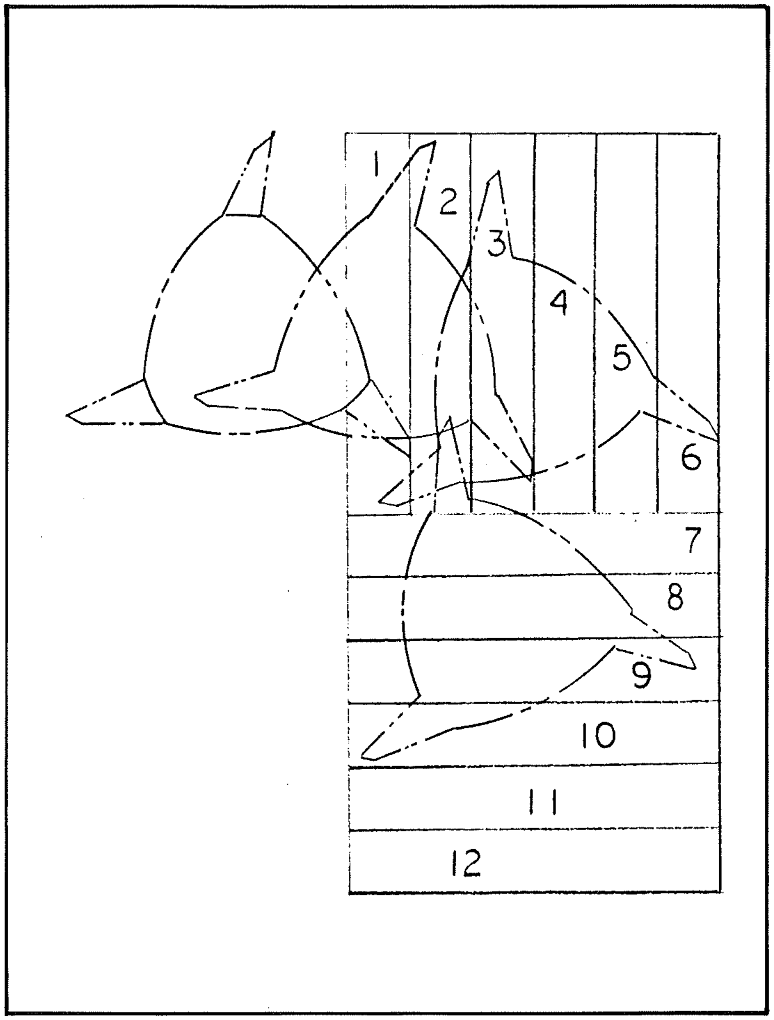


Figure 45 CUTTING PATH OF LCRH CONCEPT

Secondary crushing does not appear as a problem until Cut 4 when the clearance between the head and face is small enough to cause crushing of the trapped broken coal.

This crushing increases in Cuts 5 and 6. Cuts 7 through 12 incur no crushing because no headface interference takes place. Crushing will not produce the severe dust geneneration of regrind, and will not be fanned by a fast-rotating head. We estimate, therefore, that the dust due to secondary crushing will be approximately 10 percent of that produced by a CMM by regrinding.

Figure 46 is a comparison of the difference in cutting between a CMM and the LCRH.

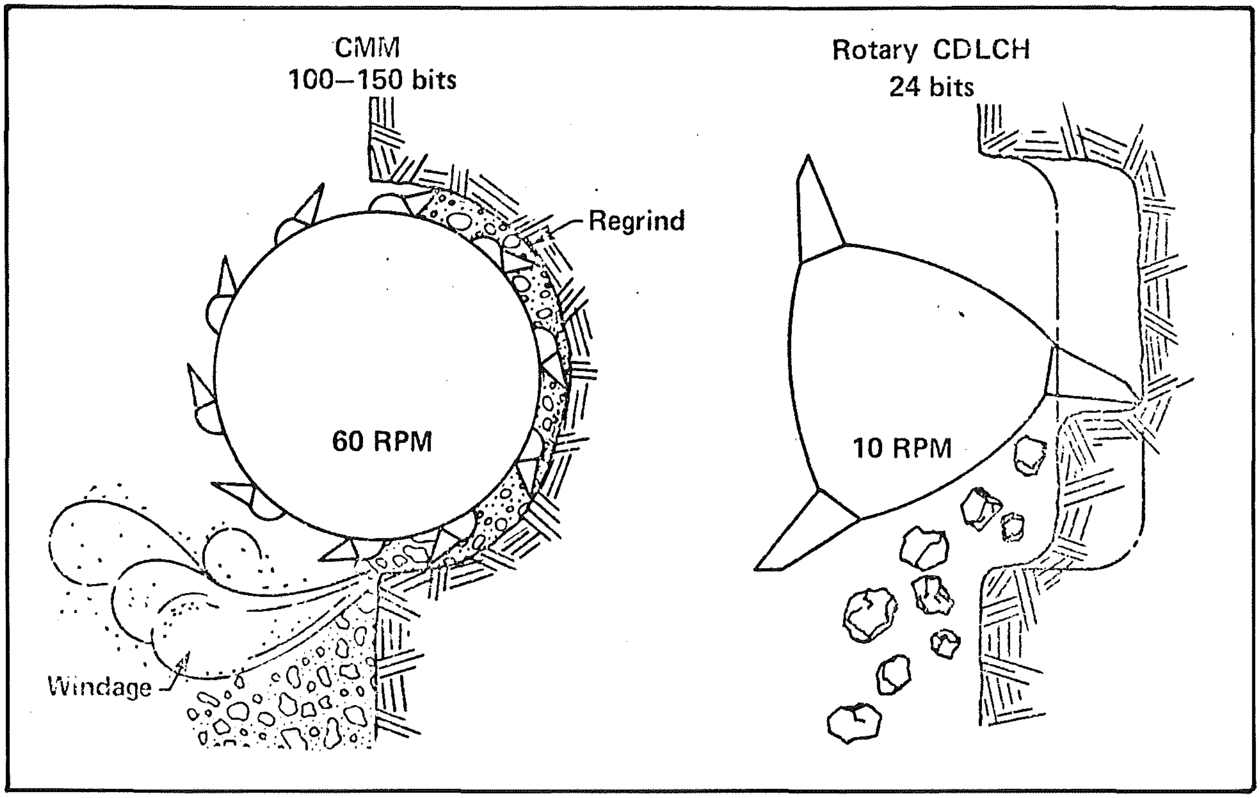


Figure 46 COMPARISON OF DUST GENERATED BY CMM AND LCRH

Total projected dust production is as follows:

- Cutting = 11.7 milligrams per ton
- Crushing = 44.3 milligrams per ton
- Loading = 44.0 milligrams per ton
- Total = 100.0 milligrams per ton

Percent change $= \frac{886 - 100}{886} \times 100 = 89$ percent reduction in ARD generation when compared to the CMM.

The LCRH concept dust production is based on the linear cutting test on Illinois Number 6 coal, given the following:

- $1.05 \times 10^8 \mu^3$ of airborne respirable dust (ARD) is produced at 1-inch depth of cut per linear foot cut; this value increases 17 percent per inch depth of cut increase, based on previously mentioned Bureau laboratory tests.
- The LCRH concept removes 7.2 tons of coal per cutting cycle at a depth of cut of 6 inches (refer to Section 5.2.2 for details).

- The total distance each bit travels per cycle is 36 feet. For eight cutting bits, this distance is 288 feet.
- For a 6-inch cut, dust generation per linear foot is $2.3 \times 10^8 \mu^3$.

Total dust generated due to cutting:

$$(2.3 \times 10^8 \frac{\mu^3}{\text{foot}}) (288 \text{ feet}) = 6.62 \times 10^{8\ 3}$$

$$\text{or} \quad \frac{6.62 \times 10^{10} \mu^3}{7.2 \text{ tons}} = 9.2 \times 10^9 \frac{\mu^3}{\text{ton}} \text{ or } 11.7 \text{ milligrams per ton.}$$

4.4.4 Dust Due to Cutting Only

It is evident that if secondary dust generation due to loading could be eliminated in the SSH and LCRH concepts, nearly all ARD generation would be eliminated. Considering the cutting process only:

• CMM	Cutting	=	355 milligrams per ton
	Regrind	=	443 milligrams per ton
	Total	=	798 milligrams per ton.
• SSH	Cutting	=	14 milligrams per ton
	Brushing	=	2 milligrams per ton
	Total	=	16 milligrams per ton.
• LCRH	Cutting	=	11.7 milligrams per ton
	Crushing	=	44.3 milligrams per ton
	Total	=	56.0 milligrams per ton.

- SSH percent change $= \frac{798 - 16}{798} \times 100 = 98$ percent reduction in ARD generation due to cutting.
- LCRH percent change $= \frac{798 - 56}{798} \times 100 = 93$ percent reduction in ARD generation due to cutting.

4.4.5 Peak ARD

A factor worthy of discussion is peak ARD generation. Multiplying the peak cutting rate of a machine by dust generation per ton will give peak ARD generation per minute. Table 7 tabulates these values.

Table 7 PEAK AIRBORNE RESPIRABLE DUST GENERATION PER MINUTE

Concept	Dust generation, milligrams per ton	Peak cutting rate, tons per minute	Peak dust generation, milligrams per minute	Percent reduction
CMM	886	7.53	6,679	--
SSH	60	4.46	267	96
Second generation	100	18.00	1,800	73

4.4.6 Concentration

A final comparison might be beneficial in relating dust generation by a given machine and how it relates to a mine environment. Consider a sealed room 6 feet high, 20 feet wide, and 30 feet long, a room large enough to house a coninuous miner. Evenly distribute peak ARD generation for 1 minute in the room, and the comparison of Table 8 results.

Table 8 DUST CONCENTRATION

Miner	Dust generation, mg/meter^3	Coal mined, tons
CMM	65.00	7.5
SSH	2.61	4.5
LCRH	17.60	18.0

4.5 COMPARISON OF LINEAR CUTTING ROTARY HEAD WITH DEEP-CUTTING CONTINUOUS MINING MACHINE

The USBM is testing a deep-cutting continuous miner (Contract H0122039). This machine, capable of cutting at three speeds, is powered by 450 horsepower at the head. A sumping rig (similar to that of the LCRH) is incorporated in aiding the sump, and the shear is facilitated by use of shear jacks that react against the roof.

With the exception of the head and related gear train, the deep-cutting CMM and the LCRH are basically in the same total weight, size, and horsepower range. Table 9 presents a physical and performance comparison of the two machines. The LCRH head speed was set at 25 rpm so that it could be compared at the same horsepower as the deep-cutting CMM. In looking at peak cutting rate, the LCRH shows 22.7 tons per minute compared to 8.4 tons per minute for the deep-cutting CMM.

It should be noted here that the deep-cutting CMM was limited by the amount of coal it could haul away from the face, and that a more efficient haulage system could very well increase its capabilities of moving coal.

The test program of the deep-cutting CMM has concluded that for 3-inch depth of cut, a 4-inch bit spacing was most efficient for coal breakout and power reruirements. In contrast, the LCRH bit spacing is 6 to 9 inches (the optimum bit spacing is two to three times depth of cut), thus reducing bit maintenance and power requirements.

The LCRH will cut at a deep constant depth with a coal breakout angle between bits that enables the concept to take advantage of optimum spacing.

ARD was calculated for both the deep-cutting CMM and the LCRH using laboratory data from linear cutting tests conducted at the Bureau's Twin Cities Mining Research Center. Actual data from in-mine test is available for the deep-cutting CMM, and is shown in Table 9.

Table 9 IN-MINE DUST GENERATION TEST DATA, DEEP-CUTTING CMM

Factor	LCRH	Deep-Cutting CMM
Depth of cut (inches)	3	3
Weight (pounds)	130,000	130,000
Length (feet)	35	35
Head width (feet)	10.33	10.33
Head speed (rpm)	25	9, 18, and 51
Torque (foot-pounds)	55,000	116,000***
Power (hp)	450	450
Peak cutting rate (tons per minute)	22.7	8.4
ARD generation (calculated) (mg/ton)	113*	273*
ARD generation (actual) (mg/ton)	--	3,300**
Number of bits	14	30
Bit spacing (inches)	9	4

*Average value 2- to 3-1/2-inch depth of cut, all speeds.
**Calculated from TCMRC linear cutting tests.
***HO-122039 draft final report, maximum torque.

It is obvious from the table that a wide discrepancy exists between the calulated data and the actual measured data. Until some correlation is made between laboratory data and in-mine data, only general comparisons can be made. In the laboratory data, the LCRH shows a 58-percent reduction in ARD over the deep-cuting CMM, and if this ratio remains true for in-mine tests, the deep-cutting CMM would generate 3,300 milligrams per ton and the LCRH 1,914 milligrams per ton ARD. The difference in ARD generation between the two machines is caused by regrind and additional bits inherent with the deep-cutting CMM.

4.6 ANALYSIS OF POWER REQUIREMENTS AND ARD GENERATION FOR LCRH AND CMM AT 3-INCH DEPTH OF CUT

Much of the CDLH concept engineering in the early stages of the contract involved bits that cut 6 inches deep. In the concluding phases of the program, there appeared to be some advantages in designing an LCRH machine that would cut only 3 inches deep. The cutter head forces would be reduced and the resulting LCRH miner would be improved in the following ways:

- The cutter head power train would be lighter because of reduced torque demands.
- The electric cutter head motors would be standard off-the-shelf units used on existing continuous miners.
- The sump jack unit at the back of the miner could be eliminated.
- The machine would be easier to maneuver.
- High levels of production would continue to be excellent.
- ARD reduction would continue to be excellent.

The following is an analysis of the power requirements and ARD generation levels for an LCRH miner and deep-cutting CMM with a 3-inch depth of cut. The 3-inch depth was choosen because actual force data is available to make a preliminary evaluation of the power necessary to cut to such a depth. As previously discussed, the force necessary to cut to 6 inches has been extrapolated from force data taken from shallower cuts. This analysis is based on a mean cutting force of 2,700 pounds derived from Twin Cities tests that used a point-attack bit cutting 3-inches deep in Wyoming seam coal.

Table 10 is a summary of the analysis showing comparisons for various cutting head speeds for LCRH and two versions of a CMM.

Table 10 POWER REQUIREMENTS AND ARD GENERATION, LCRH, CMM(TH), AND CMM(A)

Miner	Head speed, rpm	Power, hp/hour	Peak cutting, tons/minute	Peak ARD mg/minute	Sump rate, inches/second	Specific energy, tons/hp
LCRH	10	177	9.0	1,017	1.50	0.050
CMM(A)	10	99	3.3	1,419	0.50	0.033
CMM(TH)	10	46	3.3	710	0.50	0.070
LCRH	20	355	18.0	2,034	2.25	0.050
CMM(A)	20	198	6.6	2,838	1.00	0.033
CMM(TH)	20	92	6.6	1,419	1.00	0.070
LCRH	25	450	22.7	2,565	3.79	0.050
CMM(A)	25	247	8.3	3,569	1.25	0.033
CMM(TH)	25	115	8.3	1,784	1.25	0.070
LCRH	30	533	27.0	3,051	4.50	0.050
CMM(A)	30	297	9.9	4,257	1.50	0.033
CMM(TH)	30	138	9.9	2,128	1.50	0.070
LCRH	40	710	36.0	4,068	6.00	0.050
CMM(A)	40	396	13.3	5,719	2.00	0.033
CMM(TH)	40	184	13.3	2,860	2.00	0.070
LCRH	50	888	45.0	5,085	7.50	0.050
CMM(A)	50	495	16.6	7,138	2.50	0.033
CMM(TH)	50	277	16.6	4,278	2.50	0.070
LCRH	60	1,066	54.0	6,102	9.00	0.050
CMM(A)	60	594	19.9	8,557	3.00	0.033
CMM(TH)	60	277	19.9	4,278	3.00	0.070
LCRH	7-1/3	132	6.6	746	0.80	ARD generation, mg/ton: LCRH = 113 CMM(A) = 430 CMM(TH) = 215
CMM(A)	20	198	6.6	2,838	1.00	
CMM(TH)	20	92	6.6	1,419	1.00	

Depth of cut 3 inches. Wyoming seam coal.

The two versions of the CMM are labeled CMM(TH) for CMM theorectical case and CMM(A) for CMM actual case. The CMM(TH) is based on an optimum bit spacing of 9 inches for 3-inch depth of cut). Although recent underground testing indicates that optimum bit spacing is not obtainable because of the nature of the rotary cut, it is included for comparison.

It is a very effective tool in comparing specific energy (tons of coal cut per horsepower input) and graphically shows the benefit on specific energy of cutting with optimum bit spacing. The CMM(A) case is based on the actual bit configuration chosen to be most efficient in the underground testing program of the deep-cutting CMM. Twenty-eight bits are used (not conidering side-cutting bits), single laced around the drum and spaced at at 4 inches.

It should be noted that in other sections of this report ARD was calculated by considering a sump and shear cut, whereas only the sump cut is considered here. By considering the sump cut only, difference between cutting patterns does not influence the analysis, and the peak cutting capacity of the machine can be calculated. In addition, the sump cut is the dustiest cut and this is reflected in the ARD figures. The horsepower figures shown in the table include a 60-percent efficiency from prime mover to cutting head. The peak cutting rate and the peak ARD rate are calculated from the sump cut only.

The horsepower figures were calculated by using a 2,700-pound force on each bit sumped at maximum depth of 3 inches. The LCRH uses 14 bits, so total force required is (14)(2,700) = 37,800 pounds. The CMM(TH) uses 14 bits, single laced; therefore, only seven bits are in contact with the face at any time. The total cutting force is calculated by assuming one bit is at maximum depth, 3 inches, one bit is at zero depth, and the remaining five bits are equally stepped at intermediate depths from 0 to 3 inches. The forces are then factored relative to each bit depth, and the sum of the forces is calculated. The total force that the CMM(TH) head must deliver is 9,450 pounds. The same procedure is used in calculating horsepower for the CMM(A), except that 28 bits must be considered, or 14 interacting with the face at any time. Total head force to cut coal for the CMM(A) is 20,244 pounds.

In Table 11 it can be seen that for a given rpm the LCRH requires approximately 44 percent more horsepower than does the CMM(A) but produces nearly three times as much coal and generates 28 percent less ARD. The CMM(TH) produces the same amount of coal as the CMM(A) and reduces dust by 50 percent. The CMM(TH) uses 74 percent less power than the LCRH and 53 percent less than the CMM(A). This is directly reflected in the specific energy values.

Table 11 COMPARISON OF HORSEPOWER REQUIREMENTS AT 20 RPM

	Power (hp)	Percent difference	Peak cutting (tons/min.)	Peak ARD (mg/min.)	Percent difference	Specific energy (tons/hp)
LCRH	355	--	18.0	2,034	--	0.050
CMM(A)	198	-44	6.6	2,838	+28	0.033
CMM(TH)	92	-74	6.6	1,419	-30	0.070

The optimum cutting parameters for the LCRH, for 3-inch depth of cut, are 20 to 25 rpm involving 355 to 450 horsepower. At 25 rpm (Table 12), the LCRH would produce 22.7 tons of coal per minute and generate 2,565 milligrams per minute of ARD. If the CMM(A) or CMM(TH) matched this output, they would have to operate at 60-plus rpm. This high rpm increases ARD dispersion by fanning, and substantially increases the hazard of methane ignition due to the faster bit speed. At this rate, the CMM(A) would require 32 percent more power and generate 233 percent more ARD. Even using the theorectical model, the CMM(TH) shows a 66-percent increase in ARD generation and only a 38-percent reduction in power over the LCRH.

Table 12 COMPARISON OF DUST GENERATION AT 20-PLUS TONS PER MINUTE

	Head speed (rpm)	Power (hp)	Percent difference	Peak ARD (mg/min.)	Percent difference
LCRH	25	450	--	2,565	
CMM(A)	60	594	+32	8,557	+233
CMM(TH)	60	277	-38	4,278	+66

If a particular mine has a serious dust problem, an LCRH will reduce dust and maintain a high production rate. For example, by operating an LCRH at 10 rpm (Table 13) it could still produce coal at a rate of 9 tons per minute. For a CMM(A) to produce an equivalent amount of coal,

Table 13 COMPARISON OF DUST GENERATION AT 9 TONS PER MINUTE

	Head speed (rpm)	Power (hp)	Percent difference	Peak ARD (mg/min.)	Percent difference
LCRH	10	177	--	1,017	--
CMM(A)	30	297	+67	4,257	+318
CMM(TH)	30	138	-22	2,128	109

it would have to operate at 30 rpm, require 67 percent more power, and produce 318 percent more ARD. Conversely, if dust were not a problem, an LCRH could operate at 25 rpm and cut 22.7 tons per minute. As stated before, the CMM(A) would need 32 percent more power and produce 233 percent more ARD for an equivalent production rate.

Another comparison worthy of discussion involves automated continuous miner/bolters capable of taking very long lifts or operating in a truly continuous manner. If such a miner could cut at a rate comparable to existing machines (6 or 7 tons per minute) continuously over long lifts, productivity would be substantially increased. Therefore, using an existing CMM as an automated miner/bolter would increase productivity without the need for increasing the cutting capabilities of the machine.

Table 14 is a comparison of the LCRH, the CMM(A), and the CMM(YH) and an added machine, an existing CMM, CMM(E), cutting at 6 to 7 tons per minute. The existing CMM will be considered as cutting 1 inch deep with 300 horsepower available at the head. A value of 886 milligrams per ton ARD generation will be used as calculated from the ARD study in Section 4.4. The peak cutting rate is calculated from a sump rate of 1 inch per second at 60 rpm. Peak cutting rate is, therefore, 6.2 tons per minute.

Table 14 COMPARISON OF DUST GENERATION AT 6 TO 7 TONS PER MINUTE

	Depth of cut (inches)	Head speed (rpm)	Power (hp)	Percent difference	Peak ARD (mg/min.)	Percent difference	Peak cutting (tons/min.)
LCRH	3	7-1/3	132	-56	746	--	6.6
CMM(A)	3	20	198	-34	2,838	+280	6.6
CMM(TH)	3	20	92	-69	1,419	+90	6.6
CMM(E)	1	60	300	--	5,493	+636	6.2

Table 14 shows that the LCRH can cut 6.6 tons per minute with only 132 horsepower, 56 percent less than that of an existing machine and 33 percent less than the CMM(A). In addition, the LCRH drum rotates at 7-1/3 rpm and generates only 746 milligrams per minute of ARD. The CMM(A) produces 280 percent more ARD, the CMM(TH) produces 90 percent more ARD, and the CMM(E) produces 636 percent more ARD than the LCRH.

4.7 NOISE

In a noise survey, the USBM found that the critical noise levels for a continuous miner occurred during the cut and load cycle with a mean level of 97 dBA. The range of noise was 89 to 107 dBA for cutting and loading.

The major noise generator of a CMM is the gathering and conveying system. If the noise level of these components could be reduced by use of a new concept, it is conceivable that with the reduced number of bits (LCRH and SSH) and the reduction of gearing (SSH), overall noise reduction could be achieved. At this stage of development, however, no positive statement or prediction can be made concerning noise levels.

4.8 VENTILATION

The law requires that 3,000 cubic feet per minute of air be supplied to the face, and that this air be controlled either by tubing or brattice cloth maintained within 10 feet of the face. This requirement applies to both a CMM mining system and a CDLCH mining system. The use of secondary ventilation such as suction fans and scrubbers employed by some CMMs will not be necessary with the CDLCH concepts.

V. ECONOMIC FEASIBILITY STUDY

The economic feasibility study conducted during the CDLCH project also resulted in an investigation of the production potential of each recommended concept and a Gantt chart study of the on-shift capabilities of the linear cutting rotary head. This material is presented in the following order:

- Base production potential study
- Gantt productivity study
- Concept capital investment cost.

5.1 BASE PRODUCTION POTENTIAL STUDY

Production studies from in-house reports were examined, and a base production comparison was made.

The following material is extracted from "The development of a miner/ bolter system, modification #3," FMC, April 1975.

Standard data: tramming rate = 35 fpm forward.

Note: Because the CDLCH concepts perform essentially the same functions as a CMM miner, only production comparisons are made. That is, the actual physical ability of the machine to remove and load coal is compared with that of existing machines. It is not anticipated that the self-sumping head (SSH) concept will require mine plans and ancillary equipment modifications. The mining rate (tons per minute) of the linear cutting rotary head (LCRH) concept, when cutting at 6-inch depth, has been increased to the point that a new high-capacity coal gathering system and conveyor must be designed to match the cutting rate. Also the size and bulk of the miner will make maneuvering difficult unless the crosscuts are turned at some angle less than 90 degrees. However, at 3-inch depth of cut, this bulk can be reduced and the sumping rig eliminated, giving the LCRH the same maneuverability as an existing CMM.

The load cycle (Joy 12CM continuous miner) is summarized in Table 15.

Table 15 SUMMARY - LOAD CYCLE (JOY 12CM CONTINUOUS MINER)

Function	Description		Time (seconds)	Time (minutes)
Load	Step 1	Sump at 1.5 inches per second 23.2 inches	15.5	
	Step 2	Shear down 34 inches at 1.5 inches per second (38 inches cutter O.D.)	22.7	
	Step 3	Brush floor (remove cusps) at 2 inches per second 23.2 inches	11.6	
	Total		49.8	0.8
Cleanup				0.3
Return				0.3
Total Cycle assuming 10-foot head, 6-foot seam, 2-foot sump			84.0	1.4
Total coal per cycle = (10)(6)(2)(80) = 4.8 tons, or 3.42 tons per minute				

Operator reaction time has not been considered.

Table 16 includes time study report data gathered by FMC and other mining-oriented companies from actual in-mine studies.

Table 16 TIME STUDY REPORT DATA

Number of Shifts	Mining Time (minutes)
4	143.0
4	140.0
4	143.2
3	135.0
6	142.0
5	129.0
4	142.0
11	127.3
6	117.9
8	135.0
Total	1,354.4
Average 136 minutes actual mining time per shift	

Mine studies have shown that of the total time available to mine coal, only a small percentage is effectively used. Not all delays are caused by the continuous miner; and with this in mind, it is reasonable to expect similar available mining time with the CDLCH. However, some maintenance time can be eliminated on the CDLCH with respect to changing bits, as discussed in a subsequent subsection.

5.2 CONCEPT PRODUCTION POTENTIAL

The production analysis for each concept is standardized so that all concepts can be evaluated on equal terms. This standardization is as closely matched as possible to that used on the base production miner (Joy 12CM) discussed earlier in this section. The following criteria apply to all concepts:

- Seam: 6 feet
- Sump: 1 inch to 3 inches per second
- Shear: 3 inches to 12 inches per second
- Head width: 10 feet to 11 feet.

In addition, function times are determined by component speeds, and operators' reaction times are not considered.

5.2.1 SSH Concept Cutting Cycle and Production Potential

- Tram: 35 feet per minute
- Maximum rotation of head: 216 degrees
- Head cylinder speed: 11.6 inches per second.

Activity times are shown in Table 17.

Table 17 ACTIVITY TIMES

Activity		Time (seconds)
Start (set at face ready to proceed)		
Sequential sumping of head +73 degrees	Segment 1, 2 bits	1.09
	Segment 2, 2 bits	1.09
	Segment 3, 2 bits	1.09
	Segment 4, 2 bits	1.09
Shear down 30 inches at 12 inches per second		2.50
Sequential rotation of head +143 degrees	Segment 1	2.15
	Segment 2	2.15
	Segment 3	2.15
	Segment 4	2.15
Raise boom and rotate head -216 degrees		4.00
Tram forward 6 inches		0.85
Total		20.31

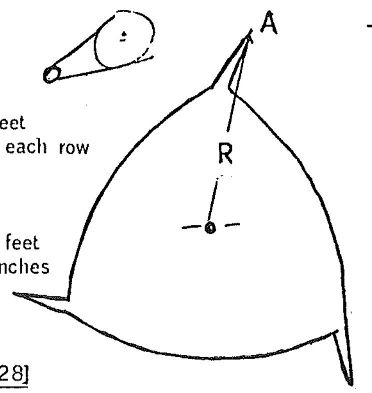
Total coal cut per cycle: 2,310 pounds or 1.15 tons

Mining rate: $\frac{(60 \text{ seconds})\ 1.15 \text{ tons}}{20.31 \text{ seconds (1 minute)}}$ 3.41 tons per minute

For 136-minute shift: 464 tons per shift; for 148-minute shift: 505 tons per shift

5.2.2 LCRH Concept Cutting Cycle and Production Potential

Figure 47 illustrates the LCRH concept cutting cycle and production potential.



Let: R = 18 inches
W head length = 10 feet
N (number of bits) 8 each row or 3(8) = 24 total

RPM = 10
Seam height = 4R = 6 feet
d (depth of cut) = 6 inches

Velocity of Point A

$$V_A = RW = \frac{[18][10][628]}{[60]} \quad [IN]\left[\frac{REN}{MIN}\right]\left[\frac{RAd}{RW}\right]\left[\frac{Min}{Sec}\right]$$

= 18.84 inches/second

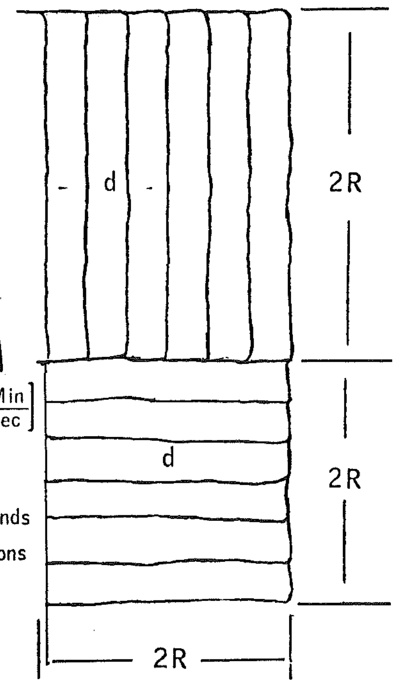
= 18 inches/second

Time to remove (10 feet X 6 feet + 3 feet) = (2)(12) = 24 seconds

Total coal removed = 180 cubic feet = 14,400 pounds = 7.2 tons

Production

$$\frac{72}{24/60} = 18 \text{ tons per minute}$$



Cycle	Time (seconds)
• Start at face, chocks set ready to sump	0
• Sump in 3 feet	12
• Shear down	12
• Lift boom tram back 3 feet	7
• Lower and lift chocks	5
• Tram forward 3 feet	7
• Set chocks	5
	48

Total tons cut = 7.2
Total time = 48 seconds

Production potential

$$\frac{7.2}{48/60} = \frac{9 \text{ tons}}{\text{minute}}$$

For 136-minute shift: 1,224 tons/shift

Bit change ratio

Number of bits = 30 $\quad \frac{30}{150}(13.1) = 2.62 \quad 3$ minutes.

Subtracting 3 minutes from 13.1 gives a saving of 10 minutes/shift

Second-generation-concept shift = 146 minutes

Therefore: 1,,314 tons/shift production potential

Figure 47 LCRH CONCEPT PRODUCTION POTENTIAL

5.2.3 Production Potential Summary

Table 18 summarizes production potential. The CMM and the SSH concepts are so close in mining rate (tons per minute) that they can be considered equal in production potential. The SSH miner provides a small advantage over the CMM because of the 12 minutes extra time available for each shift. The reason the SSH and the LCRH concepts have more time available per shift is that, due to the reduced number of bits (10 for the SSH and 30 for the LCRH), maintenance and bit replacement time reduced.

Table 18 PRODUCTION POTENTIAL

Miner	Average cutting, tons/minute	Peak cutting, tons/minute	Available time, minutes/shift	Tons per shift
CMM	3.42	7.5	136	480
SSH	3.41	4.5	148	505
LCRH	9.00	18.0	146	1,314

FMC conducted an extensive in-mine study involving 274 shifts in an attempt to isolate continuous mining machine delays and time duration. Three makes of mining machines were included in this study. Of primary interest here is the time delays related to bits and associated problems. According to the data gathered, 13.1 minutes per shift is the average delay time due to bits. However, in many cases bits are changed during other delays, and times for these changes are not reflected in the average. It appears from the data that if no significant delays occurred during a shift, at least 20 minutes per shift would be devoted to bit maintenance.

It has also been found that a complete bit change occurs once a week; that is, within a 1-week time, it can be expected that all the bits on a rotary head will have been changed. If the rotary head contains 150 bits, and the bits cost $2 each, $300 dollars a week is used to purchase bits.

The CDLCH concepts provide a drastic reduction in number of bits; however, the bits are generally of a specialized nature and are subjected to higher stresses than conventional bits. At this stage, no concrete claims involving reduced maintenance time for the CDLCH concept can be made. For comparison, it might be said that maintenance time could be reduced by the bit ratio of the two machines. The maintenance time for the SSH bits is equal to 10/50 times 13.1 minutes which is 0.87 minute per shift. Because the LCRH concept uses 30 bits, or a 30/150 ratio, the bit maintenance time per shift is 3 minutes.

Delay time due to actual dust control could not be determined from FMC data or other available data. In other words, it does not appear to be common practice to delay the mining operation due to high dust levels. Because dust monitors worn by miners are not instantaneously analyzed, there is no system to indicate that dust levels are above standards until after the fact.

In reviewing the data on time delays, very minimal time is spent on dust control devices such as water spray and exhaust systems. It appears that if malfunctions occur with these devices, they are dealt with during a convenient break or shutdown.

It does not seem likely that a significant difference in delay time due to dust control can be inferred for the CDLCH in comparison with an existing miner.

5.3 GANTT PRODUCTIVITY STUDY

A comparison study of the productivity potential of a standard CMM and the LCRH concept was performed. A mine plan was set up (Figure 48) to duplicate as nearly as possible a real mine situation. To enhance the reliability of the comparison, the mining cycle was made as identical as possible for the two machines.

The CMM mining cycle utilizes two Joy 16SC 5-ton-capacity shuttle cars. The CCM cutting cycle is as follows:

- 1, Sump
- 2, Shear
- 3, Remove cusp
- 4, Shuttle car leaves
- 5, Return to face-ready
- 6, Sump
- 7, Shear
- 8, Remove cusp
- 9, Shuttle car leaves

- 10, Cleanup (back tram, raise gathering table)
- 11, Cleanup (drop gathering table, tram forward)
- 12, Return to face.

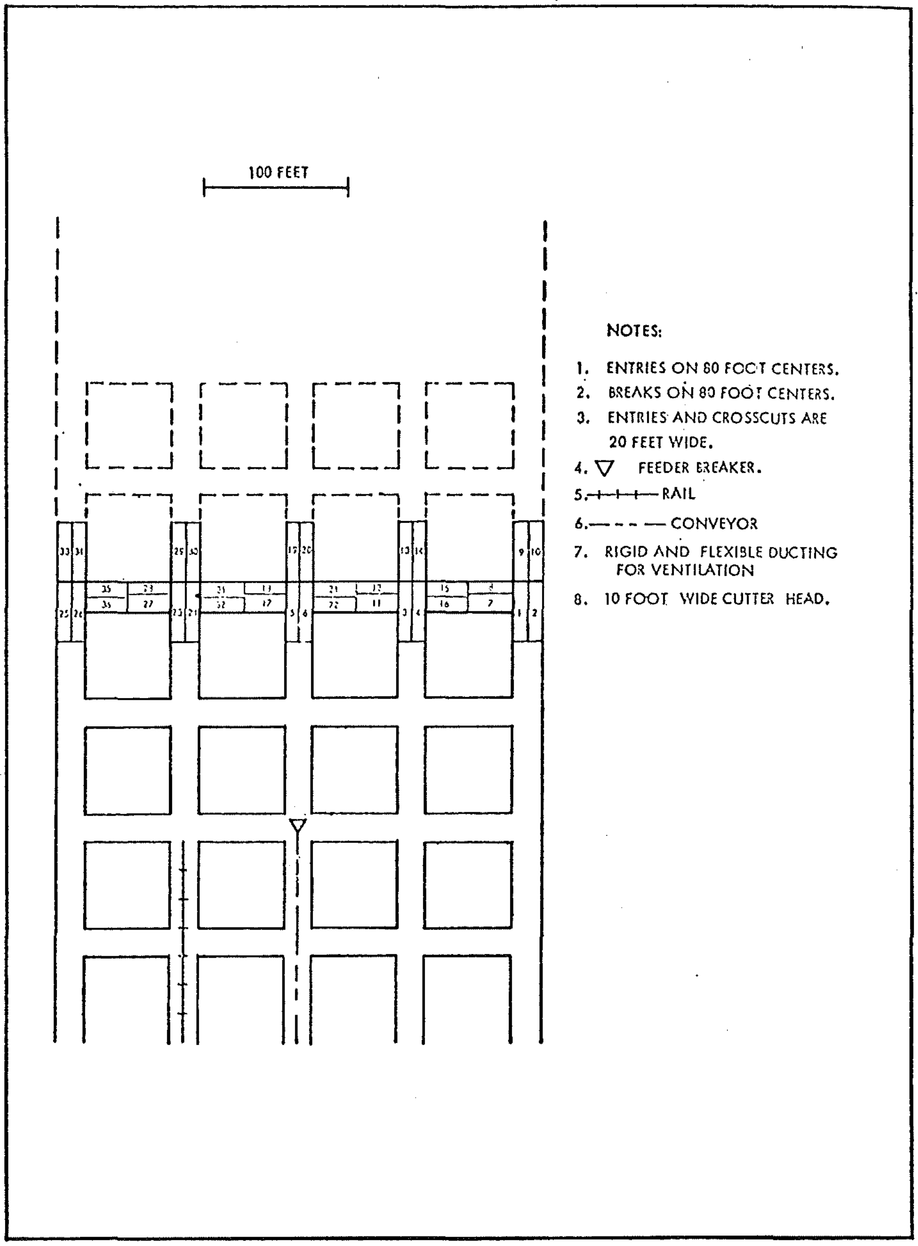


Figure 48 MINE PLAN AND CUT SEQUENCE

The shuttle car leaves as soon as the cusp is removed, and cleanup is performed every second cutting cycle. This arrangement keeps the floor as clean as possible and minimizes the loose material the crawler tracks must travel over. Mining will be two-pass, and a 20-foot lift will be taken.

On the basis of the mine plan, a partial Gantt chart (Figure 49) was prepared and analyzed. This chart covered the activities of the CMM in taking one 20-foot lift (Cuts 5 and 6, Figure 49). In addition, the time to change places was estimated. From this information, the number of place changes per shift could be estimated and thus the productivity potential. The results show that for a potential mining time of 395 minutes in a shift, the CMM will produce 646 raw tons of coal at a rate of 1.63 tons per minute.

The LCRH mine plan is the same as the CMM mine plan. The shuttle cars must load out 7.2 tons per trip; therefore, a larger-capacity vehicle is required. The shuttle cars used are two FMC Model 10L-18, 10-ton-capacity vehicles. The CDLCH cutting cycle is as follows:

- 1, Sump
- 2, Shear
- 3, Shuttle car leaves
- 2, Shear
- 3, Shuttle car leaves
- 4, Reposition and set up for next cut
- 5, Sump
- 6, Shear
- 7, Shuttle car leaves
- 8, Cleanup (back tram, raise gathering table)
- 9, Cleanup (drop gathering table, tram forward)
- 10, Reposition and set up for next cut.

The shuttle car leaves at the end of the shear cycle and again cleanup is performed every second cutting cycle.

A partial Gantt chart is shown in Figure 50. This represents a mining cycle for a two-pass mining operation and a 21-foot lift. A 21-foot lift was used rather than the 20-foot lift for the CMM as a matter of convenience. The LCRH sumps 3 feet, while the CMM sumps 2 feet. The results show that for 395 minutes available to mine, the LCRH will produce 849 tons of raw coal per shift for a mining rate of 2.15 tons per minute. This is a 31 percent increase in productivity over a CMM.

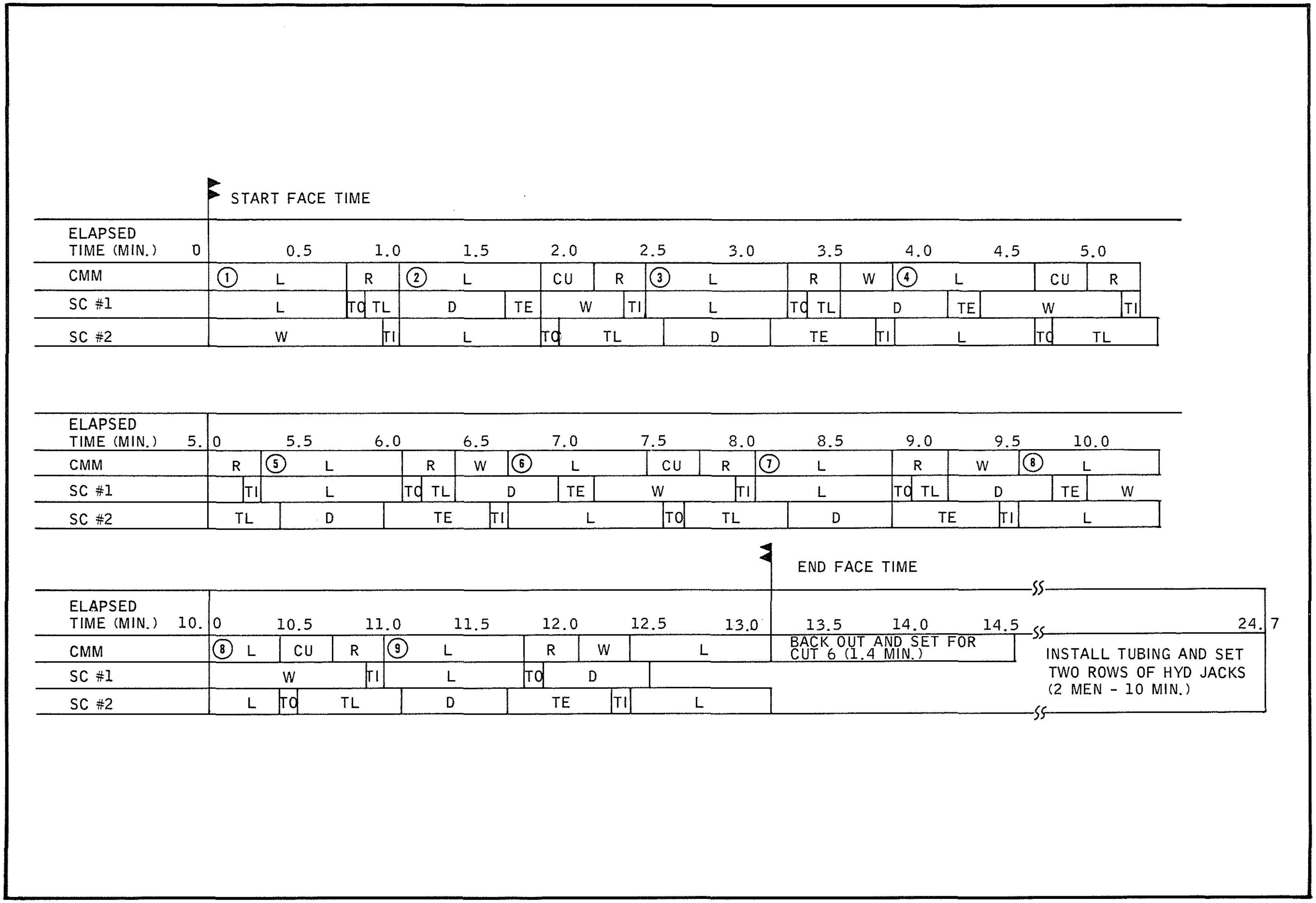


Figure 49 CMM GANTT CHART ANALYSIS

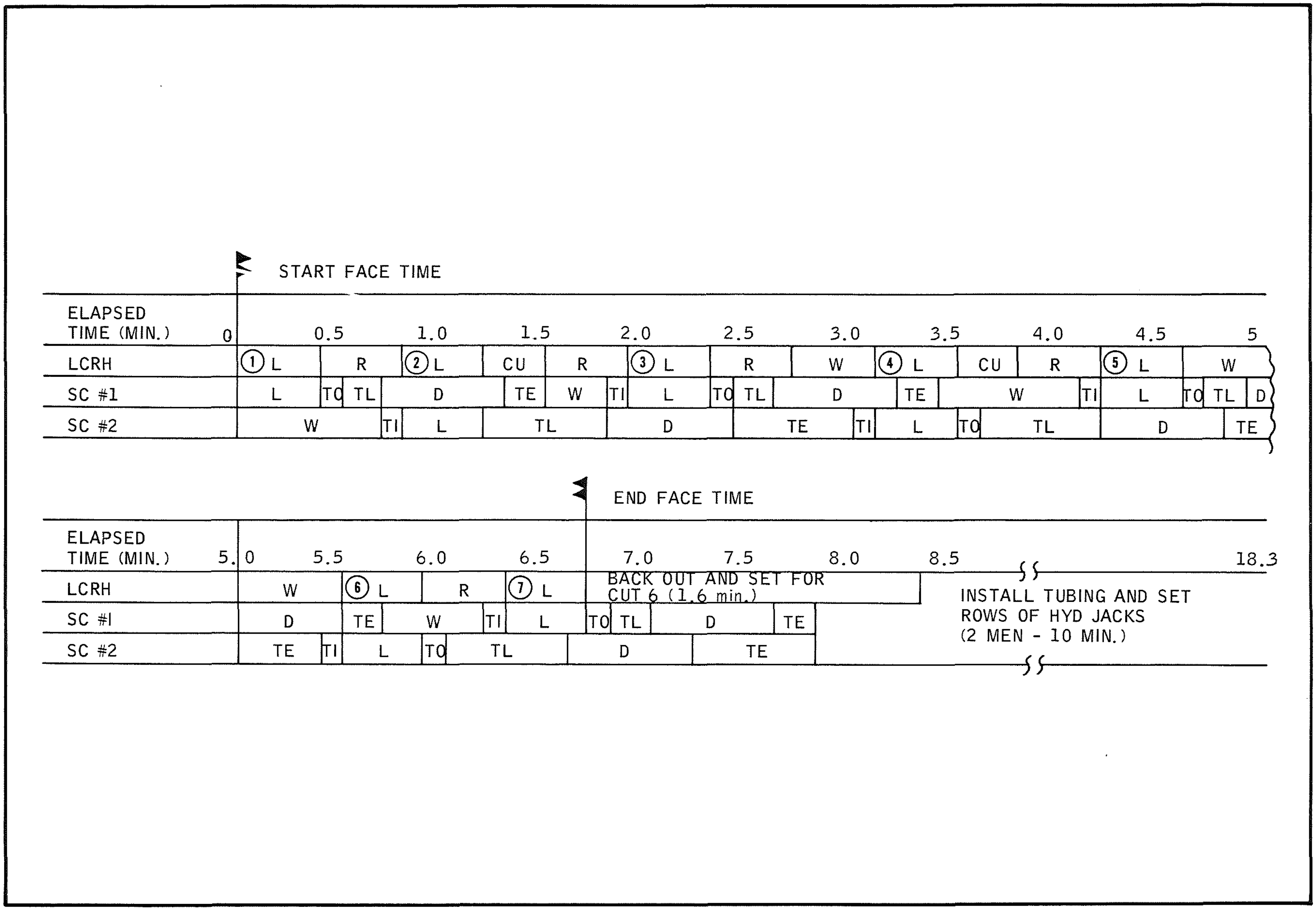


Figure 50 LCRH GANTT CHART ANALYSIS

Table 19 is a summary of the results of the Gantt chart study.

Table 19 PRODUCTIVITY STUDY RESULTS

Miner	Total lift time (minutes)	Face time (minutes)	Place change (minutes)	Total lifts (lifts per shift)	Coal cut (tons)	Production rate (tons per minute)	Percent increase
CMM	38.1	180	23.1	6.73	646	1.63	
LCRH	25.0	113	23.1	8.43	849	2.15	31

Gantt chart standard data:

A CMM	Load rate: 10-foot-wide sump, 24 inches deep = 0.8 minute Tramming rate: 35 feet per minute Cleanup: at 35 feet per minute forward and reverse
B Two Joy 16SC Shuttle Cars	Travel rate (empty and loaded on level bottom): 4.5 miles per hour Dump time: 0.6 minute Capacity per car: 5.34 tons of raw coal
C Feeder	3-way dump
D LCRH concept	Load rate: 10-foot-wide sump, 36 inches deep = 0.4 minute; Reset for next cut = 0.4 minute Tramming rate: 35 feet per minute Cleanup: at 35 feet per minute forward and reverse
E Two FMC 10L-18 Shuttle Cars	Travel rate (empty and loaded on level bottom): 4.5 miles per hour Dump rate: 0.6 minute Capacity per car: 7.2 tons

Other time data	Dimensional data
A Travel time to section: 30 minutes	A Five-entry system on 80-foot centers with breaks on 80-foot centers
B Travel time from section: 30 minutes	B Width of entries: 20 feet
C Travel from man station to face: 5 minutes	C Mining height of coal: 6 feet
D Prepare-to-work time: 10 minutes	D Sump widths: 10 feet
E Time preparing to leave section: 5 minutes	E Depth of lifts: 20 and 21 feet.
F Travel from face to man station: 5 minutes	
G Total time available to mine: 395 minutes	

Close examination of the LCRH Gantt chart reveals that the mine plan, and not the haulage system, is the limiting factor in productivity. The LCRH spends less time at the face (113 minutes compared with 180 minutes) but consequently more time changing places (194 minutes compared with 155 minutes) than the CMM. The LCRH can cut a given amount of coal much more quickly than a CMM, but this necessitates more frequent place changes, thus more valuable time is wasted in nonproductive activities. To best utilize the capabilities of this concept, a more compatible mine plan must be devised or a method of taking longer lifts. An automated miner/bolter arrangement allowing a 40-foot or longer lift would greatly enhance the productivity potential of the LCRH concept.

5.4 CDLCH CONCEPT CAPITAL INVESTMENT COST

A recent survey of continuous mining machine manufacturers was made to determine a dollars-per-equipment-pound figure based on present industry figures for underground mining machinery.

The present cost per pound for continuous miners (sample of 11 machines) is $3.06 (Table 20). A dollars-per-pound estimate has been a relatively good indicator for predicting equipment production cost. The average of the prices quoted from the 1975 catalog list price for the 11 continuous mining machines was $260,000.

Table 20 COST STUDY RESULTS

	Continuous Miner		Shuttle Cars		Roof Bolters				Diesel Locomotives	
					Single		Double			
	Number in sample	Cost per pound ($)	Number in sample	Cost per pound ($)	Number in sample	Cost per pound ($)	Number in sample	Cost per pound ($)	Number in sample	Cost per pound ($)
Low Model	3	3.82	4	2.47	2	2.45	N/A	N/A	N/A	N/A
High Model	8	2.78	5	2.07	2	2.04	3	2.32	2	2.09
Total/Average	11	3.06	9	2.25	4	2.24	3	2.32	2	2.09

Data from vendor quotations based on October 1975 catalog list price and gross vehicle weight

In determining the overhaul cost of underground mining equipment, a general estimating technique has shown reasonable accuracy. If the new cost of an item of equipment is X dollars, the X dollars will be spent every 3 years to maintain the machine. The X dollars is a constant value over a 10-year period, the expected useful life of the equipment. This constant dollar value reflects that as the machine ages, less money is expended to refurbish it. For example, if a continuous mining machine cost $260,000 new, after 9 years the total expenditure on the machine would equal $260,000 + 3 ($260,000) = $1,040,000.

5.5 PRODUCTION AND RETROFIT PRODUCTION KIT COST

5.5.1 SSH Production and Retrofit Cost

Weight of a Joy 12CM miner minus the cutting head, cutting head motors and reducers, and trailing cable is approximately 68,000 pounds.

The weight of the head on the SSH concept has been estimated as 20,000 pounds. Total weight is 88,000 pounds.

Based on the $3.06 value per pound of machine weight, a production cost of the self-sumping head concept is (88,000) (3.06) = $269,280.

As a retrofit kit on a production basis, the cost would be $61,000, based on the $3.06-per-pound value.

The price of a major overhaul for a continuous miner is 50 to 60 percent of its new cost. In our previous study, the average price of a continuous miner was $260,000; 50 percent of that is $130,000. We also calculated that a retrofit kit would cost $61,000. The two costs (overhaul and retrofit) total $191,000. A production-type retrofit kit installed at a major overhaul period would cost $191,000. It should be noted that no consideration has been made as to the components of a CMM that would not be used in the retrofit, rotary head, and related components. A scrap or resale of such components could reduce the overhaul-retrofit cost substantially.

5.5.2 LCRH Production Cost

The total weight of the LCRH concept is estimated as 130,000 pounds. This can be projected to be a production cost of $398,000 based on $3.06 per pound of machine weight.

This concept should be built from the ground up, without benefit of a retrofit kit.

Table 21 is a summary of production and retrofit cost of the LCRH and the SSH, plus a comparison with existing USBM CMMs and the deep-cutting continuous miner, Contract HO122039.

Table 21 PRODUCTION AND RETROFIT COSTS

Miner	Total Weight (pounds)	New Cost ($)	Head Weight (pounds)	Overhaul Cost ($)	Overhaul Retrofit Cost ($)
CCM*	85,000	260,000	24,000	130,000	
SSH	88,000	269,000	20,000	134,000	191,000
H0122039	129,000				
LCRH	130,000	398,000	30,000	199,000	

*Based on Table for average of 11 CMM's.

5.6 ANCILLARY COST

The significant reduction of dust by the CDLCH concepts eliminates the need for secondary ventilation, dust collectors, and/or scrubbers. Water sprays will not be necessary on the head, but some sprays will be needed for the gathering table and conveyor.

Although initial cost savings are minimal when compared with machine cost, a significant saving could be realized because of reduced parts inventory, maintenance, and manpower requirements, items directly proportional to ancillary equipment reduction.

5.7 IMPROVED COAL QUALITY

The CDLCH concepts will produce fewer fines and larger-chunk coal than now produced by existing CMMs, and thus will reduce the cost of mining coal. In a report prepared by the Electric Power Research Institute, titled "Underground Coal Mining, An Assessment of Technology," the ramifications of coal quality were discussed: "In comparing the run-of-mine coal product for continuous versus conventional face systems, the continuous system yields more noncombustible material and finer particle sizes. The response of the cleaning operation to these effects means: (1) the yield of specification coal is reduced (often this reduction is greater than 25 percent), and (2) the proportion of the mined product that can be processed by coarse coal procedures (least expensive and most efficient) is reduced. At the same time those portions of mined coal reporting to the extreme fines (minus 28 mesh) for processing is increased (most expensive and least efficient processing)."

VI BIBLIOGRAPHY

1. C. D. Pomeroy, Mining Research Establishment report No. 2036, 1956 Research Programme Reference No. 1.1, The Relationship Between Depth of Cut, Cutting Forces and Fragment Size Distribution in Small Scale Ploughing Experiments on Various Coals.

2. C. D. Pomeroy, Colliery Guardian, July 24, 1964, Breakage of Coal by Wedge Action.

3. D. Whittaker, Colliery Guardian, August 23, 1962, Effect of Pick Shape on Cutting Forces.

4. Parviz F. Rad, Bureau of Mines Information Circular 8584, 1973, Mechanical Properties and Cutting Characteristics of Coal.

5. I. Evans, Journal of the Institute of Fuel, National Coal Board Mining Research Establishment, June 1968, The Properties of Coal in Relation to Mechanical Coal-Winning.

6. Pomeroy, C. D., Colliery Guardian, November 21, 1963, The Breakage of Coal by Wedge Action.

7. Pomeroy, C. D., Brown J. H., Journal of Strain Analysis, Volume 3, No. 3, 1968, Laboratory Investigation of Cutting Process Applied to Coal-Winning Machines.

8. Pomeroy C. D. The Mining Engineer, June, 1968, Mining Applications of the Deep Cut Principle.

9. O'Dougherty M. J., Burney, A.C., Mining Research Establishment Report No. 2211, 1962, Research Programme Reference No. 1.1, A Study of the Forces Acting on a Single Coal Cutter Pick: An Examination of a Standard Pick and a Straight-Bar Pick Cutting in Teversal Dunsic.

10. USBM RFP No. JO265010, Engineering Feasibility Study of a Constant Depth Linear Cutting Head Concept.

11. Dumbleton, M. J., O'Dougherty, M. J., Shepherd, R., Mining Research Establishment, National Coal Board The Effect of Blade Angle and Other Factors on Coal Ploughing.

12. Warner E. M., American Mining Congress, May 11-14, 1970, Machine and Cutting Element Design.

13. Evans I. Mining Research and Development Establishment, National Coal Board, Stanhope Bretby, Burton-upon-trents, Staffs, 24 August 1971, Line Spacing of Picks for Effective Cutting.

14. Strebig, K. C., Zeller, W. H., U. S. Bureau of Mines, Report of Investigation 8042, Effect of Depth of Cut and Bit Type on the Generation of Respirable Dust.

15. Technical Report 2742, Advanced Products Division, FMC Corporation, Automated Miner Bolter, Rolling Resistance of Modified Joy 12CM Continuous Miner, Contract No. HO242057

16. USBM Contract No. HO242057, The Development of a Miner Bolter System, Phase I Report, FMC Corporation.

17. USBM Contract No. HO155192, Innovative Machine Design Concepts, April 1976, FMC Corporation

18. Matta, J. E., TPR 96, Effect of Location and Type of Water Sprays for Respirable Dust Suppression on a Continuous Mining Machine.

19. Roepke, Wallace W., Lindroth, D. P., Hanson, B., Engineering Evaluation of a Continuous Mining Machine and Constant Depth Linear Cutting Head to Optimize Configuration for Airborne Respirable Dust Reduction (Unpublished private communication).

20. Roepke, Wallace W., Lindroth, D. P., Myren T. A., Reduction of Dust and Energy During Coal Cutting Using Point-Attack Bits, Report of Investigation 8185, USBM, Department of the Interior.

21. USBM Contract Number HO122039, Preliminary Testing of Deep Cutting Continuous Mining Machine and Respirable Dust Measurements. Phase III Ingersol Rand Corporation.

22. Lamonica, J. A., Mundell, R. L., Muldoon, T. L., Report of Investigation 7550, USBM Department of Interior, Noise in Underground Coal Mines.

23. Electric Power Research Institute, EPRI AF-219, Project 284-1 Final Report July 1976, Underground Coal Mining, An Assessment of Technology.

Appendix A
OTHER CONCEPTS CONSIDERED

Appendix A

OTHER CONCEPTS CONSIDERED

1.0 V-FACE CONCEPT

1.1 DESCRIPTION

Figure A-1 is an artist's concept drawing and Figure A-2 is a general arrangement drawing of the V-face concept. The retrofit is shown on a Joy 12CM continuous mining machine. The head of the machine consists of two sets of four-stage telescoping hydraulic cylinders, encased in square steel tubing. Each set contains seven cylinders fitted with wedge-shaped shearing bits. The cylinder sets are mounted on the end of the boom at a common pivot point, and are maneuvered by position cyliders as shown. The entire cylinder head assembly can be extended beyond the gathering table (coal-cutting mode) and it can be retracted above the gathering table for cleanup.

The concept is unique not only because of the method of coal extraction, but also because the actual face of the coal is radically altered. On encountering a flat face, the machine must chip the face away until the working V shape is obtained. Once this shape is established, the face can be worked by taking 6-inch slices alternately from the lower and the upper portions of the V. Once the V is established, it can be maintained throughout a heading, but must be re-established for a crosscut. The action of the head closely resembles a longwall plough in that its method of extraction is shearing slices from the face.

1.2 MINING SEQUENCE

Following is a description of the sequential operation of the concept (see Figure A-2) after the V face is established:

- The lower cylinder set is lowered to the floor and rests at an angle of 60 degrees.
- The main boom extends, sliding the cylinder set along the floor until the blades touch the lower portion of the V approximately 6 inches from the apex of the V.

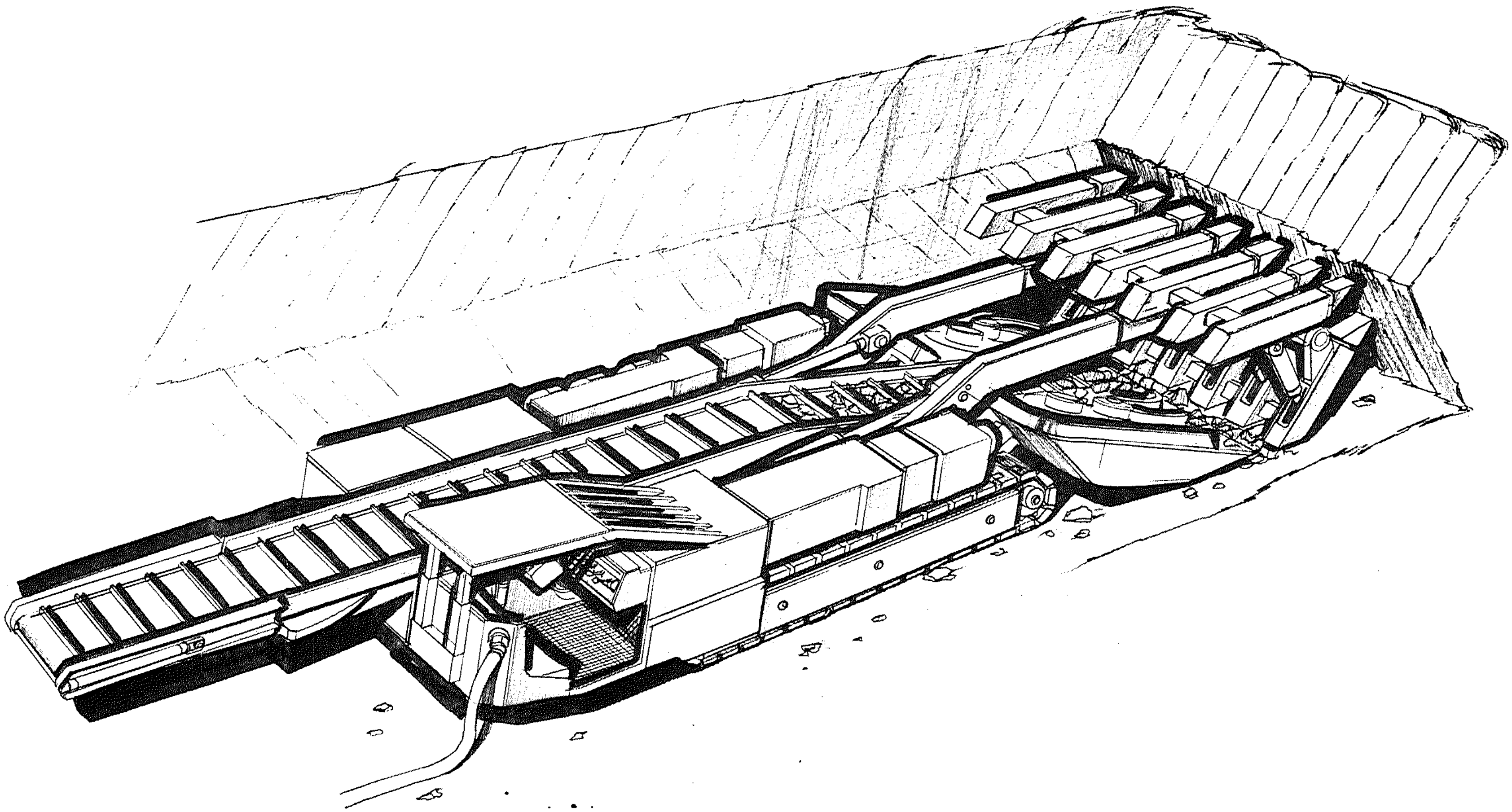


Figure A-1 ARTIST'S DRAWING, V-FACE CONCEPT

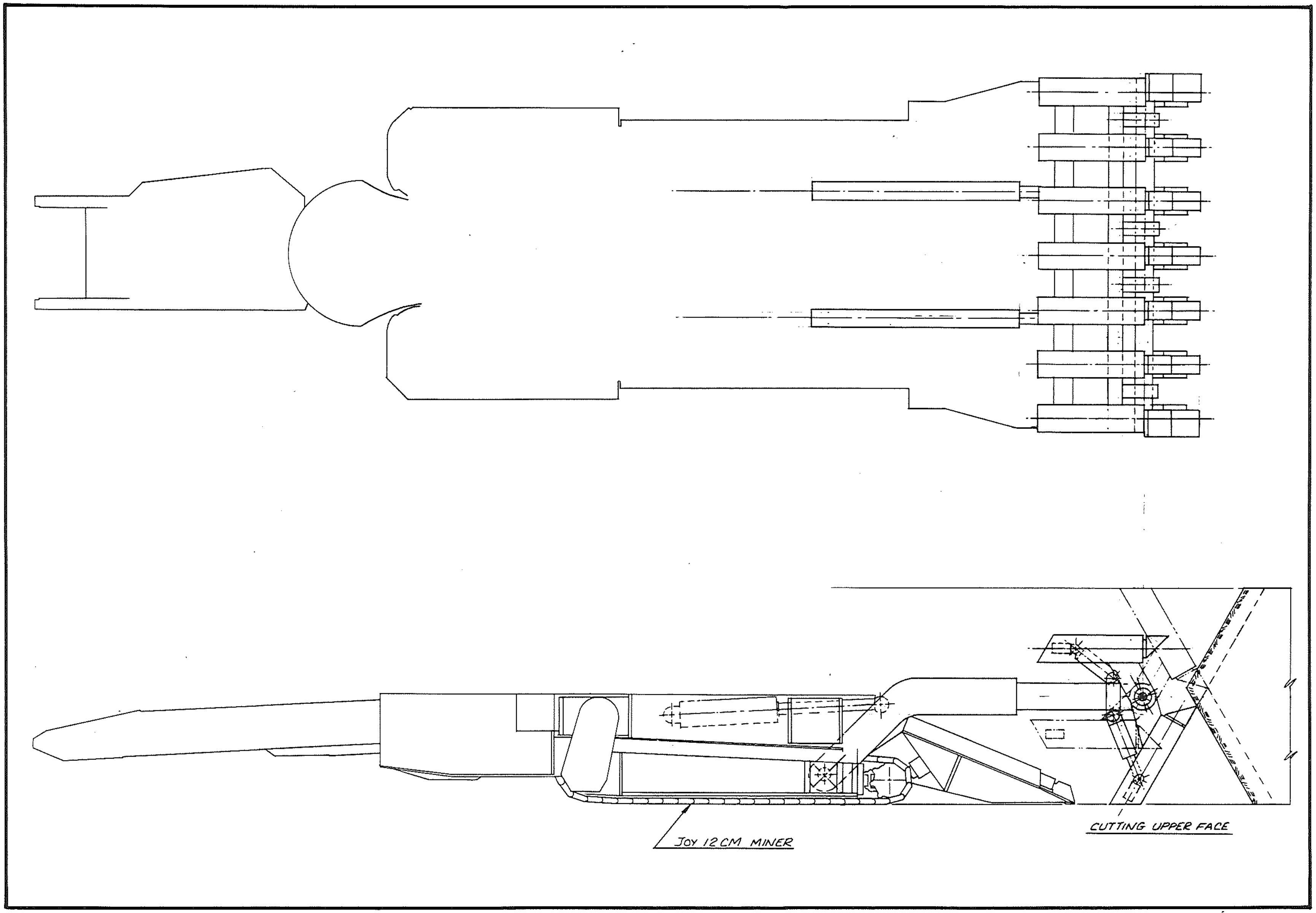


Figure A-2 LAYOUT DRAWING, V-FACE CONCEPT

- The lower cylinders are activated, extending the bits into the coal, shearing the 6-inch slice. The reaction is taken through the cylinders to the floor.
- The shear stroke is determined by the seam height.
- After the top slice is made, the lower cylinders are retracted.
- The lower cylinders are then swung out of the way and tucked close to the boom.
- The upper cylinder set is swung into a 60-degree orientation against the roof and slid into position by the boom. In this position, the bits will be 6 inches above the apex of the V.
- The cylinders are then extended, shearing off the lower 6-inch slice.
- The top cylinders are then retracted.
- Both sets of cylinders are then rotated and tucked in close to the main boom. The boom then retracts the cutter assembly above the gathering table.
- The miner then trams forward approximately 3-1/2 feet, brushing the roof as it goes and gathering up the broken coal. The roof brushup is accomplished by manuevering the top cylinder set as shown in Figure A-2.
- If floor brushing is necessary, the machine must back up, extend the main boom, and position the lower set of cylinders so that floor brushing can be accomplished.
- The miner then trams back 3 feet and positions for another cutting cycle.

1.3 RETROFIT COMPONENTS

The V-face concept is shown (Figure A-2) as a retrofit on a Joy 12CM continuous miner. The boom is constructed of steel members and plates and is pivoted at the same position as the original rotary-cutting-head boom. The boom is also manuevered by the same head cylinders as the original machine. Within the confines of the boom are two large cylinders to extend and retract the head. The head consists of 14 telescoping cylinders and eight small positioning cylinders, plus the 14 specialized bits. Major components and changes necessary to accomplish the retrofit are as follows:

- Fourteen double-action, four-stage hydraulic cylinders, PMC 12,300 6x5x4x3, Prince Manufacturing Corporation
- Two 6-inch-diameter, 2-1/2-foot-stroke boom cylinders
- Eight 3-inch-diameter, 5-inch-stroke positioning cylinders

- Fourteen specially manufactured wedge-shaped bits (material not determined)
- Two 200-hp electric AC motors
- Two 171-gpm hydraulic pumps.

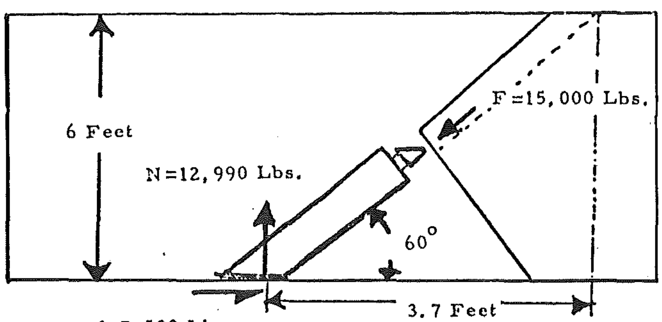
The remainder of the miner is unchanged and includes the following components :

- 70-hp electric tram
- 60-hp electric conveyer and gathering head
- 50-hp hydraulic pump for all other hydraulics.

Total horsepower is 580; this is 100 hp more than available with the CMM.

1.4 FORCES AND POWER

The total head hydraulic flow requirement is 343 gpm. The system pressure requirement is 2,122 psi. Head horsepower is 424; total horsepower is 580. See Figure A-3.



Forces Acting on Each Cycle

1.5 CUTTING BITS

The cutting bits employed in this concept are wedge shaped and approximately 7 inches at the legs and 6 inches wide, with a cutting angle of 45 degrees.

1.6 AUXILIARY SUPPORT

Auxiliary support is not required in this concept.

1.7 PRODUCTION POTENTIAL

The V-face concept mining cycle consists of taking two 6-inch slices from the V-shaped face (an upper and lower slice), then cleaning up the fallen coal. Listed below are the sump, shear, and tram characteristics:

- Tram forward and reverse: 35 feet per minute
- Shear: 12 inches per second
- Sump: 1 inch per second.

The V-face mining cycle and production potential are tabulated in Table A-1.

Table A-1 V-FACE MINING CYCLE AND PRODUCTION POTENTIAL

Function	Time (seconds)	Tons of Coal
Up cut	3.70	0.74
Retract cylinder	3.00	
Reposition for down cut	3.00	
Down cut	3.70	0.74
Retract	3.00	
Reposition for cleanup (includes retracting head)	6.00	
Tram forward and clean up (3.6 feet)	6.17	
Return (3 feet)	5.14	
Reposition (includes extending head)	6.00	
Totals	39.71	1.48
Total coal per cut = (3.7 feet)(10 feet)(0.5 foot) 80 pounds per cubic foot = 0.74 ton		
Tons per minute = 2.23		
Production for 136 minutes available mining time = (136)(2.23) = 303 tons per shift		

2.0 ARTICULATED HEAD CONCEPT

2.1 GENERAL DESCRIPTION

Figure A-4 is an artist's rendering and Figure A-5 is a general arrangement drawing of Concept 2, the articulated head. This concept is also shown as a retrofit on a Joy 12CM continuous miner. Mounted on each side of the miner is a chock system. The chock system is connected to the miner frame by a slide mechanism. The top plate of the chock is raised to the roof and the bottom plate rests against the ground. Pressurizing the main cylinders creates the necessary force (120,000 pounds) so that the miner can be reacted off the chocks and sumped into the face. Roof and floor

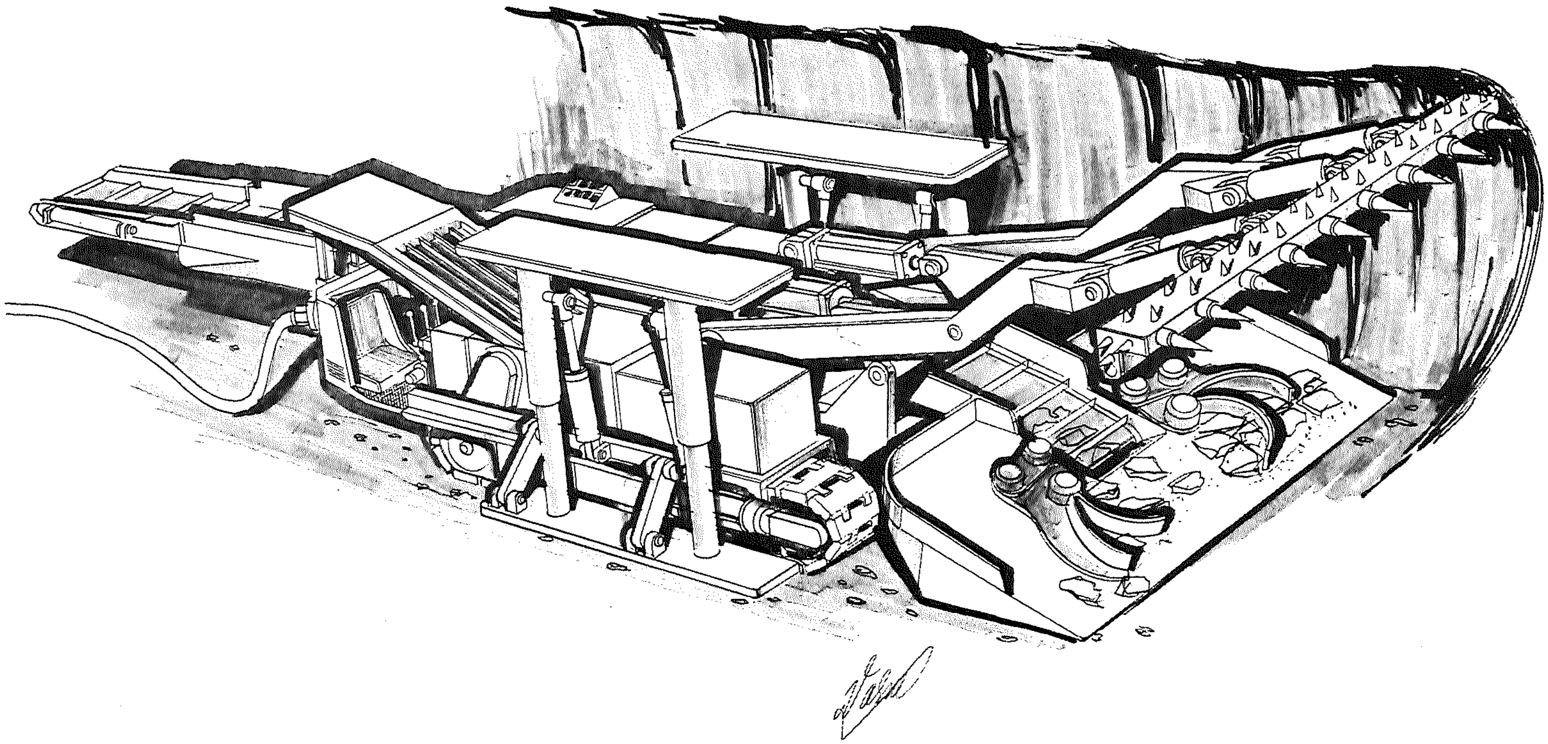


Figure A-4 ARTIST'S DRAWING, ARTICULATED HEAD CONCEPT

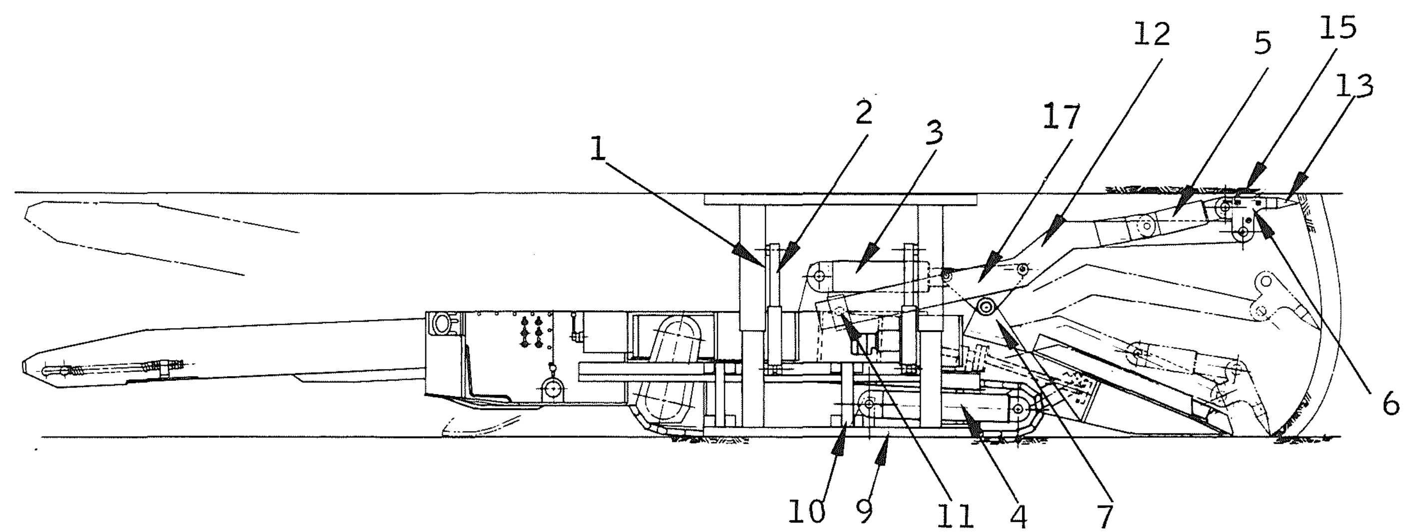


Figure A-5 LAYOUT DRAWING, ARTICULATED HEAD CONCEPT pressure of 100 psi can be decreased by increasing the chock plate area. The chocks are designed so that the machine can slide between the chocks and the chocks can react both horizontal and upward vertical forces (i.e., shear forces).

Mounted to the chocks at one end, and to the machine framing at the other end, are sump cylinders (4). These cylinders react off the chocks and push the entire miner forward, sumping the head into the face. The stroke of the sump cylinders (4) is 3 feet, and for 6-inch sumps a total of six sump cycles can be achieved before the chock system must be reset. The chock system is carried by the miner for tramming and resetting. This is accomplished by lowering the main cylinders (1) and raising the small cylinders (2). This procedure lifts the bottom plate (9), pivoted at links (10), and thus the entire chock system off the ground.

The operation of the head is accomplished by two shear cylinders (3) and four head cylinders (5). The boom (12) is raised so that the head (6) is positioned parallel to the roof with the bits (13) in a sump position (Figure A-5).

The machine is pushed forward 6 inches by the sump cylinders (4), sinking all eight bits into the coal, and at the same time brushing the roof with the brushing teeth (15). The shear cylinders (3) are then activated, forcing the boom mechanism down. At the same time the head cylinders are powered, maneuvering the head to an optimum cutting angle. The boom assembly is a slider crank mechanism and its path is elliptical with a large radius at the roof and a smaller radius at the floor. This arrangement allows the head to be drawn in close to the gathering table at the culmination of the shear. This facilitates cleanup and forces the broken coal into the gathering pan. The head can be rotated further to aid floor brushing and cleanup.

2.2 MINING SEQUENCE

A typical mining sequence can be described as follows:

- The miner trams to the face, raises the boom, and touches the face with the bits.

- The chock s stem is energized raising the upper plate to the roof and lowering the lower plate to the floor. (The machine is now ready to advance 3 feet into the face by a series of sumps and shears.)
- The sump cylinders move the machine forward 6 inches, reacting from the chocks and sumping the bits.
- The boom then shears down, rotating the head to an efficient cutting angle.
- At the end of shear-down, the head is further rotated to brush the floor and cleanup.
- The boom is raised and the miner is ready for another sump and shear-down.
- The sump/shear-down cycle is repeated five more times.
- After the sixth sump/shear-down cycle, the miner trams backward 3 feet. The chock system is lowered and lifted from the floor.
- The miner then trams forward 3 feet, sets the chocks, and is ready for another series of 6 sump/shear-down cycles.

2.3 RETROFIT COMPONENTS

The articulated head concept is retrofitted to a Joy 12CM continuous miner, and the basic concept idea can be adapted to similar miners of other manufacturers. In considering the Joy machine, it is anticipated that the tram, conveyor, and gathering head power units and related controls will remain the same. However, the following changes will be necessary to transform the miner into a CDLCH machine:

- The rotary head and boom assembly will be replaced by the CDLCH head and boom assembly.
- Shear cylinders will be installed to the boom and pivoted at a welded plate located at the frame above the miner body (3); see Figure A-5.
- The boom will also be pivoted at the welded plate (17). The plate (7) will be welded to the machine frame.
- A slide mechanism (11) will be attached to the boom and pivoted on the frame.
- A chock system will be installed on each side of the miner by means of a slide mechanism.
- The articulated head will be attached to the main boom by pivot pins. The head is articulated by four hydraulic cylinders and contains eight replaceable bits.

- Two sump cylinders are pivoted at the chock bottom plates and connected to the front track sprockets.
- A separate power center and hydraulic system will be necessary to operate the retrofit components.

The following is a list of major components needed to accomplish the retrofit:

- Eight specially designed pyramid-shaped bits (material unspecified)
- Four 6-inch-diameter, 7-inch-stroke hydraulic head cylinders
- Two 8-inch-diameter, 3-foot-stroke hydraulic sump cylinders
- Two 6-inch diameter, 2-foot-stroke hydraulic shear cylinders
- Four 6-inch-diameter, 27-inch-stroke hydraulic chock lift cylinders
- Four 3-inch-diameter, 18-inch-stroke hydraulic chock lift cylinders
- Four chock boards, upper and lower
- Main boom and head assembly.

2.4 FORCES AND POWER

Forces and power of the chock system are shown in Figures A-6 and A-7.

2.5 CUTTING BITS

The cutting bits for this concept would be specially made, cone shaped, approximately 3 to 4 inches at the base. The material and final configuration have not been determined.

2.6 AUXILIARY SUPPORT

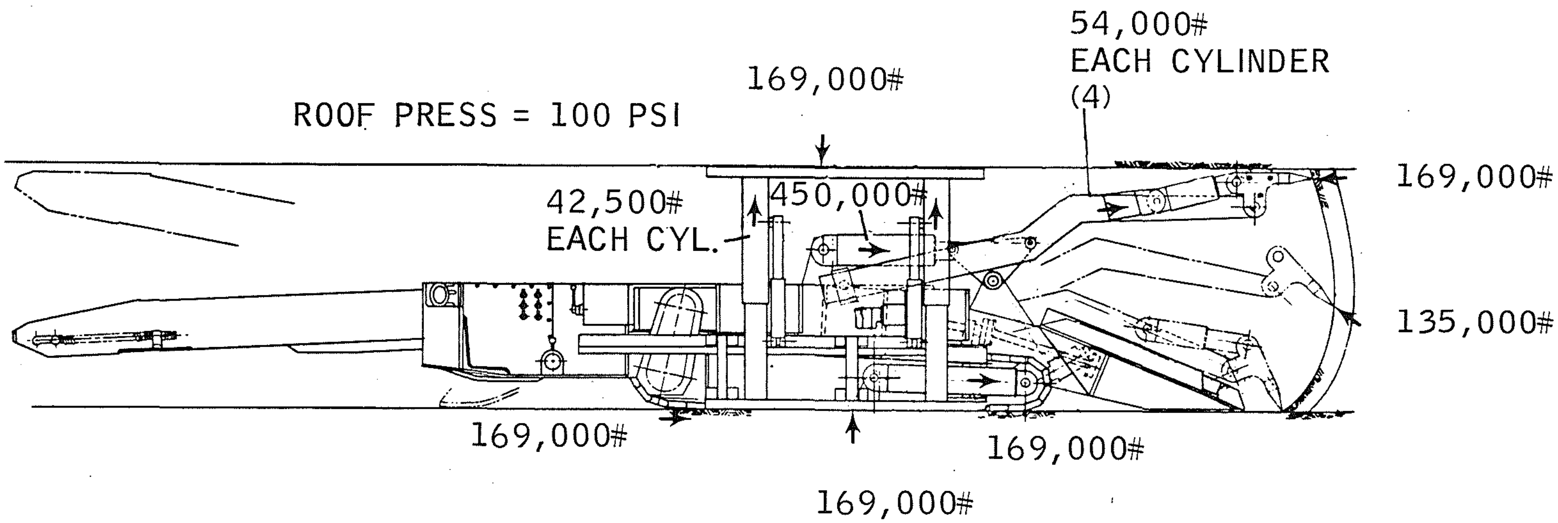
The articulated head concept is envisioned to operate with a sliding chock system. All cutting forces are reacted off the chocks. The chocks require that the head of the machine be wider, thus requiring more bits.

2.7 PRODUCTION POTENTIAL

- Tram forward and reverse: 35 feet per minute
- Shear: 12 inches per second
- Sump: 1 inch per second

The articulated head concept incorporates a chock system to react sump and shear forces. The chocks are set, then a series of six cuts can be made before the chocks must be reset. To estimate a production value, activity

SUMP CYLINDERS (2) = 84,500# EACH
SHEAR CYLINDERS (2) = 225,000# EACH
HEAD CYLINDERS (4) = 54,000# EACH
CHOCK CYLINDERS (4) = 42,500# EACH



TOTAL REQUIRED HP:	SUMP-SHEAR-CHOCKS	=	300
	GATHERING HEAD-CONVEYOR	=	60
	TRAM	=	70
	HYDRAULIC PUMP	=	50
	TOTAL		480 HP

Figure A-6 FORCES ON ARTICULATED HEAD CONCEPT times for a 21-foot lift are caculated so that an average cycle time can be determined. The manuevers are as listed in Table A-2, starting with the chocks set.

3.0 CONCEPT 3, CHAIN RIPPER

3.1 GENERAL DESCRIPTION

Figure A-8 is an artist's drawing, and Figure A-9 is a general arrangement drawing of the chain ripper concept. The concept consists of eight cutter chains, each chain containing one cutting bit. The path of each cutter chain is dictated by three sprockets. Links 4 and 5 connect Sprocket 3 to Sprockets 1 and 2. Sprocket 2 is attached to the main boom (6) and is free only to rotate. However, Sprockets 1 and 3 can be adjusted by means of cylinders (7) to adapt to varying seam heights. The entire head is driven by two drive chains connected to the lower sprocket set at the drive sprockets (9). Power is supplied by two electric motors (11) and reducers (10).

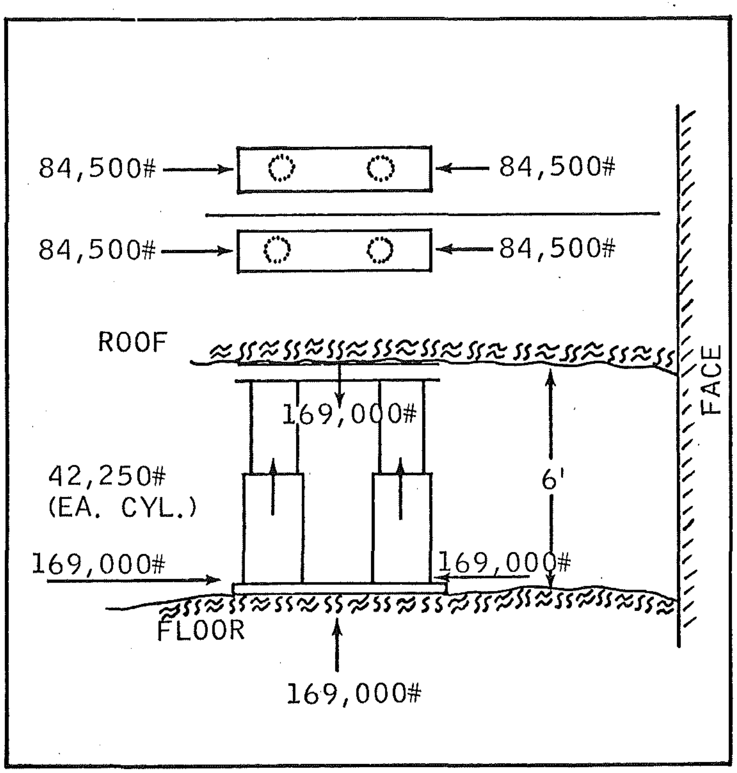


Figure A-7 FORCES AND POWER OF THE CHOCK SYSTEM

Table A-2 ARTICULATED HEAD CYCLE TIMES AND PRODUCTION POTENTIAL

Maneuver				Time (seconds)
Cutting A	Sump 6 inches			6.00
	Shear 6 feet			6.00
	Return			5.00
Repeat A for a total of six cycles. Time for 3-foot advance				102.00
Chock	Tram back 3 feet			5.14
Repositioning	Lower and lift chocks			2.00
B	Tram forward 3 feet			5.14
	Set chocks			2.00
Total B activity time				14.20
Total time for 21-foot advance:		Activity	Time (seconds)	Advance (feet)
		A	102.0	3
		B	14.2	
		A	102.0	3
		B	14.2	
		A	102.0	3
		B	14.2	
		A	102.0	3
		B	14.2	
		A	102.0	3
		B	14.2	
		A	102.0	3
		B	14.2	
		A	102.0	3
		B	14.2	
		Totals	813.4 (13.55 minutes)	21

Total cutting cycles = 6 x 7 = 42; cycle time = $\frac{813.4 \text{ seconds}}{42 \text{ cycles}}$ = 19.36 seconds per cycle

Total tons cut in 21-foot advance: (10 feet)(6 feet)(21 feet)(80 pounds per cubic foot) = 50.4 tons

Mining rate = 50.4 tons per 13.55 minutes = 3.71 tons per minute

Tons per cycle = 50.4 per 42 cycles = 1.2 tons per cycle

For 136 minutes available mining time: 504.5 tons per shift
For 148 minutes available mining time: 549.0 tons per shift

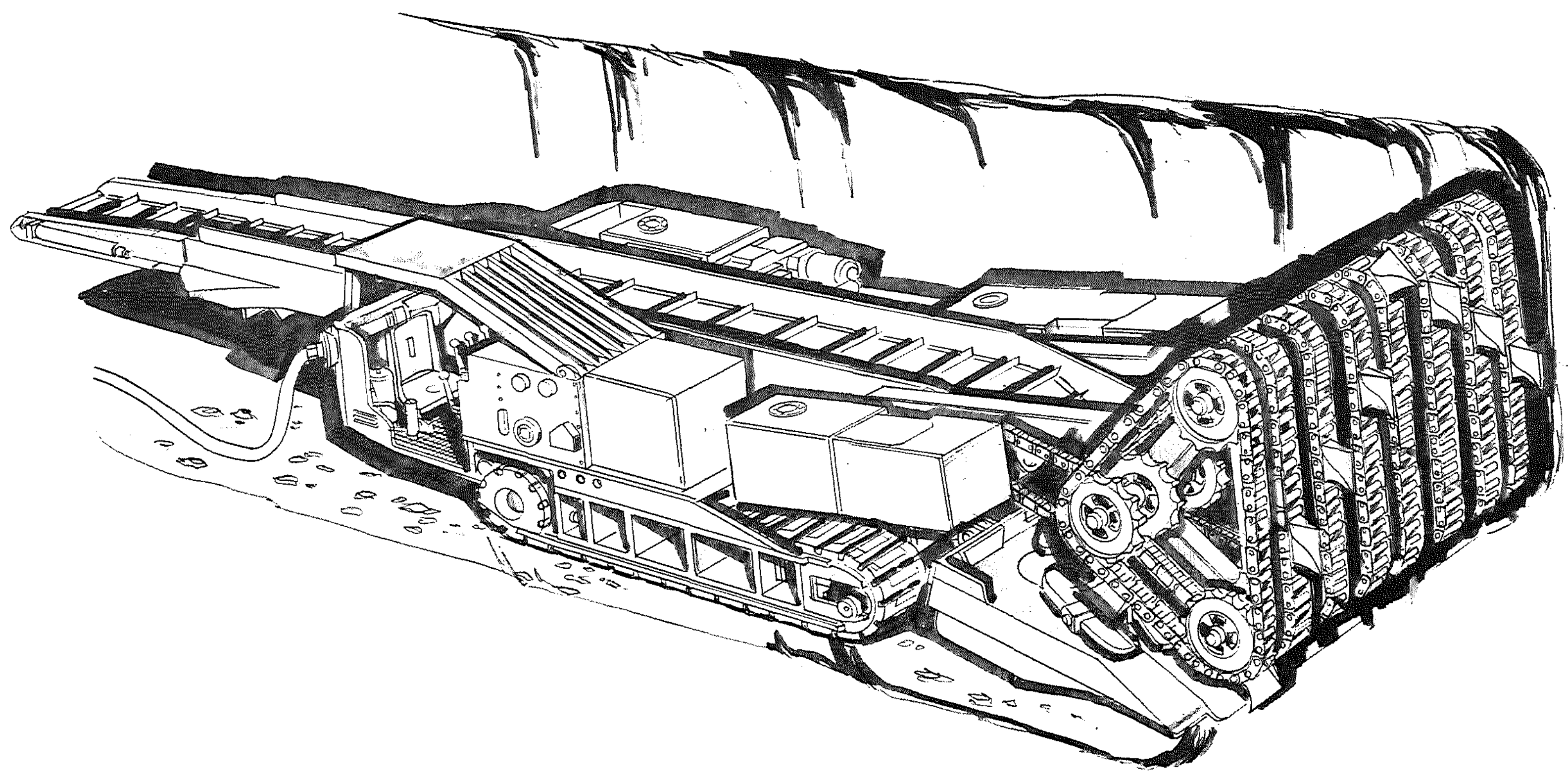


Figure A-8 ARTIST'S DRAWING, CHAIN RIPPER CONCEPT

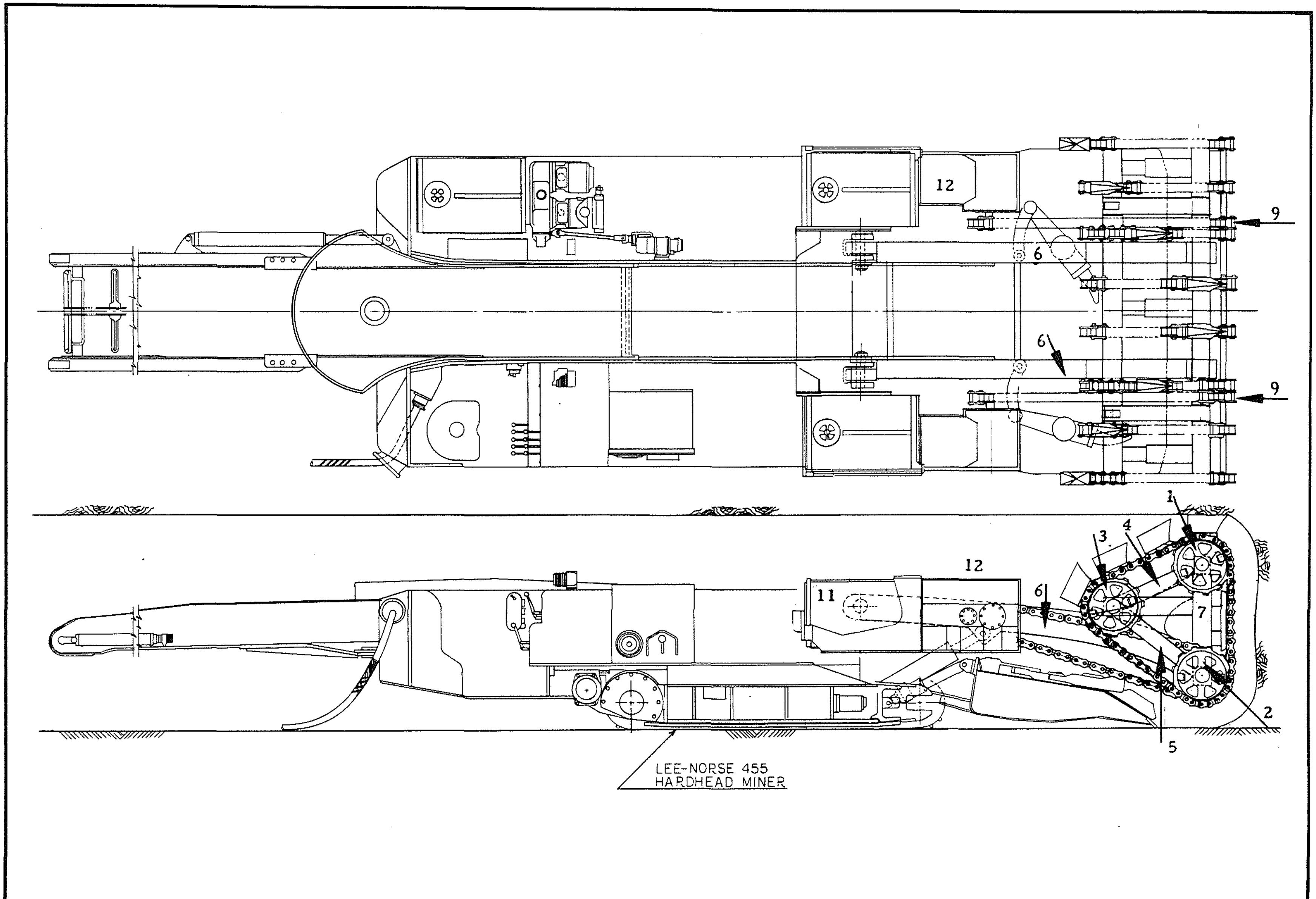


Figure A-9 LAYOUR DRAWING, CHAIN RIPPER CONCEPT

The bits sump into the face as they round the top sprocket (1), and shear at a constant depth the entire face. The bits are dragged by the chain and the forces are always in the same direction, eliminating the high bending moments inherent in point-attack-type bits. Several bits pattern schemes have been developed, to reduce forces or increase production.

Figure A-10 shows Bit Configuration 1.

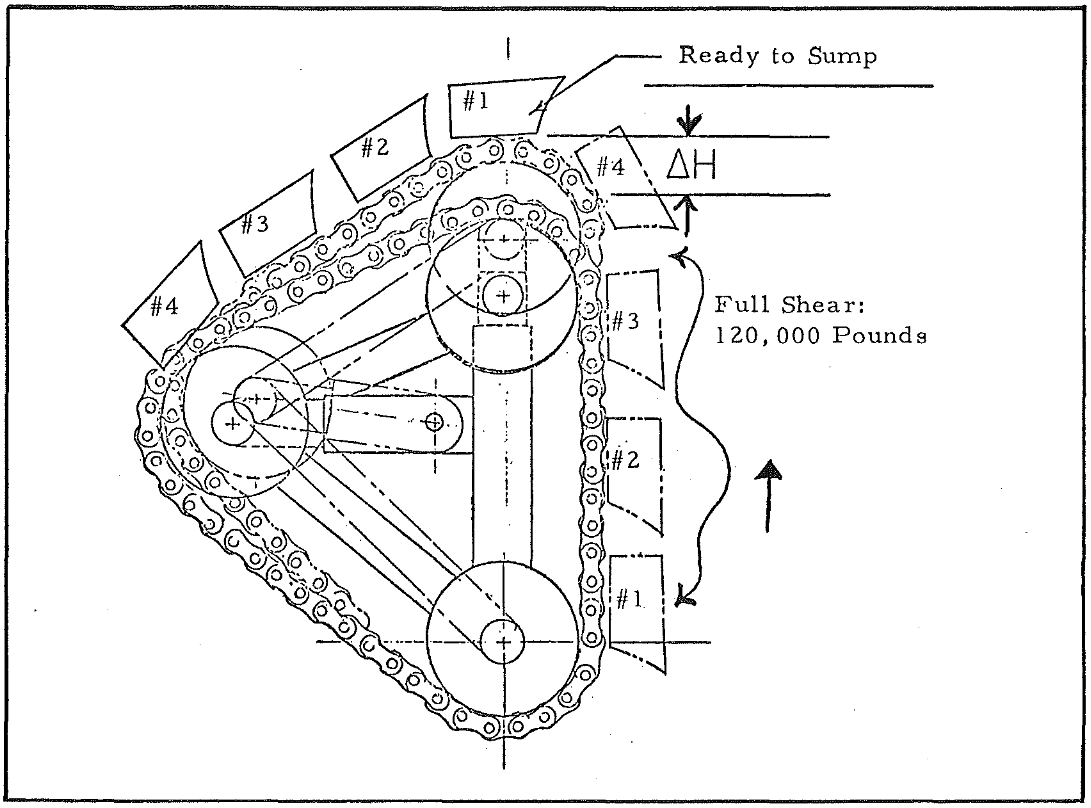


Figure A-10 BIT CONFIGURATION 1

The pattern for Bit Configuration 1 is exactly as represented in Figure A-9. In the side view each bit shown is actually a set of bits, in this case two bits. A total of eight bits are contained on the head. Figure A-10 shows the bits in two positions, a ready-to-sump position and a shear position. Based on a force of 15,000 pounds to sump and shear per bit, only two bits sump at a time, resulting in a sump reactive force of 30,000 pounds. However, in shear, all eight bits would be in action, giving a shear force of 120,000 pounds. This would necessitate additional reactive support.

Figure A-11 shows Configuration 2.

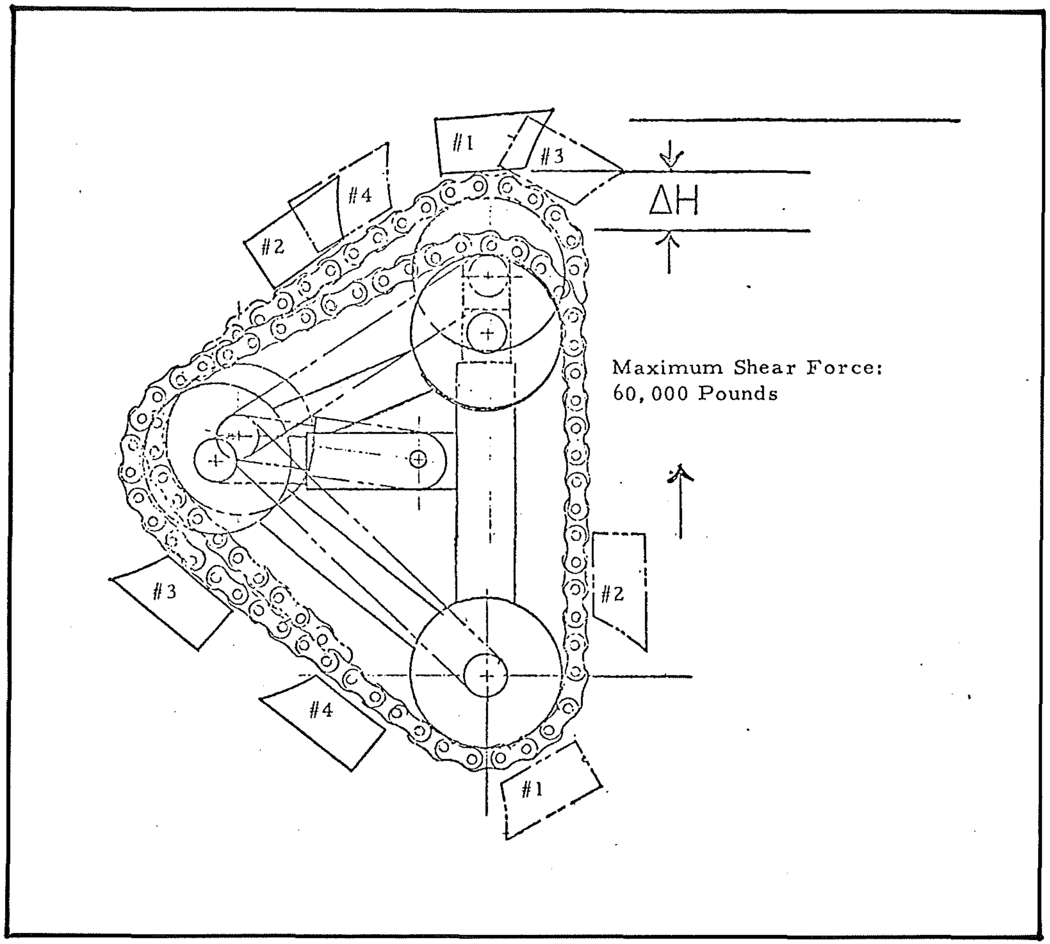


Figure A-11 BIT CONFIGURATION 2

In Configuration 2 (Figure A-11), the bit sets (again two bits per set) are spaced such that only four bits are ever engaged in the shear or sump mode at one time. This reduces the maximum shear force to 60,000 pounds. A rear stabilizer would be required to handle this force.

Figure A-12 (Configuration 3) shows four sets of bits consisting of four bits per set, or a total of 16 bits. The geometry of the head would be such that Sets 1 and 2 would sump and shear and clear the face so that the machine could be advanced just before Sets 3 and 4 would be ready to sump. Again, sizable shear forces would have to be dealt with, but the net effect would be a significant increase in production potential.

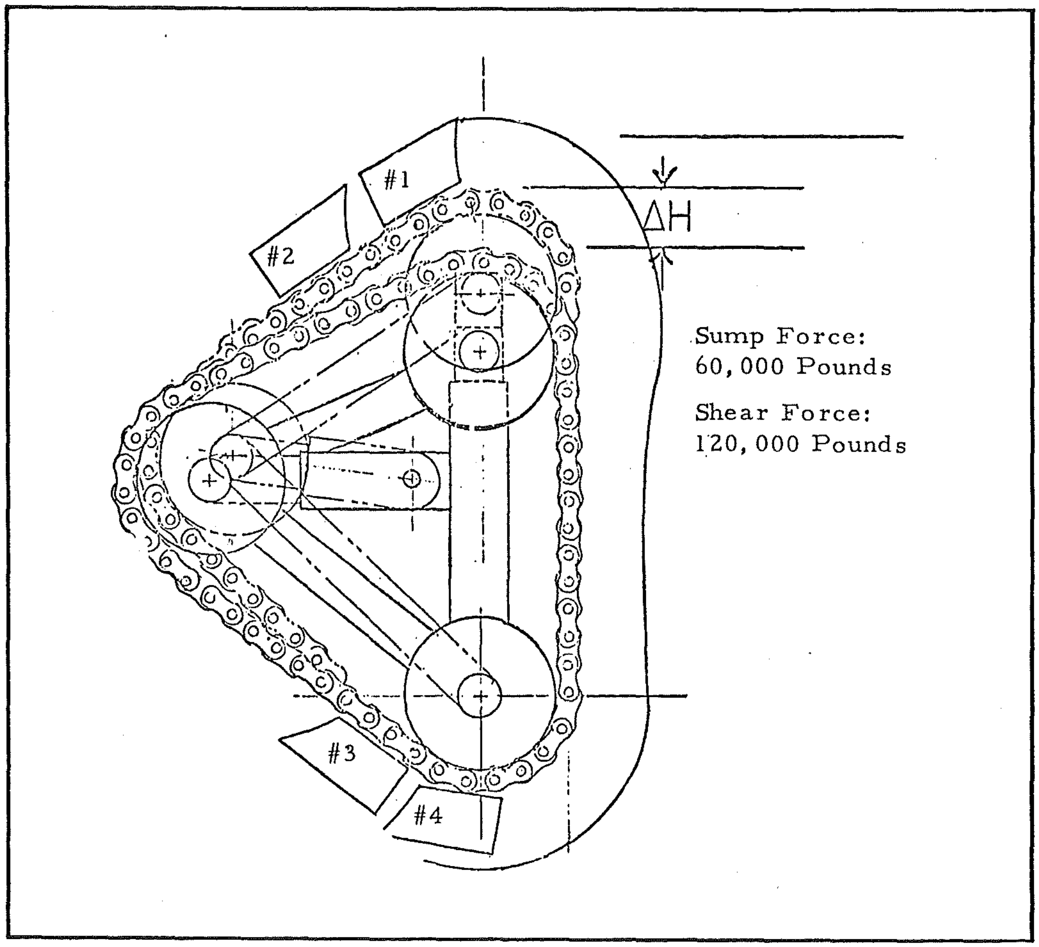


Figure A-12 BIT CONFIGURATION 3

Another possibility is using two chains per cutting path, one bit per chain, so that a staggered cutting pattern could be achieved, allowing a more even breakout pattern. In still another consideration, some bits would be in counter-rotation to others, thus balancing forces.

In all configurations, cleanup would be facilitated because the cutting blades would tend to sweep the broken coal toward the gathering table.

3.2. MINING SEQUENCE

The mining sequence described in the following paragraphs is based on use of Bit Configuration 2 (Figure A-11). This configuration requires only a rear stabilizer for auxiliary support. The sequence is as follows:

- The miner trams to the face and positions the head flush against the face.
- Sprocket 1 and 3 are positioned for the seam height desired.
- The blades are in position as shown by Figure A-11.
- The rear stabilizer is engaged and the head motor is activated.
- After the final set of blades has cleared the face, the tram automatically engages, moving the machine forward 6 inches into the void just created.
- The sequence is repeated until the desired lift is taken.

3.3 RETROFIT COMPONENTS

The chain ripper concept is shown in Figure A-9 (retrofitted to a Lee-Norse 455 hard-head continuous mining machine. As with all concepts presented, the general arrangement of components is adaptable to most existing rotary-head miners.

The retrofit involves replacement of the standard rotary head and boom with a chain-ripper-type head and boom.. The head consists of eight cutter chains, with one or more bits attached to each chain The cutter chains are driven by two 150-hp motors and reducers connected to the drive sprockets by drive chains.

Following is a list of major components, materials, and modifications required to accomplish the retrofit:

- Eight or more specially designed cutting blades .
- Twenty-six 20-inch-diameter sprockets. Number 1 sprocket set (see Figure A-9) consists of eight sprockets connected to a steel shaft. When the sprockets (9) of Sprocket Set 2 are engaged, they drive all sprockets of Sets 1, 2, and 3 simultaneously. Sprocket Set 1 is connected to the main frame of the boom by four hydraulic cylinders (7) which are encased in square tubing. Sprocket Set 3 consists also of eight sprockets connected by a shaft to the upper (4) and lower (5) connecting links. Sprocket Set 2 consists also of eight cutter sprockets plus two drive sprockets.
- Approximately 160 feet of RC 240 Link-Belt roller chain.

- Four- to five-inch hydraulic head adjusting cylinders (7) with 6-inch stroke.
- Two sets of upper (4) and lower (5) connecting links. When the head is adjusted for varying seam heights by the cylinders (7), the connecting links allow Sprocket Sets 1 and 2 to float while maintaining head rigidity.
- Three 5-inch, 9-1/2-foot-long steel shafts.
- The necessary steel plates and members to construct the head and boom structure.
- Two 150-hp electric motors.
- Two 49-to-1 gear reduction units.
- Related controls and components.

3.4 FORCES AND POWER

Figure A-13 is a force diagram of the chain ripper head using Bit Configuration 2 (Figure A-11):

- Head speed: 11.5 rpm
- Drive torque: 45,000 foot-pounds each chain
- Chain pull, cutter chains: 27,000 pounds each
- Total head power: 300 hp
- Maximum sump force: 30,000 pounds
- Maximum shear force: 60,000 pounds.

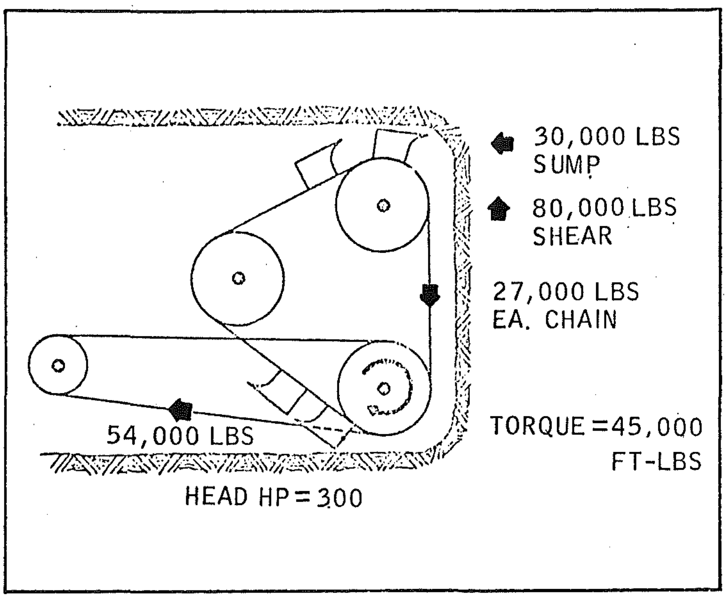


Figure A-13 FORCE DIAGRAM, CHAIN RIPPER

3.5 CUTTING BITS

The bits envisioned for this concept are pentagonal, pointed at the top of the nose and swept back to a width of 3 inches at top rear. The base is 4-1/2 inches wide, and the length is 9-1/2 inches at the base and 11 inches at the top. The bit is connected to the chain links at front and rear by pivot pins. The shape of the bit will allow easier penetration because of the pointed nose, and as depth of penetration increases, the bit width correspondingly widens along the long dimension as well as to the base to facilitate breakout and add bulk to the high-stress areas of the bit. The material of the blade has not been determined at this time.

3.6 AUXILIARY SUPPORT

Auxiliary support is dictated by bit configuration. In Bit Configuration 1, it will be necessary to react the 120,000-pound shear force by some auxiliary method. This problem has not been studied, but it is anticipated that hydraulic cylinders with roof boards mounted on the boom may supply the necessary reactive force. All that Configuration 2 requires is a stability pad located near the rear cònveyor. Such devices are standard on some mining equipment, such as the Joy 12CM continuous mining machine. Configuration 3 will require auxiliary support similar to that of Configuration 1, plus a stabilizer pad.

3.7 PRODUCTION POTENTIAL

To shear at a rate of 12 inches per second, the linear cutting chain speed is 12 inches per second. Total distance of travel for one complete bit cycle is 15 feet, for a total time of 15 seconds.

To tram 35 feet per minute, the parameters are as listed in Table A-3

Table A-3 CHAIN RIPPER PARAMETERS AND PRODUCTION RATE

Parameter	Time (seconds)
Total cycle time (15 seconds + 0.85 second (6-inch tram)	15.85
Coal loaded per cycle: (0.5 foot)(6 feet)(10 feet) = 30 cubic feet = 2,400 pounds = 1.2 tons	
Cutting rate: $\frac{(1.2 \text{ tons})60 \text{ seconds per minute}}{15.85 \text{ seconds}}$ = 4.54 tons per minute	
For a 136-minute shift: 617 tons per shift; for a 148-minute shift, 671 tons per shift	

Appendix B

PATENT APPLICATION 604,566; METHOD OF OPERATING A CONSTANT DEPTH LINEAR CUTTING HEAD ON A RETROFITTED CONTINUOUS MINING MACHINE; by W. W. Roepke, K. C. Strebig, and B. V. Johnson

APPENDIX B

PATENT APPLICATION SERIAL NO. 604566

SPECIFICATION

BE IT KNOWN, that we, WALLACE W. ROEPKE, KELLY C. STREBIG, and BRADLEY V. JOHNSON have invented a new and useful improvement in a METHOD OF OPERATING A CONSTANT DEPTH LINEAR CUTTING HEAD ON A RETROFITTED CONTINUOUS MINING MACHINE of which the following is a specification.

ABSTRACT

A method of operating a machine having a constant depth linear cutting head which is retrofitted to a continuous mining machine replacing the rotary head. By altering the usual configuration of the cutting head from the high speed rotating type with a large number of bits, as is currently being used, to one employing a non-rotary type head with 10 percent or less of the usual number of bits, and also operating a combined sumping and shearing action without the bits exiting the coal face being cut, less respirable dust is produced at the mine face. In addition to decreasing the dust and amount of menthane gas - when coal is mined - which is liberated, our method also produces more coal on the average for each cut in the mine face by deeper constant depth cuts in the 3- to 6- inch range by first sumping into the mine face and then shearing the face, without withdrawing or rotating the point attack bits. Sumping may begin near the mine face roof or floor and shearing may be in either a vertical or horizontal direction with or without the aid of high pressure water. One modification calls for shearing with two opposite cutting heads moving towards the mine face center.

BACKGROUND OF THE INVENTION:

Field of the Invention:

The invention described herein is a method for operatin a continuous mining machine with a linear cutting head having a new mechanical configuration.

DESCRIPTION OF THE PRIOR ART:

Continuous mining machines employing cutting bits on a rotating head have been used for some time. Our invention employs a non-rotating type head with fewer bits modifying the previously used methods by first sumping into the mine face and then shearing the mine face without retracting the cutting bit from the mine face. Of the known prior art U.S. Patent No. 2,730,343 to W. W. Sloane appears closest to our invention. However, significant differences exist in that Sloane's invention uses a wedging action to impact the bits and insert the cutters into the coal thereby breaking out large pieces and withdrawing the cutting head from the coal face to reinsert it for the next breakage to occur by wedging action. Such a method would not only produce much less mined material per unit time than our invention but would also produce more dust, both of which are contrary to the stated objectives of this invention.

SUMMARY OF THE INVENTION:

The continuous mining machine of this invention is moved to a position adjacent the mine face. Then beginning at the roof or floor of the mine face, the point attack bits are sumped into the face a given distance which is at least 3 inches. Next, without retracting the cutting bits from the face, the face is continuously sheared top to bottom or bottom to top across most of its full width in one pass and the material extracted is conveyed away from the face and mine machine. Normally, the sumping into the mine face is about 6 inches and the shearing substantially the total height and width of the of the mine face. After completing both steps, the machine is moved up to the mine face while the cutting bits are moved to the roof or floor, again sumped into the mine face, and then shearing takes place. During this process the extracted coal is continuously being conveyed away from the mine face. This process continues until the desired amount of material is extracted.

The primary object of this invention is an improved method of extracting material from a mine using a continuous mining machine retrofitted with a constant depth linear cutter head.

FIG. 1 is an energy profile graph for a rotary head cutter.

FIG. 2 is a schematic diagram of the steps to be taken to practice our method in a mine.

FIG. 3 is a side view of one type of cutting head usable to sump and shear the material from a mine face.

FIG. 4 illustrates a top view of the FIG. 2 cutting head.

FIG. 5 is the illustrated cutting head retrofitted on an existing continuous mining machine.

Although the invention will be described with respect to coal mining for which it was primarily developed, other types of mining operations faced with the same problems could conceivably benefit. Before elaborating on the details of the invention, the problems it is directed to should be looked into. The major problem sought to be solved by our invention was to reduce respirable dust at the mining face from a continuous mining machine operation without sacrificing operational efficiency. If this could be accomplished, then the next problem would be to increase production without sacrificing safety.

One of the most widely used types of continuous mining machines (CCM) employs a rotary cutting head having 100 to 150 bits and a bit rotational speed of about 60 revolutions per minute.

These cutting bits usually penetrate no more than one inch into the coal mine face and thereby produce excessive quantities of respirable dust as they cut in the coal. Generally, they may be thought of as rotating shallow types of cutters. Research conducted by the United States Bureau of Mines has shown that by cutting with this type of rotary head and by imparting a lower number of revolutions per minute (rpms) to the head, less of this unhealthy and dangerous dust is producted. However, to attain the lower number or rpms needed and still achieve the depth of penetration desired presents a problem since not enough torque can be transmitted to the rotating head.

The graph of FIG. 1 illustrates typical tests results obtained from a rotating cutter. It is the plot of the energy profile for a single plumb-bob bit with a bit attack angle of forty-five degree where there are two inches between the centers of cuts. The Y-axis shows the specific energy in joules per gram of coal extracted and the X-axis the depth of the cut in inches between .25 and 1.0 into the coal mine face. The dashed graph lines represent extrapolated values below .25 inches based on analytical results. The basic conclusion to be drawn from this graph is that at a depth of one inch a rotary cutting head has its best or most efficient energy profile. Test data for depths greater than one inch support this conclusion i.e., the amount of energy consumed decreases as the cutting depth increases. If this conclusion is considered in light of a second finding - namely that the amount of airborne respirable dust generated is a cubic function of a cutters energy profile - then it can be stated as a corollary that using a rotary cutter is not the way to reduce dust. Tests have in fact shown that the less the depth of the cut the greater will be the amount of respirable dust and energy per unit volume generated. When the depth of the cuts are less than one inch, the dust generated has been shown to increase exponentially towards a maximum value as the depth of cut approaches zero varying as the cube of the energy curve in FIG. 1.

Our approach to overcome this problem has been to develop a deep cutting non-rotary head design which cuts the mined material at a constant depth. This approach will not only produce less dust per cut but has been shown to be more efficient in terms of reduced power consumption per volume of coal removed. Further, less of the coal surface area will be generated due to the deeper cuts thereby liberating less of the potentially explosive methane gas. To better illustrate the relationship between the cut depth and reduction of dust generated for a single bit on a rotary head making one complete revolution, Table I was developed to show the effect of reducing the area of maximum dust production between zero and one-half inch depth by increasing the depth of cut. For a one inch deep crescent (shaped) cut by a point attack bit making one pass at the face on a continuous mining machine (CMM) greater than 65 percent of the cutting energy will be expended while producing at least 88 percent of the primary dust at the mine face in less than 15 percent of the total area of coal removed. Based on our tests, we have concluded that the dust produced with a CMM can be decreased by increasing the depth of cut until an economic and engineering optimum depth between three and six inches is reached.

TABLE I

Percentage of Area Between 0 and 1/2 Inch for Total Cut Area	Maximum Depth of Crescent Shaped Cut (Inches)	Percent Reduction of Dust Producing Area, Between 0 and 1/2 inch
100	0.5	0
13.4	1.0	87
3.2	2	97
1.4	3	98.5
0.77	4	99.3
.50	5	99.5
.34	6	99.6

In order to achieve our objective of reducing the respirable dust generated at the mine face and at the same time maintain or exceed the four to seven tons per minute of the cut material now expected from a CMM, it is necessary to modify the existing equipment available by eliminating the rotary head. It should be pointed out that an average production rate of 700 tons per shift is being achieved nationally. This means that only 2.1 to 4.6 hours of machine time are used each day. This low level of use is partially due to the fact that any greater use would create excessive dust.

Our invention addresses itself specifically to this problem since the low level of dust generated by our device will allow truly continuous operation without exceeding the standards set out in the regulations implementing the Federal Coal Health and Safety Act of 1969 (Public Law 91-173) as to the maximum amounts of respirable dust allowable.

FIGS. 3 to 5 illustrate the preferred type of equipment which could be used to practice our method. In FIGS. 3 and 4 a cutting head 10 having seven bits 13 that can sump into the coal seam and then shear it is illustrated. The spacing, d, between consecutive bits follows the general practice of 2.5 to three times the depth of penetration. Thus, for a six inch penetration depth the spacing between adjacent bits would be fourteen to fifteen inches. This head 10 can be moved forward into the coal seam face under hydraulic pressure and also up and down (or if desired sideways) under hydraulic pressure. It may also be desirable to augment the cutting action of these bits with high pressure (10,000 psi or more) jets of water. Normally, these jets located at the center line of the bits' point would precut holes or slots into the coal face for the bits to sump into. In this way, the need to generate a high sumping force would be eliminated.

These same high pressure water jets may also be used to reduce the amount of shear force needed. Generally, without the use of these supplemental jets, a force of about 12,000 pounds would be required for each bit to sump or shear the six inches needed into the coal seam. This 12,000 pound force, which is well within the present state of the art for continuous mining machines, will be generally the same for both sump and shear operations.

To get an idea of the amount of coal production possible with our invention, assume a six foot high times ten foot wide times six inch deep cut is to be made at a sump rate of an inch per second, a sheer rate of one foot per second, and allow five seconds for the return of the bits to the next cutting position on the coal face. Then the amount of coal with an 80 pound cubic foot density would be 2,400 pounds per cut in 17 seconds per pass. For each minute of continuous operation, this amounts to 4.24 tons per minute of production or 254 tons per hour. During the normal seven hour working shift (eight hour day) this works out to 1,788 tons of coal. Even this figure can be increased if the constant depth linear cutting head were composed of two identical heads mounted in such a manner that one sumped at the roof and cut to the mid-stream height with the other head simultaneously sumping at the floor and cutting up to meet at mid-seam. This type of arrangement would reduce the 17 second cycle per pass by three seconds on the shear and 2.5 seconds on the return. Thus, by using two heads a 48 percent increase over our original estimate could be achieved or a production rate of 2,600 tons per day. This potential rate is much faster than present haulage systems can handle and, therefore, modifications to the haulage systems would be required.

Dust generation during cutting must be reduced to comply with safety regulations of the Mining Enforcement and Safety Administration. At the same time, the President's goal of doubling coal production by 1985 has to be considered. When present high speed rotary cutting heads enter and exit from the coal face at depths of less than one inch, there is an inherent large amount o. dust produced due to the shallow cutting action during entry and exit of each bit but this is increased by regrinding and fanning action of the rotary head. This dangerous condition has been eliminated by our invention without sacrificing coal production.

FIG. 2 schematically illustrates how our invention works: Initially, at the step 1, the cutting head of the continuous mining machine (CMM) is positioned at the mine roof and then sumped into the face as shown by step 2. The coal is then sheared from the top of the seam towards the bottom. Upon reaching the end of its shear cycle (step 3), the cutting head is raised to the top of the mine face as the machine advances (step 4) to a position to begin the sump-shear cycle again. Thereafter or simultaneously with repositioning, the coal is conveyed away (step 5) and the process is started again at step 6 which corresponds to the initial sumping step. As is common in continuous mining operations, once the mined material is sheared off the mine face it may be conveyed away (step 5) from the mine face and mining machine to a shuttle car (not shown) via a loader located beneath the coal mine face. Sumping may also originate at the bottom of the coal face in steps 2 and 6, in which case shearing (step 3) is from the bottom to the top of the coal mine face.

FIG. 5 illustrates how the cutting head of FIGS. 3 to 4 could conceivably be retrofitted on an existing ~~Jeflrex~~ Jeffrey 120 rotary drum continuous mining machine. Basically, this modification would remove the dust producing rotary head and replace it with the nonrotary seven bit head of FIGS. 3 and 4. Appropriate hydraulic cylinders 14 would be powered by electrically powered pumps from a remote electric power source via cable 15 to provide the power to sump and shear the coal face. These cylinders cause the head to move up and down. Shearing could also be accomplished in a horizontal or a side to side direction by orienting the cylinders differently and turning the head 90° so that its bits were aligned in a vertical plane.

Notwithstanding the foregoing illustrative example in FIGS. 3 to 5 of the type of equipment which could be used to practice our method, no limitation of the invention should be construed thereof as the scope and extent of the invention should be measured only by the claims which follow.

We claim:

1. A method of operating a continuous mining machine having a non-rotary type cutting head comprising the steps of:

positioning said machine in an operative position near to the mine face surface to be worked;

sumping into said mine face surface beginning on one of the peripheral sides thereof at a depth of at least three inches with said non-rotary cutting head;

shearing said mine face the same depth as sumped across most of its entire width and height without retracting said cutting head from its sumped depth;

conveying said dislodged material away from said mining machine and mine face; and

repeating the positioning, sumping, and shearing steps in that order.

2. The method of claim 1 wherein said sumping is at a depth of about six inches beginning near the mine roof; and

said shearing step takes place beginning at the same position and continues to the mine face floor.

3. The method of claim 1 wherein said sumping step takes place with a cutting head having a plurality of substantiall identical bits that are horizontally aligned with each other.

4. The method of claim 1 including the additional step of supplying water under a pressure of several thousand pounds per square inch pressure to the mine face prior to said sumping step.

5. The method of claim 4 including the additional step of supplying said water under pressure during said shearing step to the mine face.

6. The method of claim 1 wherein said shearing takes place horizontally from one side of the mine face to the other with said head turned ninety degrees to position the bits in a vertical line prior to sumping.

7. The method of claim 1 wherein said shearing takes place vertically from the top of the mine face to its bottom.

8. The method of claim 1 wherein said sumping step begins near the mine floor at a depth of about six inches; and

said shearing step takes place beginning at the same position and continues to the mine face roof.

9. A method of operating a continuous mining machine have two identical nonrotary type heads comprising the steps of:

positioning said machine in an operative position near the mine face area to be worked;

first sumping into said mine face near the roof at a depth of at least three inches with one of said heads;

sumping into said mine face simultaneously near its floor opposite said first sump at a depth of at least three inches with the other of said two heads;

shearing said mine face with both of said heads, approximately the same depth as sumped, towards each other without retracting said cutting heads from the mine face while shearing;

conveying said dislodged material away from said mining machine and mine face; and

repeating the positioning, sumping and shearing steps in that order.

10. The method of claim 8 wherein said sumping steps take place at a depth of about six inches.

11. The method of claim 8 including the additional step of supplying water under a pressure of several thousand pounds per square inch pressure to the mine face prior to said sumping step.

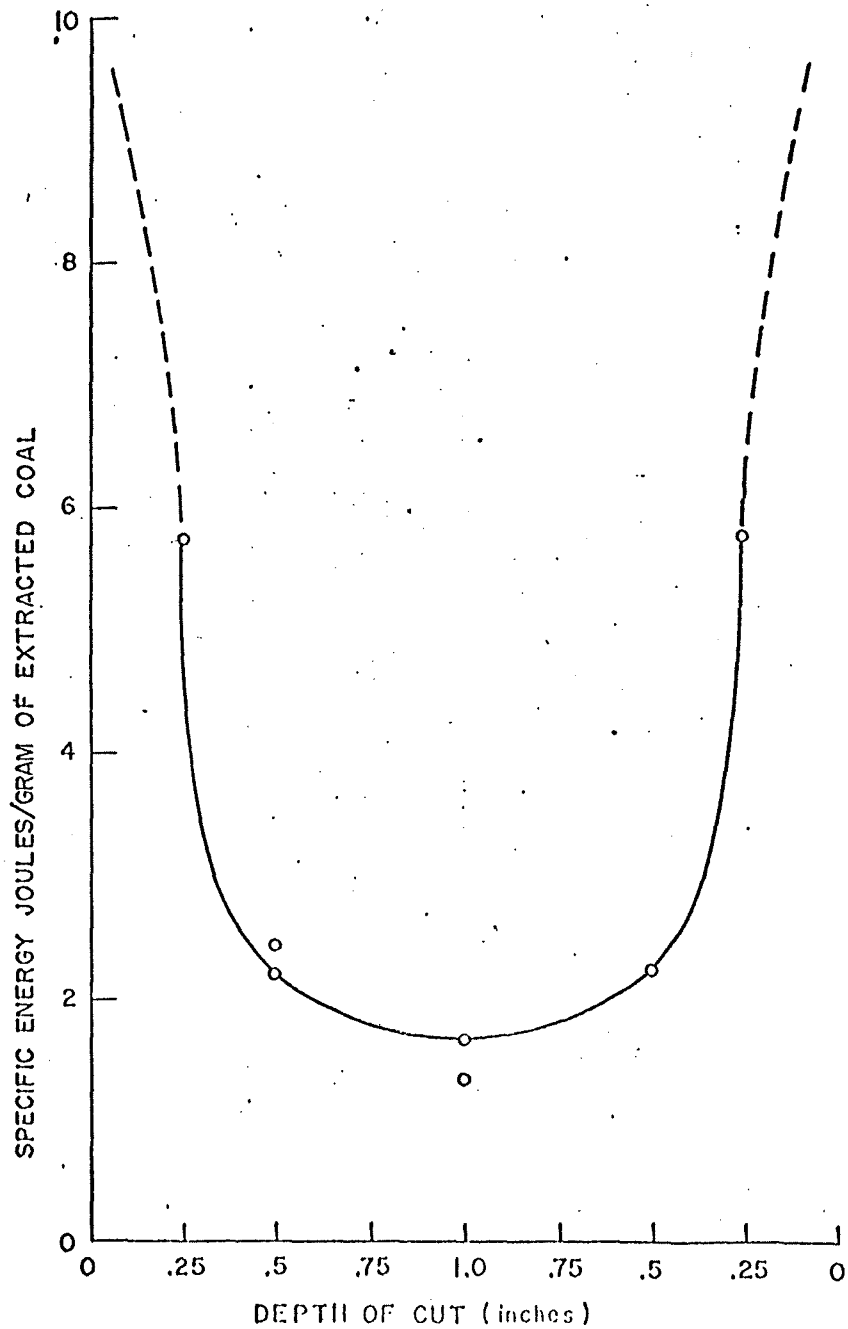

SPECIFIC ENERGY JOULES/GRAM OF EXTRACTED COAL
10
8
6
4
2
0
0
.25
.5
.75
1.0
.75
.5
.25
0
DEPTH OF CUT (inches)

FIG 1

Appendix C

PATENT APPLICATION 702,373; LINEAR ROTARY HEAD CONTINUOUS MINING MACHINE; by W. W. Roepke, D. P. Lindroth, and J. W. Rasmussen

APPENDIX B

Patent Application Serial No. 702,373

MIN 2533

LINEAR CUTTING ROTARY HEAD CONTINUOUS MINING MACHINE

by

Wallace W. Roepke, David P. Lindroth, and Joseph W. Rasmussen

ABSTRACT OF THE DISCLOSURE

The triangular-shaped rotary head mounted on an eccentrically driven shaft rotates at a speed determined by a ring/pinion gear ratio in a manner similar to a Wankel engine, such that cutting tools mounted on the apices of the triangular-shaped rotary head follow a square path traverse the face of the coal seam to be cut at a top corner and make a long linear vertical cut at a constant depth of approximately one and one-half times the diameter of the head/rotary motion, greatly reducing dust generation.

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates to continuous coal mining machines and more particularly to an improved rotary cutting head which permits an increase in production while decreasing respiral dust formed during the cutting process.

DESCRIPTION OF THE PRIOR ART

Many different methods have been employed in the mining of coal and in the past fifty years the development of mechanization in the mining of coal has virtually eliminated manual mining techniques. A large increase in productivity has been obtained by the design and development of the rotary head continuous mining machines which use a multiplicity of bits fixed to a rotating drum which may be advanced into the coal face and moved up or down to fragment the face of the coal seam or formation. With over 2,000 of these machines now in use and accounting for approximately one-half of the production of coal from underground coal mines, the employment of these machines has increased the problem of primary dust generation at the faces during cutting by rotation of the cutting teeth or tools. During the fragmentation process at the face of the coal deposit, which is responsible for the production of both airborne and non-airborne dust, dust generation is determined by such machine parameters as bit type, bit angle, spacing between bits, depth of cut and rotational speed. Research by the Bureau of Mines has involved an analysis of the effect of rotary cutting heads on a continuous mining machine and a determination of where and how primary dust is produced at the face. As result of that analysis, it has become apparent that where a pick or tool bit enters the coal face at zero depth due to its epitroichoidal path, the machine has an inherent potential for high dust production with an associated high energy demand. Thus, presently employed rotary head continuous mining machines are inherent dust producers. It has been determined that the limiting factor to dust reduction is the circular path with continuous entry and exit of each pick or bit in the face.

It is accordingly an object of the present invention to provide a new linear cutting rotary head for a continuous mining machine which will cut at a constant depth.

A further problem in the use of conventional rotary head continuous mining machines is that the constantly changing depth of a bit following an epitroichoidal path does not permit an optimum spacing for the cutting bits. Since deep cutting of coal with rotary machines appears to be the solution to dust generation during cutting, this presents the problem of using fewer bits with wide spacing to accommodate the deeper cutting most effectively which then produces coring at shallow cuts since there are too few bits for shallow cutting. Indeed, this is a paradox because one should cut deep to avoid dust but one increases the amount of dust by coring during deep cuts because there are too few bits. It is obvious, therefore, that the presently designed rotary head machines are therefore not amendable to dust reduction with high productivity due to their inherent design faults. It is apparent, therefore, that an ideal cutting machine would comprise a rotary head for high productivity using only deep linear cuts to reduce dust generation to a minimum while maintaining optimum bit spacing.

It is, therefore, a further object of this invention to provide an improved rotary head continuous mining machine which optimizes these three parameters.

It is a further object of this invention to provide an improved continuous mining machine which may be modified by the substitution of a new rotary cutting head which provides full linear shear and sump cuts without the necessity of modifying all other existing parts including those needed for propulsion, trackage, electric and/or hydraulic motors to the power track, existing boom with vertical and/or horizontal movement and the existing means of collecting cut coal and conveying it to an appropriate shuttle car or belt transport system.

SUMMARY OF THE INVENTION

The present invention comprises a continuous mining machine having a chassis movable in the direction of its longitudinal axis, a boom carried by the chassis for pivotable movement through an arc at right angles to the direction of chassis movement, an eccentric crank mounted to said boom for rotation about an axis at right angles to the longitudinal axis of the boom. A head of triangular cross-sectional shape is rotatable eccentrically on said boom with cutting teeth mounted on the apices of said triangular-shaped head and projecting outwardly therefrom such that during rotation of the head, the cutting bits follow an essentially square path to cause

The present invention is directed to the rotary cutting head assembly, indicated generally at 29 which comprises left and right side cutting heads or drums 30 and 32 when viewed from the front of the machine, Figures 1 and 4. Each cutting head assembly carries fixedly mounted cutting bits of pyramidal configuration as at 34 along particular edges thereof. The present invention is particularly directed to the employment of rotary cutting heads or drums 30 and 32 of triangular cross-sectional configuration mounted and driven such that the apices of the triangular-shaped rotary cutting heads follow a square path with the apices carrying the cutting bits 34 and thus causing the cutting bits to follow a square cutting path and to enter the face of the coal formation C at one (top) corner and make a long lineal cut at a constant depth and over one and one-half times the diameter of the rotary ~~motion of~~ head making the cutting ~~heads.~~ motion.

By reference to Figure 4, it may be seen that the boom 16 terminates at its outboard end relative to chassis 12 in a rotary cutting head drive motor which is indicated generally at 42, this motor being an electric motor, hydraulic motor, pneumatic motor or the like, but being constituted by an outer housing 48 of circular configuration. Rotatably supported to the sides of boom 16 are heads 30 and 32. A crank 44 which has an axis of rotation coaxial with that of the motor housing 48 and being driven therein terminates in eccentric portions 44a at the outboard ends of the crank. Fixedly mounted to the motor housing 48, on each side of motor 42, are ring gears 46 which may comprise integral parts of the circular motor housing 48. Each ring gear carries internal gear teeth as at 52. The crank 44 extends through a circular hole 50 within the center of each ring gear 46, the hole 50 being of sufficient size to permit the eccentric portions 44a of the crank to rotate freely within the fixed ring gears46. In the illustrated embodiment, pinion gears 54 are rotatably mounted on the eccentric portions 44a of the crank 44 so as to rotate about the axis of the eccentric portions 44a in response to rotation of the crank 44. The pinion gears 54 carry gear teeth 55 on their peripheries which are in mesh with the gear teeth 52 of the ring gears 46. Preferably, the ring gears 52 have a gear ratio of four to three to pinion gears 54 so that for every four revolutions of crank shaft 44, the internal eccentric driven pinion gears will have rotated three revolutions.

Each rotary head or drum 30 and 32 takes the shape in cross-section of an expanded (spherical) equilateral triangle. The head incorporates three mounting arms 56 defining a triangle support for the head, the arms being fixedly mounted at 57, Figure 4, to an end face of the pinion gear 54 with arms 56 being fixed at their outboard ends 59 to the drums or heads. The drums or heads comprise three sidewalls or faces as at 60, 62 and 64, which are joined at their longitudinal edges to form apices 36, 38 and 40. All of the members of the rotary head assembly 29 may be formed appropriately of metal with the parts being suitably welded together or affixed by other conventional means. By energization of the motor 42, the drums or rotary heads 30 and 32 will be rotated about the axis of the eccentric portion of crank 44 in such a manner that the drums follow an eccentric ellipse and the tips of each cutting bit 34, Figure 2, follow a square path defined by straight lines except for a slight radius at the corners, where transition of the bit motion occurs from the vertical to the horizontal portion of the rectangular path or vice versa.

Figure 2 illustrates the cutting path of one tip B of one bit 34 during the sump cycle with the shear cycle being the same except horizontal. It is to be noted, that this linear rotary cutting head concept works in similar fashion on all four sides of a box cut. This allows the head to be sumped its full diameter before a shear cut is started, with the shear cut also removing the coal by a linear cut. The only difference between sump and shear is a linear sump cut perpendicular to the bedding and a linear shear cut horizontal to the bedding (not parallel thereto).

Further appreciation of the cutting action of the improved linear rotary cutting head assembly of the present invention may be had by the following mathematical description with reference to Figures 2 and 3. It may be seen that the cutter bits 34 which are mounted on respective apices of the triangular-shaped rotary cutting heads or drums 30 and 32 and which bits incidentally for respective apices are offset relative to the longitudinal axis of the cutting head, will follow a linear path from roof to floor at the mine face during the rotary motion of the ring and pinion. The movement of the tip B of each cutting bit 34 which is shown in Figure 3 for a distance R about the center of the internal gear 46, is covered by the equation:

$$R = \sqrt{E^2 + 2Er(\cos\theta \cos\frac{\theta}{3} - \sin\theta \sin\frac{\theta}{3}) + r^2}$$

θ (theta)

where:

E equals the eccentric length of 1/8 length of pitch diameter or internal ring gear 48, r equals the apex length of the cutting arm from the center of rotary pinion gear 54 (C_{pn}) to tip B_n of cutter bit,

θ equals the angle made by $C_I C_{pn}$ and $C_I B_1$ about the drive axis and the output shown by $\emptyset_n$ = angle $\angle B_n C_I B_1$.

From the above, one complete square cutting path for any bit 34 will be described by π (pi) radians for the angle θ.

It may be seen by reference to Figure 3, and from the equation, that the distance R reaches the maximum at the top (B_1) and the bottom (B_3) corners of the cut where the eccentric arm (C_I, C_{p1}) is at zero degrees (C_{p1}) and 270° (C_{p3}). The minimum distance R is obtained at the horizontal center line of the head (B_2) when the eccentric arm (C_I, C_{p2}) is at 135° (C_{p2}). Using this description, B_n can be plotted for any angle θ at C_{pn}, and this is the manner in which the cutter path shown in Figure 2 was developed.

Further, if the two dimensional figures of Figures 2 and 3 are visualized as being three dimensional with the long dimension being an elongation of the triangle perpendicular to the sheet of drawings, then such a device is seen as capable of carrying several bits suitably spaced at the various apices of the elongated triangular-shaped cutting heads as seen in Figure 1. Thus, each bit at any apex of the eccentrically rotated triangles for both heads or drums will follow a path best described as a square. This permits the triangular-shaped head to be mounted horizontally on a mining machine boom as a replacement for the standard rotary head as illustrated, and when the triangular-shaped head is driven by an appropriately geared ring and pinion in an eccentric path, then the cutting bits 34 mounted at the apices will take a square face cut at a constant depth after being sumped.

From the above, laboratory linear cutting experiments combined with the theoretical analysis of the rotary cut lead to the conclusions as follows:

(1) Both specific airborne respiral dust and specific non-airborne respiral dust are monitonically increasing functions of specific energy.

(2) Specific dust and specific energy are inversely proportional to the depth of cut.

(3) An optimum value of the space to depth ratio of the cutting bits exists between 2 and 3 for linear cutting.

(4) Rotary cutting has an inherent bit spacing problem since the correct bit spacing is only obtained at maximum depth for each bit.

(5) Rotary cutting is an inherently poor low volume recovery in the first 60% of advance distance for each bit on the drum making this portion of the rotary cut highly inefficient with abnormal amounts of dust.

(6) Specific airborne respirable dust generated from the rotary cut is greater than that generated from the linear cut.

In conclusion, the laboratory results show that the greatest dust generated per unit volume occurs at cuts less than one inch deep, and it becomes apparent that all cutting should occur deeper than one inch. From the analysis of the rotary cut, it is equally apparent that when a bit enters the coal face at zero depth, goes to some maximum depth, and exits the face at zero depth due to its mechanical configuration, as in the standard continuous mining machine, it is inherently a high energy, dusty cutting mechanism.

The linear cutting rotary head modified continuous mining machine of the present invention as described above completely eliminates these problems and minimizes respirable dust generation. With respect to the illustrated embodiment, it should be noted that the drum cross-section may take the shape of modified equilateral triangles whose sides may be changed symmetrically into other forms of conic section as are compatible with gear sizes and head sizes needed for the coal seam being cut, and that auxiliary fragmentation subsystems may be placed at the cutting bits 34, the subsystems may include thermal heaters, hydraulic impact rams, electromagnetic heating, mechanical impact, high pressure liquid jets or any combination of the same.

WHAT IS CLAIMED IS:

1. A continuous mining machine for mining a horizontally extending coal vein or the like, said machine comprising:

a chassis movable longitudinally parallel to said vein

a boom carried by said chassis for pivotable movement at right angles to the direction of chassis movement,

shaft means mounted to said boom for rotation about its axis at right angles to the longitudinal axis of said boom,

means for rotating said shaft,

at least one rotary cutting head, triangular-shaped in cross section mounted on said shaft for rotation about an elliptical eccentric path, and

longitudinally spaced cutting bits mounted on said triangular-shaped rotary head at the apices thereof;

whereby, said cutting bits follow a square cutting path during rotation of said at least one rotary head and effect linear shear and sump cuts of said coal vein during rotation thereof.

2. The continuous mining machine as claimed in claim 1, wherein said shaft means comprises a crank arm mounted for rotation about an axis at right angles to the longitudinal axis of said boom, said crank arm having an eccentric portion, pinion means is mounted on said eccentric portion for rotation about the axis of the eccentric portion of said crank, a ring gear concentric with the axis of rotation of said crank and having internal gear teeth in mesh with gear teeth on the periphery of said pinion for controlling the rotational ~~speed~~ path of said pinion as said crank rotates with respect to said ring gear, and means for fixedly mounting said at least one triangular-shaped cutting head to the side of said pinion gear so as to rotate eccentrically with respect to said crank axis.

3. The continuous mining machine as claimed in claim 1, wherein: said at least one rotary head comprises three edge joined faces, said cutting bits project outwardly from said at least one cutting head at said apices and are generally in line with the trailing face at each apex in terms of the direction of rotation of said head.

4. The continuous mining machine as claimed in claim 1, wherein said gear ratio between said pinion means and said ring gear is 3 to 4.

said bits to enter the face of the coal formation at the front of said continuous cutting machine linearly to effect a sump motion and to make a long linear cut at constant depth a distance of approximately one and one-half times the diameter of rotary ~~motion of~~ said cutting ~~head~~.

Preferably, the bits are mounted to the apices generally longitudinally in line with the adjacent trailing face of the triangular head in terms of the direction of rotation of said head. The faces of the triangular-shaped cutting head may comprise spherical segments. A triangular-shaped rotary cutting head may be mounted on each side of the boom with the boom centered with respect to the chassis and the bits which are longitudinally spaced along the apices of each triangular shaped head are preferably longitudinally offset with respect to the bits of the other apices of the same head.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of one embodiment of the improved linear cutting rotary head continuous mining machine of the present invention.

Figure 2 is a diagrammatic view of the cutting path of the linear cutting rotary head of the machine of Figure 1 during machine operation.

Figure 3 is a diagrammatic view of the cutting path of the linear cutting rotary head of the machine of Figure 1 illustrating the change in position of the parts effecting the movement of the cutting bits performing the cutting action.

Figure 4 is a front elevational view of a portion of the machine of Figure 1, partially in section, illustrating the construction of the linear cutting rotary head assembly.

Figure 5 is a sectional view of a portion of the linear cutting rotary head assembly of Figure 4 taken about line 5-5.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference to Figures 1, 4 and 5 illustrates the present invention as a modification to a conventional continuous rotary head mining machine 10. In that respect, the machine 10 is of conventional design and consists of a chassis 12 being mounted for movement in the direction of the longitudinal axis of the chassis 12 by means of tracks as at 14 or the like, permitting the machine to move forwardly with respect to a coal formation or vein C and to effect a cutting action with respect to that coal deposit; whereupon, the cut coal C' which breaks up during the cutting action falls by gravity in front of the uncut portion of the coal formation on a scoop or shovel 24 which is fixed to the chassis 12 by hinge connection means 25, the scoop or shovel 24 carrying appropriate lateral walls 26 which tend to guide the cut and broken coal fragments towards the center of the shovel 24 for removal to the rear of the machine by a conveyor mechanism indicated generally at 28. This portion of the machine is conventional as is the structural make up and operation of pivotable boom 16. The boom 16 is pivotably supported at the rear of the machine by means (not shown), such that it rotates through a vertical arc caused by extension and retraction of a pair of pistons 20 supported by hydraulic cylinders 18 and coupled to the boom by means of trunions 22. Again, this portion of the machine is conventional and is unmodified by incorporation of the present invention, the boom 16 being raised or lowered to present the rotary cutting head assembly to different positions with respect to the coal formation C.

5. The continuous mining machine as claimed in claim 2, wherein said gear ratio between said pinion means and said ring gear is 3 to 4.

6. The continuous mining machine as claimed in claim 3, wherein said gear ratio between said pinion means and said ring gear is 3 to 4.

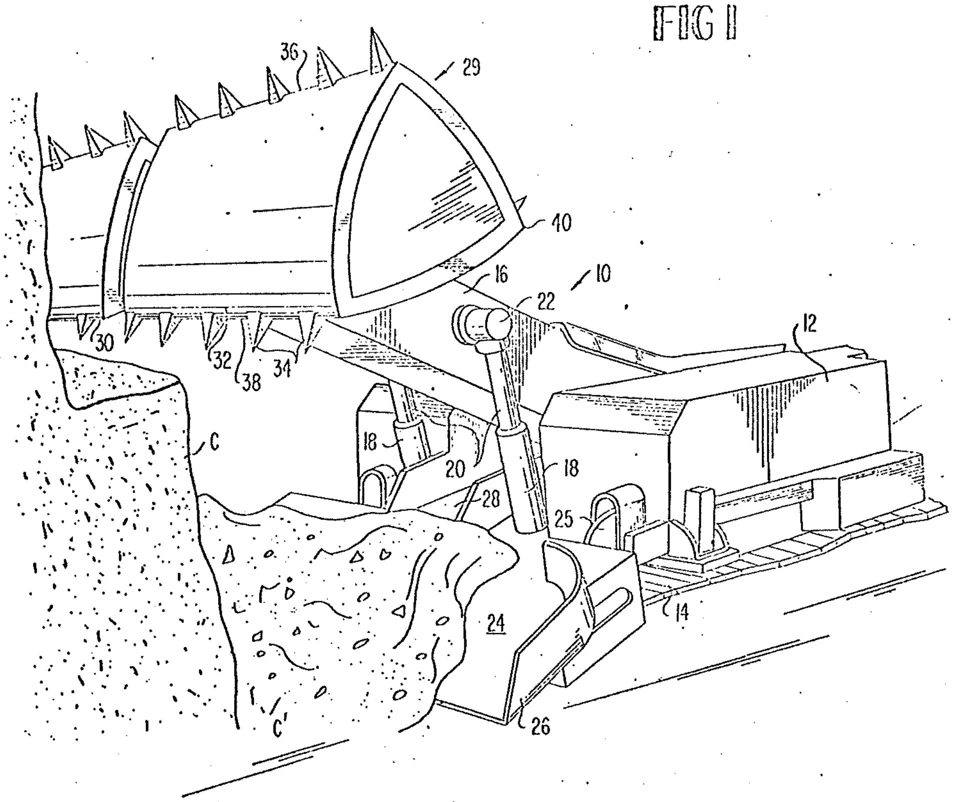
7. The continuous mining machine as claimed in claim 1, wherein a plurality of bits are carried on said at least one rotary cutting head on each apex thereof, and wherein the bits of one apex are longitudinally offset with respect to the bits carried on another apex.

8. The continuous mining machine as claimed in claim 2, wherein a plurality of bits are carried on said at least one rotary cutting head on each apex thereof, and wherein the bits of one apex are longitudinally offset with respect to the bits carried on another apex.

9. The continuous mining machine as claimed in claim 1, wherein the longitudinal faces of said at least one rotary cutting head comprise spherical segments joined at their longitudinal edges.

10. The continuous mining machine as claimed in claim 1, wherein said rotary cutting heads comprise two in number, said means for rotating said shaft comprises a motor fixedly mounted to said boom, and said rotary heads are operatively coupled to said motor on respective sides of said boom.

FIG I


36
29
40
10
16
22
12
30
32
38
34
C
18
20
28
18
25
24
14
C'
26

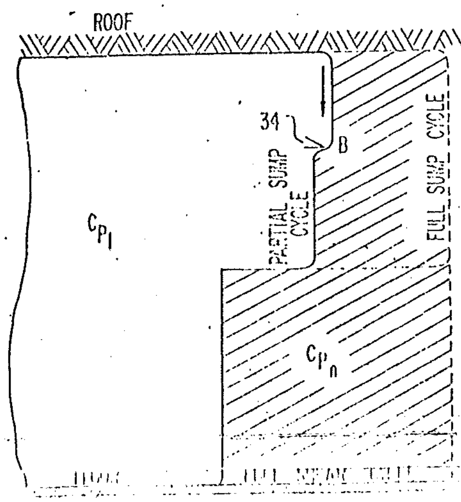

ROOF
34
B
PARTIAL SUMP CYCLE
FULL SUMP CYCLE
C_{P_1}
C_{P_n}

FIG 2

FIG 3

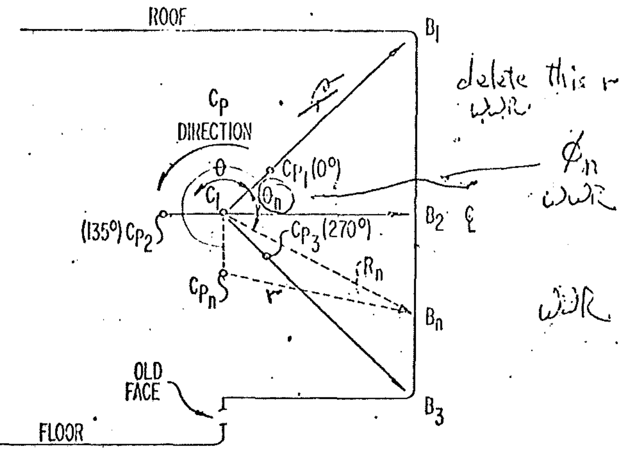


FIG 4

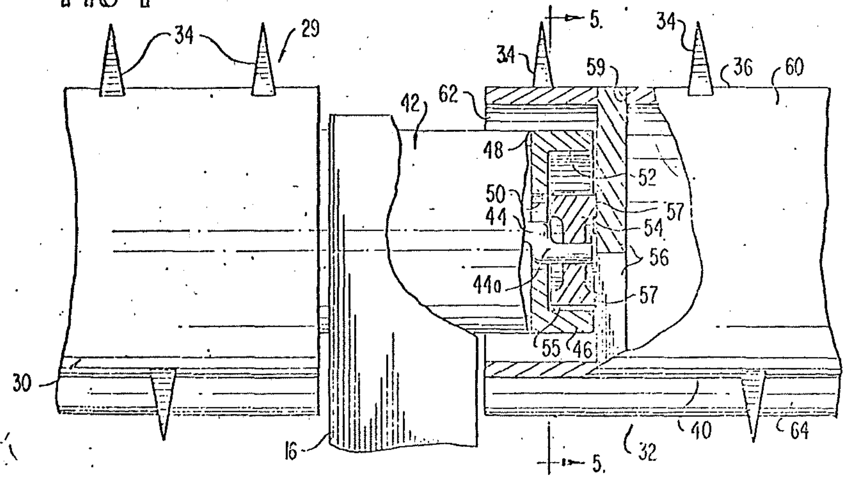
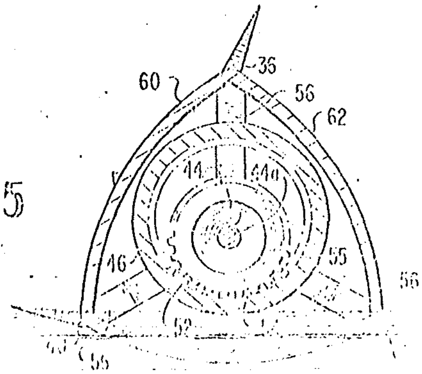


FIG 5



Appendix D

PATENT APPLICATION 732,676;
AUTOMATIC FACE TRANSFER
LINEAR CUTTING ROTARY HEAD
CONTINUOUS MINING MACHINE;
by W. W. Roepke, D. P. Lindroth,
and R. J. Wilson

Patent Application Serial No. 732,676

SPECIFICATION MIN 2563

BE IT KNOWN THAT we, WALLACE W. ROEPKE, DAVID P. LINDROTH, and RICHARD J. WILSON, have invented a new and useful improvement in an AUTOMATIC FACE TRANSFER LINEAR CUTTING ROTARY HEAD CONTINUOUS MINING MACHINE of which the following is a specification.

Abstract of the Disclosure

A coal mining apparatus and its method of use in which a continuous mining machine removes and transfers cut material reducing airborne respirable coal dust generated in the cutting and collection process. The conventional high speed head rotating with the bits going forward at the top is replaced by a triangular shaped dished out linear cutting head rotating with the bits mounted at the apexes going rearward at the top. This produces a box cut in the mine face with a square cross-section. After the head has made a box cut by sumping the full head diameter beginning at the mine floor, it is sheared upwardly producing a linear shear cut. This shear step is at a constant depth equal to the complete cutting head diameter. The modified cutting head is used as part of the loading and transfer mechanism. This is accomplished by reversing its direction of rotation and cutting on the upstroke from floor to roof so that the head acts as a bucket collecting the cut coal, then transfered to an adjacent transport system which allows the cut coal to be loaded and conveyed away from the mine face without further dust generation due to free fall fracture on the floor or intermediate handling by a

dust generating gathering head mechanism. To insure that the coal is consistently discharged at the proper position, a movable bridge conveyor and follower assembly is used with the cutting head.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention is a continuous mining machine which allows coal to be cut from the mine face and transported therefrom while at the same time greatly reducing primary and secondary generation of airborne respirable dust in the process.

Description of the Prior Art

Two copending United States patent applications commonly assigned to the United States Government constitute the best known prior art relating to this invention. These include the application bearing Serial No. 604,566, filed August 14, 1975, entitled "Method of Operating a Constant Depth Linear Cutting Head on a Retrofitted Continuous Mining Machine," by W. W. Roepke et al (hereinafter referred to as Method of Linear Cutting); and the application bearing Serial No. 702,373, filed July 2, 1976, entitled "Linear Cutting Rotary Head Continuous Mining," by W. W. Roepke et al (hereinafter referred to as a Linear Cutting Rotary Head). The essential difference between this invention and what these two inventions disclose is the method of operation of the rotary head and its associated transport system. Thus, the invention disclosed in the Linear Cutting Rotary Head disclosure has been modified by this invention to allow it to be used to accomplish the Method of Linear Cutting plus a loading and transporting function has been added which at the same time reduces secondary airborne respirable dust generation.

SUMMARY OF THE INVENTION

To practice the method taught by our invention, a continuous mining machine has a retrofitted rotary head which is shaped in cross-section like a dished out Reuleaux or equilateral triangle. Connected thereto is at least one bridge conveyor. Initially, the machine is positioned near the mine working face. Beginning near the mine floor face with its head rotating, the head is then sumped in the face until the head's full diameter is reached. By rotating the head in the upstroke direction, the cut materials are projected upward and over it. Apparatus is provided to load and transport the cut materials from the mine face by a bridge conveyor and follower assembly located immediately behind the cutting head's discharge and near the front end of an attached boom support. After sumping takes place, the mine face is sheared its total height at constant depth the same depth as sumped by raising the cutting head.

The apparatus to practice the invention has a rotatable cutting head which is shaped in cross-section like a dished out equilateral triangle. This head is movably attached to a bridge conveyor. The head and its bridge conveyor move together due to the follower assembly so that when the head as a unit is moved forward or up its conveyor maintains the same relative position with respect to it. Gathering arms below the bridge conveyor may be combined with it to feed cut material to a rearwardly located main conveyor.

The primary object of this invention is an improved method and apparatus for use with a continuous mining machine having a linear cutting rotary head.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a isometric view of the front end of the preferred embodiment at mine face after a partial sump cycle has taken place.

FIG. 2 and FIG. 3 are pictorial views showing a conventional continuous mining machine as modified by incorporating the preferred embodiment of our invention therein.

One of the most persistent problems encountered in mining operations, especially coal mining operations, employing machines to cut the material to be mined is that of maintaining or increasing production while at the same time reducing the generation of airborne respirable dust. The mentioned invention entitled Method of Linear Cutting discusses this problem in detail and points out one proposed solution wherein the amount of respirable dust generated is substantially reduced without sacrificing production. However, to achieve the same desired amount of dust reduction and increase production, a cutting head with a rotary motion to achieve a linear cut was proposed and described in the previously referenced Linear Cutting Rotary Head patent application. This type of linear cutting action with a rotating cutting head may be achieved by using a head which is configured like a Reuleaux triangle or an equilateral triangle in cross-section. Specific details on this type of cutting head and a drive mechanism to allow it to make box cuts are found in the mentioned Linear Cutting Rotary Head patent application. The subject matter of these two background inventions will not be repeated herein but is specifically incorporated herein by reference. It is necessary to understand their basic principles and the proposed solutions to the problems presented to fully understand this invention. Briefly, this invention takes the Linear Cutting Rotary Head and modifies its method of operation and structure. It does this by utilizing the sump and shear cycle of the Method of Linear Cutting in which the cutting head is first sumped into the mine face near the mine floor and then sheared at a constant depth to the roof with the cutting head rotating in reverse to the direction described in the Linear Cutting Rotary Head patent application and modified in such a manner as to automatically collect and transport the cut coal in buckets designed into the cutting head.

Broken coal freely falling from the place where cut causes large amounts of secondary dust generation as does the typical gathering arm mechanism for a continuous mining machine (CMM). To further reduce airborne respirable dust generation, the secondary dust generation is controlled at the face by this new cutterhead design in association with a new handling and transportation system as proposed which eliminates the major portion of the free falling cut coal.

The cross-sectional view of the working mine face illustrated in FIG. 1 schematically shows how the face would look after a partial sump cycle. As viewed, the dished out equilateral triangle shaped cutting head rotates in a clockwise direction and has sumped part of its full sump cycle. The unique combination of the shape of the cutting head and internal gearing in its attached boom allows it to make a box cut with slightly rounded corners as more fully discussed in the Linear Cutting Rotary Head patent application. With such a box cut at the mine face, it has long been a problem to find a suitable drive train. We have solved this drive train problem and it is this type of drive train or any similar combination of component parts giving the same path to the apexes which we contemplate would be used to rotate the cutting head of our invention. Since the cutting head in this invention is shaped in cross-section like an equilateral triangle such that its configuration follows the path described by Reuleaux, as disclosed in FIGS. 1 and 5 of the copending Linear Cutting Rotary Head patent application, it will cut out a square vertical face in cross-section or box cut in volume when its full sump cycle has been completed. FIG. 1 shows a side view of this square cut out section in dotted line format. One type of drive gear train that could be used in the front end of the boom to rotate the triangular shaped cutting head and achieve the desired square hole cut is described in the commonly assigned copending U.S. patent application having Serial No. 705,361, filed on July 14, 1976, by Roger J. Morrell et al entitled Square Hole Drill.

After the full sump cycle is completed the entire depth of the cutting head, the shear cycle begins. In accordance with the principles of the method described in the patent application on the Method of Linear Cutting, this shearing is accomplished, at a constant depth, without removing the cutting head from its full sumped depth, from the mine floor to mine roof. This linear cut during the sumping step is perpendicular to the bedding (direction X in FIG. 1) making up the coal seam while the linear cut during shear is parallel to the bedding shown by the Y arrow in FIG. 1. The clockwise rotation of the triangular shaped cutting head 1 as shown in FIG. 1 causes its cutting bits 3 to dislodge the coal 5 from the mine face and transport it over the head and past the side of the support boom 7 until it is deposited on the adjacent power driven attached bridge conveyor belt 9. The number of bits extending for the apexes of each of the two triangular heads is determined by the depth of cut desired. Usually the spacing between adjacent bits is 2 to 3 times the depth of cut desired with fewer bits being used for deeper cuts in the coal. The elongated boom extends in the same direction as the bridge conveyors and is located between them. In order to insure that the material being discharged from the cutting head lands on the bridge conveyors, a follower mechanism 11 is employed. Essentially this mechanism causes the bridge conveyors to follow their cutting head so that they always remain in substantially the same relative position with respect thereto. It is made up of a triangular shaped track 13 recessed in the side of the head, a roller

15 which freely rolls in this track of the head, a link arm 11 connected to the track roller at one end, a pivot connection 19 at the other end, and an elongated roller 21 with a tapered center portion which rides under the end of conveyor 9. The conventional power source to drive the bridge conveyors is not shown. Dished out recessed portions 23 of the head allow for collection of the fragmented coal during cutting operations. Once the cutterhead 1, support boom 7, and the follower mechanism 11 have advanced to their full sump cycle cut - to the left in FIG. 1 - the support boom is used to raise the rotating cutting head thereby beginning the shear cycle. When the full sump and shear cycles have been completed, each of the cutterheads (preferably two separate aligned ones with the boom between as shown in the figures) will have made a box cut from the floor to roof the depth of the sumped head.

Not only may the equilateral triangle cutting head be used with the modifications indicated and in the way described to reduce primary respirable generation during cutting, but the head assembly could be further modified as shown in FIGS. 2 and 3 to further reduce secondary dust generation produced by falling coal and excessive gathering arm handling. Essentially, the modifications consist of adding a transportation system to the cutterhead. As is described and shown in FIGS. 2 and 3, a follower mechanism 11 mechanically links the bridge conveyors directly to the cutterhead to impose an oscillatory motion on the bridge conveyors in synchronization with the rotation of the cutting heads. Guides in each of the head recess sections funnel the fragmented collected coal to the center of the head before they are dumped into the rearward bridge conveyors. The cutterhead is revolving in a direction opposite to that described in the Linear Cutting Rotary Head invention so that it cuts on the upstroke instead of the down stroke. In this way it gathers the coal cut from the seam in the cutting head recess 23 and carries it over the top of the cutterhead to the lower rearwardly located bridge conveyor 9. This arrangement reduces further secondary airborne respirable dust generated by free fall fracture on the floor, since the coal gathering and transportation system employs a conventional movable center support boom modified with two bridge conveyors, and a follower mechanism for each conveyor which keeps the conveyors in close proximity to and at the same elevation as the cutting head. Beneath this transportation system is a pair of conventional gathering arms 25 with a base pan 27. These may be utilized as a floor trimming device and to gather minor amounts of coal which have either missed or fallen off the bridge conveyors. Raising the support boom causes its cantilevered attached cutting head to rise vertically. Along with this raising action the follower mechanism attached to the CMM 29 at its pivot connections 33 are the two tension springs 35. These springs keep the elastic belts forming the bridge conveyors taut throughout the oscillatory motion of the follower mechanism as it follows the rotation of the cutting head. Near the bridge conveyor's pivot connection are two (FIG. 3) slanted chutes 31 to guide coal from the bridge conveyor belts to the lower rotating main conveyor belt system 37. A second roller 43 tapered at its center can also be used at the conveyor's other end to cradle the mined material. Thus, immediately after the coal is cut by bits 3 it is first guided by guides into dished out cutter head cavities 23 and momentarily cradled there until deposited on the inclined bridge conveyor. Thereafter, chutes 31 direct the coal to the underlying moving main conveyor 37 and away from the mine working area. Should any small fragments fall off the conveyor or miss it entirely they too will be gathered in by arms 25 and fed via their pan and then to the main conveyor.

Our invention can be seen to consist of modifications to the conventional rotary head continuous mining machine with additional material handling and transportation devices. Either the main conveyor belt 37 or a shuttle car may be used to convey the mined material from the mine face. The other parts of the system, including those used to propel the CMM and boom, may be conventional. These would include electric and/or hydraulic motors for the CMM and boom. For example, the CCM could be any electrically operated (via cable 39) conventional drum type miner with a high speed head like Model 12 CM manufactured by the Joy Manufacturing Company of Pittsburgh, Pennsylvania. Either DC or AC current may be used to power this machine on its tracks 41 to operate it as described.

The stated objective of our invention is to reduce dust generated at the mine face, especially primary and secondary airborne respirable coal dust, produced by the cutting and gathering mechanism while increasing production potential. It has accomplished this objective by using a new linear cutting rotary head which cuts at a deep constant depth with low rpm. The particular method selected to reduce airborne respirable dust is based on both experimental and theoretical analysis. From these sources we have concluded that:

1. Both specific airborne respirable dust and specific nonairborne respirable dust are monotonically increasing functions of specific energy.
2. Specific dust and specific energy are inversely proportional to the depth of cut.
3. An optimum value for the space to depth ratio of the cutting bits exist between 2 and 3 for linear cutting.
4. Conventional rotary cutting has an inherent bit spacing problem since the correct bit spacing is only obtained at maximum depth for each bit.

5. Conventional rotary cutting has an inherently poor, low volume recovery in the first 60 percent of advance distance for each bit on the rotary head drum making this portion of the rotary cut highly inefficient with abnormal amounts of dust.
6. Specific airborne respirable dust generated from the rotary cut is greater than that generated from the linear cut.
7. Conventional rotary cutting does not permit an optimum bit angle to be defined since the bit attack angle varies constantly during cutting.

From these conclusions we have determined that an ideal continuous mining machine should incorporate a rotary head for high productivity using only deep linear cuts to reduce primary dust generation to a minimum with an automatic collection device for the cut coal or other material which would reduce secondary dust generation caused by impact on the floor or by action of a gathering head mechanism. As described herein our invention accomplishes all of these desired results.

One alternative embodiment of our invention would substitute a power takeoff from the main drive shaft with a single mechanical linkage in place of the follower mechanism. When this is done, oscillatory motion is provided to the bridge conveyors to allow it to be in the proper position to receive the discharged coal.

Another embodiment would use a flat plate extender beyond the end of the bridge conveyor as a collector for any material falling between the cutterhead and conveyor. By appropriate power means, e.g., hydraulic conveyors or a power takeoff from the main drive shaft, the flat plate may be dumped into a conveyor. Raising means could be employed to maintain the plate at an angle during the times it is not being raised to dump the collected coal or being forced down to allow the cutterhead to pass. The half-raised position better facilitates collection of the falling cut material and improves the efficiency of the conveyor system by maintaining the collected coal in close contact with the main conveyor belt.

It is a characteristic feature of our invention that it will make deeper cuts than most presently operating continuous mining machines. As such, we estimate coal production can be increased from 10 to 20 tons for each minute of operation as the cutting head is slowly rotating at 6 to 10 revolutions per minute. Coupled with this increase in production will be the reduction of airborne respirable dust generated by more than 95 percent from that generated by presently used conventional CCMs. When this happens, methane ignition caused by frictional heat at the coal mine face is also dramatically reduced.

Although our invention was designed to operate mainly in coal mines to reduce the generation of airborne respirable dust at the mine face with increased production, its principles can be applied to any other type of mining operation where the same objectives are desired. None of the stated details describing coal mining operations or any other features should be used to limit the scope and spirit of our invention which is to be measured only by the claims which follow.

We claim:

1. A continuous mining machine assembly comprising:

a main machine body for moving said assembly with respect to the mine face;

a support boom movably connected to said machine body near its front end;

a rotatable cutting head operatively mounted on said boom near the end opposite to where it is connected to said body and movable vertically therewith, said head having a body whose outer cross-sectional configuration resembles an equilateral triangle, said head also having material retaining recesses;

a bridge conveyor extending and movable in the same direction as said boom for receiving cut mined material discharged from the head and transporting said same material away from the mine face; and

follower means connecting said bridge conveyor to said cutting head for causing said bridge conveyor to follow the rotation of said rotating head and to remain in substantially the same material receiving relative position with respect thereto.

2. The assembly of claim 1 wherein said cutting head comprises:

at least one cutting bit extending from each of the apexes of the equilateral triangle body and said material retaining means is formed by recesses within the body forming the sides of the equilateral triangle for momentarily retaining cut material therein during at least part of the head's rotational cycle.

3. The assembly of claim 2 also including means for rotating said head in the boom which upon rotation of said cutting head causes its bits to transverse a generally square trajectory when viewed in the same cross-sectional direction as the head's equilateral triangle.

4. The assembly of claim 1 wherein:

said follower means comprises a track mounted on said head and a freely mounted track follower extending therefrom towards said bridge conveyor.

5. The assembly of claim 4 wherein said track follower is pivotally mounted to a roller which is operatively associated with the bridge conveyor.

6. The assembly of claim 1 wherein said bridge conveyor is a movable elastic belt, and also including biasing and pivoting means attached to the bridge conveyor at its end remote from said head to keep the bridge conveyor belt taut and to allow said conveyor to be moved in a vertical direction.

7. The assembly of claim 1 also including a material gathering pan attached to the lower fromt end of said machine body;

material gathering arms within said pan to convey materials deposited therein away from the mine face; and

a main conveyor system operatively associated with the discharges from said bridge conveyor and material gathering arms to move material further away from the mine working area.

8. The assembly of claim 1 also including a second identical bridge conveyor with its own associated second cutting head disposed on the opposite side of the support boom; and

material directing means to guide the discharges from the bridges conveyors to a common output.

9. A method of mining material with a continuous mining machine having a rotatable cutting head whose cross-sectional configuration resembles a Reuleaux triangle comprising the steps of:

sumping said head while it is rotating into the mine face beginning near the mine floor to cut out a box cut therein when viewed in cross-section; and after sumping said head substantially its entire depth, steering the mine face in an upward direction substantially the same depth as sumped, without removing the head, up to the mine roof.

10. The method of claim 9 wherein said sumping step takes place in a generally horizontal plane to produce deep linear cuts which are perpendicular to the bedding planes as said cutting head cutters cut on the up stroke at the mine face; and

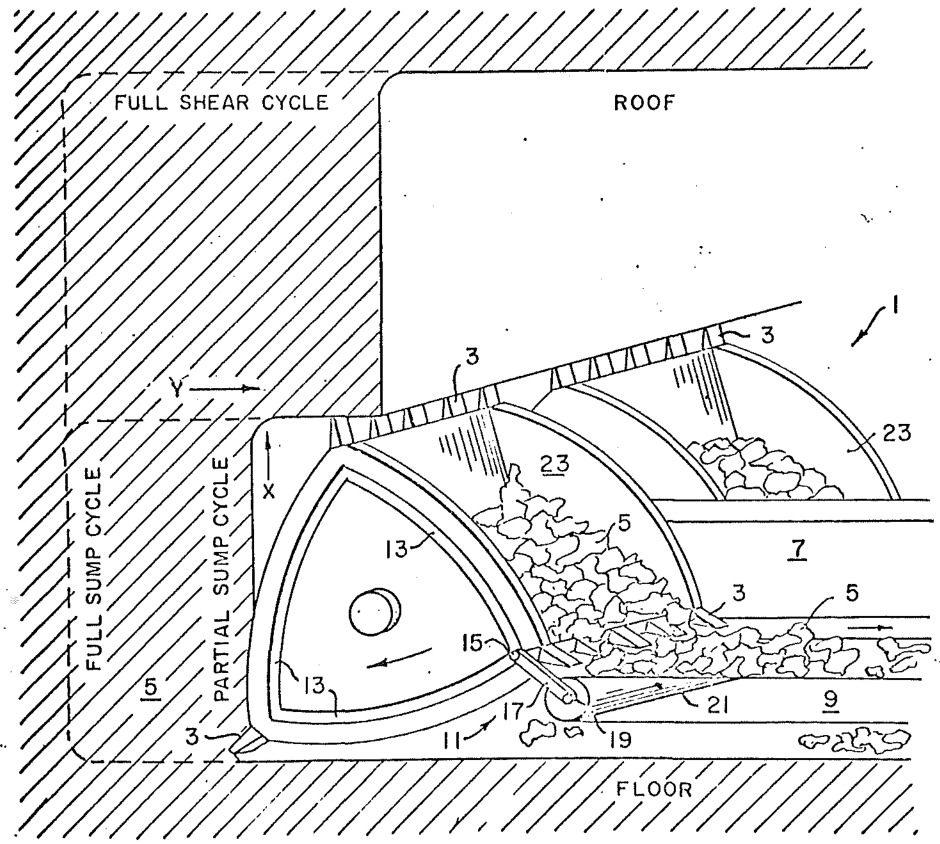
said shearing step takes place in a generally vertical plane to produce deep linear cuts parallel to the bedding planes as said linear cutting head at its upper side rotates towards said continuous mining machine.

11. The method of claim 9 also including the additional steps of transporting the cut material away from the mine face by a movable conveyor located adjacent the discharge from the cutting head; and

oscillating the front end of the conveyor so that it follows the rotation of the cutting head to remain substantially at the same discharge area therefrom.

12. The method of claim 11 also including the step of collecting the cut material in the cutter head on the cutting head's upstroke and retaining it there before transporting it to the conveyor located downward of the head.

13. The method of claim 11 including the step of guiding said deposited cut material from the discharge end of the movable conveyor to a main mine conveyor system.



FULL SHEAR CYCLE
ROOF
FULL SUMP CYCLE
PARTIAL SUMP CYCLE
FLOOR
Y
X
1
3
5
7
9
11
13
15
17
19
21
23

FIG. 1.

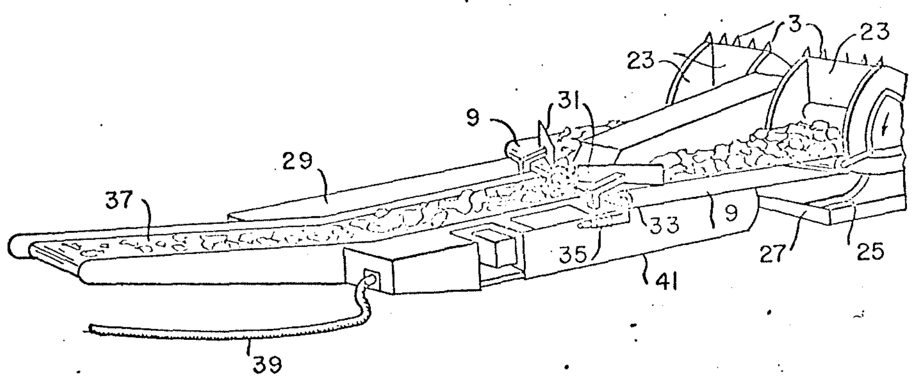


FIG. 2.

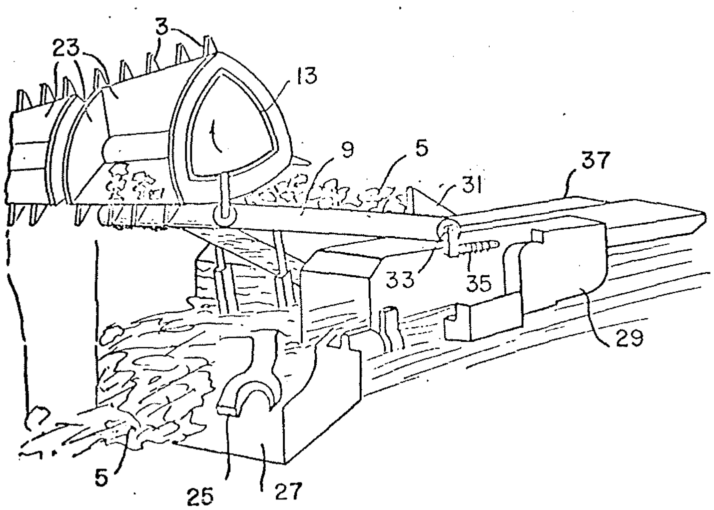


FIG. 3.