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OCTOBER 1983

DESIGN, FABRICATION, AND TESTING OF A BIDIRECTIONAL AUGER

Contract J0333910

ESD Corporation

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San Jose, CA 95126

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16. Abstract (Limit 200 words) From September 1978 to December 1983, ESD Corporation (formerly a Division of FMC Corporation) undertook the development and testing of a bidirectional auger under contract with the U.S. Department of Energy. Underground testing began in August 1981 at Peabody Coal Company's Marissa Mine near Marissa, Illinois. The auger was developed to increase mine production and coal recovery without increasing land subsidence. It bored 4-foot-diameter by 10-foot-deep holes into pillars on 7-foot centers (each hole recovering 5 tons). All operating during this test was performed by maintenance personnel with the goal of finding ways to increase the machine potential. The maximum excavation rate achieved was 1.4 tons per minute. It was concluded that the concept of drilling short holes to extract coal from underground pillars without surface subsidence was practicable with a wheel mounted auger, but that more power was desirable for this mine, and that the hydraulically driven augering system that provided experimental versatility was not sufficiently reliable for production use.			13. Type of Report & Period Covered Final Report Sept. 1978 to Dec. 1983	
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CONCLUSIONS AND RECOMMENDATIONS

Testing of the bidirectional auger between late 1981 and mid-1982 demonstrated its potential as a viable and economic method of extracting coal from underground pillars. Primary reasons for not meeting the projected production goal of 250 tons per shift were inadequate power to turn the augers, insufficient thrust on the augers, rapid cutter bit wear, and high machine downtime for unscheduled maintenance.

Because of the large worldwide interest expressed in the bidirectional auger and the optimism expressed by individuals at the demonstration mine and its parent company, further development of a viable auger for extraction of coal from underground pillars is recommended.

1.0 INTRODUCTION

Department of Energy Contract ET-78-C-01-3150, "Design, Fabrication, and Test of a Bidirectional Auger," was awarded FMC Corporation on September 30, 1978. The objective of the program was to develop an underground auger miner (see Figure 1) for removal of coal from pillars in previously developed sections of a mine.

This report documents the activities, accomplishments, and problems encountered during the engineering phase, fabrication, and in-mine testing phases of the program.

In April of 1980 the contract number was changed to DE-AC01-78ET10036.

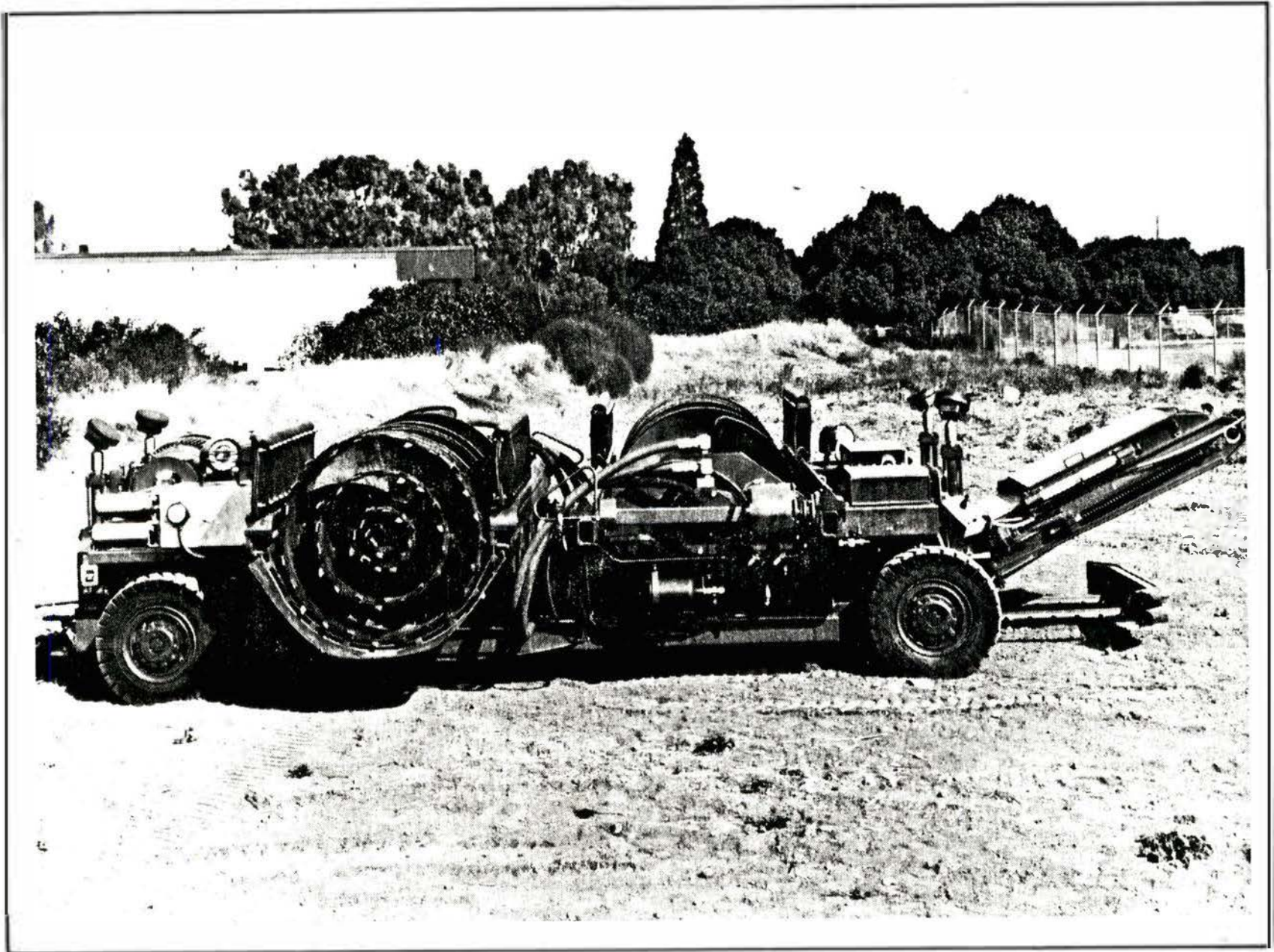


Figure 1 BIDIRECTIONAL AUGER

2.0 SUMMARY

2.1 HARDWARE DEVELOPMENT

Several experimental augers have been built and tested in underground coal seams since the 1930's. These augers failed to achieve continuing production status for many reasons. Badger Manufacturing Company revived interest in augers starting in 1972 by incorporating various improvements into a series of prototype machines. In 1974, they announced that the Coalbadger auger was available for limited production.

Preview of the prototype auger revealed some areas of design that ESD felt could be improved upon before going underground. ESD proposed a development plan to modify a Coalbadger to incorporate a means of ventilating the borehole to dilute methane released during cutting and to add conveyors that would remove the cuttings from the throat of the borehole.

Under a Bureau of Mines contract, ESD purchased and modified a Coalbadger which was demonstrated underground at Consolidation Coal Company's Ireland mine in Moundsville, West Virginia. Although the auger produced a substantial tonnage of coal, the test results identified additional improvements that would increase the auger's production potential. R-D 44

Under a Bureau of Mines contract later transferred to the Department of Energy, ESD redesigned and modified its first prototype by adding devices or features that shortened cycle time, improved maneuverability, and facilitated alignment with the coal seam. The modified prototype, now the second prototype, was also tested at the Ireland mine. Although these tests showed an average shift production increase of 125 percent, the average shift production of 88 tons per shift was short of the 123-ton-per-shift goal. The goal of 200 tons per shift maximum was also never reached, although output was increasing when the test was terminated. Guidance of the borehole over distances up to 100 feet was a major problem in meeting a viable production goal.

Concurrent with modification of the second ESD prototype, a Bureau of Mines-funded feasibility study of a bidirectional auger system was being made by ESD. This study recommended a two-chassis concept wherein one chassis drilled boreholes into the pillars on both sides of the entry, and the smaller chassis removed auger flights from the last boreholes and placed them in the drilling chassis. Bem

In 1978, a Department of Energy contract was awarded ESD to design and fabricate the two-chassis bidirectional auger. A scale model of this system was displayed in 1978 at the American Mining Congress International Mining Show in Las Vegas. Mining operators made many comments regarding the operation of the concept. ESD reevaluated the concept in light of these comments, the experience being gained from the test in progress on the ESD second prototype,

and MSHA requirements. The result was to propose a change to the contract, recommending the design and fabrication of a single-chassis bidirectional auger that would bore holes only 10 feet deep. This contract change was approved, and design and fabrication was completed.

2.2 DEMONSTRATION SITE

Several mines expressed interest or willingness to permit underground demonstration of the auger, but for various reasons, an agreement was never reached until construction of the bidirectional auger was nearly completed. Peabody Coal Company then expressed strong interest, and after several visits by Peabody personnel to review the auger and by ESD personnel to review the demonstration site at Peabody's Marissa Mine, an agreement was reached.

Test site criteria met the following requirements:

- 72- to 84-inch seam height
- Dry bottom
- Reasonably competent roof
- Minimum 16-foot-wide entries
- Freedom from major rock inclusions in the coal.

2.3 PRODUCTION TEST

Details of the demonstration are discussed in later sections of this report. The following summarizes the results:

- The auger miner operated from August 24, 1981, to June 11, 1982, experiencing four major breakdowns: Failure of the bearings supporting the conveyor chain idler shaft, severe wear of the variable-volume piston pump and both auger drive motors, all necessitating rebuild, and failure of two double-strand roller chains.
- During this period, the section operated 70 shifts, during which one or more holes were drilled. Work performed to make changes to the machine to correct operational problems or to repair leaks and failed minor components, work done to repair associated equipment on the section, and work required to make major workplace changes required the equivalent of 34 days for a total of 104 working shifts.
- During the test period, the section mined 1,520 tons of coal (equivalent to 304 holes). Shift production varied from 5 tons to 120 tons.
$$\frac{1520}{70} = 217.14 \text{ tons/shift}$$
- The average production for the 70 shifts was 22 tons per shift. The average for the last 4 weeks of operation was 36 tons per shift.
- Productivity averaged 11 tons per man shift, based on the 70 shifts of production and 18 tons per man shift for the last 4 weeks of operation with a crew of two.

Production and productivity can be expected to meet the minimum goal of 200 tons per shift, or more, by incorporating certain design, construction, and operational changes into future models.

3.0 TECHNICAL DISCUSSION

3.1 HISTORY

Experimental attempts have been made to mine coal underground by auger miners since the 1930's. Although these efforts have produced workable machines, they have been unable to match the productiveness of conventional or continuous mining methods.

These early underground auger miners did not perform well for several reasons, including the following:

- The auger miner platform was skidded, jacked, or wheeled into position against the face. Cribs or props were set around the auger miner, and timbers or jacks were placed between the frame and the back rib to react the auger thrust.
- One by one, the cutterhead and following flight sections were rolled and lifted (with pry bars and cables, but mostly by hand) into position on the platform, matched to the drive chuck, and drilled into the coal.
- As the cut coal exited the borehole, it was shoveled out into the clear for gathering by a mechanized loader. Often, the auger would have to be stopped two or three times per 6-foot advance for shoveling, or the auger miner would become muckbound.
- When the hole had been drilled to its deepest penetration, each flight section would be laboriously removed by hand and stored in the entry. The auger miner platform could then be moved one spacing away and the entire process repeated. A good crew of four or five hardworking miners might make 24 tons of coal per shift (80 feet of 36-inch-diameter borehole).

Interest in underground auger miners began to increase in the 1970's. Enforcement of the 1969 Coal Mine Health and Safety Act caused productivity to drop dramatically in both continuous and conventional mining operations.

The "energy crisis" renewed interest in coal production and utilization, particularly in the efficient recovery of the coal resources already being mined.

Room and pillar mining has left great quantities of coal underground, simply because of vast reserves and lack of efforts to develop methods of removal. This coal has the following properties:

- It underlies bad roof areas.

- It is left in barrier pillars and against outcrops for surface ground protection, or to protect more immediately recoverable coal in the seam.
- It is left in old mines or workings because no efficient secondary recovery methods existed when the development work was performed.

In 1972, as renewed interest in mining "unrecoverable" coal increased, the Badger Manufacturing Company of Summersville, West Virginia, revived the development of an underground auger miner which the company's principals had conceived a decade earlier. The machine which emerged was an improved underground auger miner which the company labeled the "Coalbadger." Their patent outlined several features stated as improvements on earlier attempts:

- Roof and floor jacks which wedged the entire machine in place in the entry to react drilling and withdrawal thrust.
- A unique sliding frame arrangement which allowed the base frame of the machine to remain fixed in the entry, while the frame to which the auger drive motor was attached shifted transversely between the hole being drilled and the previous hole. This feature allowed storage of the flight sections in the previously drilled hole and retrieval in sequence as they were needed for drilling the hole in process. The sliding frame eliminated the problems of tedious hand loading of flight sections and cutter head at the end of each completed hole and allowed more exact spacing between holes.

Of the three auger miners produced by the Badger Manufacturing Company between 1972 and 1974, the first miner proved the success of the shifting frame concept of drilling and storing auger sections. Structurally, however, the machine was deficient, and its frame and other components required redesign before the miner could be offered commercially. The second miner was greatly improved and tested for a short time in the Alyce Mine near Morgantown, West Virginia, where it successfully bored several 60-foot-deep holes and a number of 84-foot-deep holes using a 36-inch-diameter auger. The third miner was an updated version of the second miner with an extended auger trough. This machine was specially reconfigured for long-term lease to the Shannon Branch Mine of the Somet-Solvay Division of Allied Chemical, where it was used exclusively to bore airways.

In 1974, the Badger Manufacturing Company announced that the Coalbadger auger miner was available for limited production. Interest was high within the mining industry, and while its potential utility was recognized, some additional improvements were needed:

- There was still no conveyance device to carry coal away from the borehole.
- Although a methane detector and shutdown system had been added, there was provision neither for diluting the methane liberated within the borehole, nor for controlling the float dust created by cutting. (The machine was thus not in compliance with the intent of the 1969 Coal Mine Health and Safety Act.)

- There were obvious improvements to be made in the layout of controls and in the operator stations.

Recognizing that design changes could make the machine more productive, ESD Corporation, while still a division of FMC Corporation, approached the U.S. Bureau of Mines with an offer to modify a production Coalbadger auger miner and demonstrate the improved system underground in a producing mine. In June 1975, the USBM awarded Contract H0252076 to ESD for the development and testing of an underground auger panel extraction system.

A production Coalbadger was procured from the Badger Manufacturing Company and modified by ESD by adding a subauger conveyor, an entry conveyor, and hollow stem auger flight sections to provide borehole ventilation. In 1976, the modified Coalbadger (first model unidirectional auger miner) went underground for demonstration and testing at the Ireland Mine, Consolidation Coal Company, Moundsville, West Virginia.

The ESD modified auger miner generally performed well and approximately as claimed by the Badger Manufacturing Company. It did mine more coal in a given time than the production machine. The added conveyors continuously removed augered coal, whereas the production Coalbadger auger miner had to be stopped frequently for removal of coal from around the borehole by hand shovels. Although the modified machine was an improvement, its production rate was too low.

The low production was attributed to five areas of operation, or delays, which are nonproductive and, if eliminated, would increase productivity:

- Machine (miner) setup
- Panel-to-panel moves
- Mechanical/electrical malfunction delays
- Functional delays
- Normal production delays.

Machine setup requires skidding the machine 57 inches to the next location for a borehole and aligning the machine with the face by eyesight and carpenter's handlevel placed on the cutting head.

Panel-to-panel moves include moves between sites on the same panel per the approved drilling plan and moves between panels. All moves of this type require removing each flight section and the cutting head from the last borehole and moving them to the site of the next setup. For long moves, the auger miner is placed on the wheel set, and flight sections and cutting head are transported by scoop/tractor.

Mechanical/electrical delays are caused by equipment malfunctions on the auger. Functional delays occur when extra time is taken to abandon a misguided borehole and restart (another hole). Another delay occurs each time a flight section is needed. During this delay, the auger is stopped, the auger drive motor disconnected from the auger, the auger drive motor carriage shifted back to the previous borehole and connected to the auger,

one flight section withdrawn from the borehole and disconnected, the carriage, with flight section, shifted back to the new borehole, the flight section connected to the auger, and then the auger restarted.

Normal production delays are general delays which occur in normal mine production operations.

At the conclusion of the demonstration, ESD felt that design changes to specific portions of the system would result in more effective use of available production time and increased production output. ESD was awarded a contract modification to redesign and modify the first model unidirectional auger miner and demonstrate the miner underground. Redesign and modification was extensive and consisted of the following general modifications:

- A walking shoe system for tramping which provided greater maneuverability and easier alignment with the face during setup
- A separate extractor of flight sections from the last borehole
- Increased power for the conveyors and stainless steel bedpans to eliminate stalling, jamming, and stuck conveyor belts
- Powered stabilizing jacks to bear against the opposite rib for preventing machine movement during drilling
- Relocation of all controls under the operator's canopy and an operator's seat added for greater comfort.

In 1978, testing of the second model unidirectional auger miner began at the Ireland Mine. As a result of the improvements and changes incorporated into the second model, machine production output increased to 88 tons per shift average, an increase of 49 tons per shift over the first model. Although this figure was an 80-percent increase in production, it was not economically acceptable to the Ireland Mine; breakeven for Ireland is 88 tons per shift (TPS), but at least 125 TPS are preferred. The learning curve had not peaked out when the test was prematurely terminated at the request of the Ireland Mine, following failure of the main drive hydraulic motor.

The conclusion resulting from both demonstrations was that substantial improvements in borehole guidance had to be made before economical production could be realized where long (up to 100 feet) boreholes were to be drilled.

For a more detailed discussion of the two demonstrations, refer to the U.S. Department of Energy Report Number FE/12485-1, "The Development and Test of an Underground Auger Panel Extraction System."

Concurrent with the demonstration of the second model unidirectional auger miner, ESD was completing a study of the feasibility and producibility of a bidirectional auger miner for the U.S. Bureau of Mines under Contract Number J0265029 ("Feasibility Studies for a Bidirectional Auger System," Volume I). This study evaluated five different concepts for a bidirectional auger

miner and recommended that one be designed concurrently with the underground testing of the second model unidirectional auger miner.

The recommended bidirectional auger miner concept was a two-chassis machine with wheels on each unit. One unit extracted flight sections from the previous borehole or retrieved each flight section from its temporary storage place in an adjacent cross-cut and placed each section onto the auger miner chassis. The auger miner chassis had a carriage mounted auger drive motor which could bore a hole into either rib. Conveyors mounted to either side could be positioned against each rib by hydraulic jacks. Stabilizer jacks could be placed against each rib to react auger thrust against the opposite rib.

In 1977, ESD submitted a proposal to the Department of Energy for the "Design, Fabrication, and Test of a Bidirectional Auger" based on the recommendations of the above study. DOE subsequently awarded ESD Contract Number ET-78-C-01-3150, later to become Contract Number DE-AC01-78ET10036. At the beginning of the design effort, the concept was reevaluated by ESD engineers, mine operators, and MSHA personnel, resulting in concept revision (see Appendix A). The ensuing design, however, deviated from the proposed concept in several significant features:

- Boreholes would be drilled only 10 feet deep.
- There would be one chassis instead of two.
- There would be no storage or handling of flight sections and cutting heads.
- The auger miner would be controlled from off the machine.

The impetus for these changes in concept came from three sources:

- Evaluations and recommendations made by mine operators
- Experience gained from the operation of two unidirectional miners operating underground in an operating coal mine
- MSHA requirements (see Appendix B).

Based on the revised concept, design of a bidirectional auger miner commenced.

3.2 BIDIRECTIONAL AUGER DESCRIPTION

The general arrangement of the auger is shown in Figure 1. It is a single-chassis unit supported by four steerable driving wheels. Two auger sections, each integral with a cutting head, are positioned across the auger miner frame. Each auger sump and rotates individually (never simultaneously) into the nearest rib. Figure 2 lists the auger miner dimensions and performance data.

GENERAL DATA**Overall Dimensions:**

Length: 25 feet
 Width: 13 feet 4 inches
 Height: 5 feet 5 inches

Reducible to (for shipping or installation):

Length: 19 feet 7 inches
 Width: 9 feet
 Height: 3 feet 3 inches
 Total weight: 44,000 pounds

Reducible to (for shipping or installation):

28,000 pounds, main frame 16,000 pounds, carriages

Floor jacks:

Bearing area of pads: 63 in² each
 252 in² total
 Stroke: 9 inches
 Load capacity: 14 tons each
 56 tons total
 Locking mechanism: Mechanical

Roof jacks:

Bearing area of pads: 63 in² each
 252 in² total
 Stroke: 19 1/2 inches
 Load capacity: 13 tons each
 52 tons total
 Locking mechanism: Mechanical

Roof and floor jack (concurrent) operation:

Extend: 13 seconds maximum (full stroke)
 Ground pressure: 115 psi
 Ground clearance: 10 inches
 Steering: Selectable 4-wheel or crab (manual convert to front or rear 2-wheel steer)
 Required entry width for single maneuver 90° turn: 16 feet

Brakes:

Spring applied/pressure release (failsafe)
 Grade holding ability: 36-percent slope (21°)
 Gradability: 27-percent slope (15°)

PRODUCTION

Coal from one 48-inch by 10-foot borehole (based on 80 lb./cu. ft. in place): 5.0 tons

Projected production rate:

5.0 tpm (maximum) 250 tons/shift (nominal)

Productivity: 59-ton/man shift (nominal)

POWER AND PERFORMANCE**Pump Motor:**

440 VAC 30 60 HZ 200 KVA: 1,750 rpm
 Louis Allis electrical motor: 150 hp continuous; 196 hp intermittent

Auger pump:

Sunstrand hydraulic pump: Series 26, variable displacement: 100 gpm @ 3,000 psi

Auxiliary pumps:

Four Commercial Shearing hydraulic gear pumps: 54.7 gpm total @ 1,500 psi

Auger torque motor:

Dynex/Rivett HSM 300 hydraulic vane motor: 88 hp @ 53 rpm, 8,750 lb.-ft. torque

Auger Rotational speed:

Forward: 0-53 rpm inf. variable
 Reverse: Adjustable-preset at 15 rpm

Auger sump motor:

Sperry Vickers MHT 150 hydraulic vane motor: 3 hp @ 8 rpm; 2,000 lb.-ft. torque

Auger sump rate:

Forward: 13.4 fpm @ 10.7 gpm
 Reverse: 13.4 fpm @ 10.7 gpm

Auger sump thrust:

Forward and reverse: 10,000 pounds @ 1,500 psi
 Sump stroke: 10 feet maximum
 Cutterhead: 48-inch diameter with double breaker rings

Tram system:

Type: Wheel mounted, 4 tires 32 by 12.1-15 NHS, foam filled

Speed:

Forward and reverse: 0-47 fpm inf. variable

Tractive effort: 11,500 pounds

Drive (at each wheel):

Commercial Shearing hydraulic wheel motor: 7 hp each @ 420 rpm; 1,050 lb.-in. torque
 With Borg Warner planetary gear reducer: Ratio 40:1

Conveyor:

Type: Chain flite, 304 single strand (Joy)
 Pitch: 2-5/8 inches
 Drive: Char-Lyn hydraulic Motor 27 hp @ 161 rpm; 10,400 lb.-in. torque
 Width: 30 inches
 Speed: 300 fpm @ 30 gpm
 Capacity: 6 tpm
 Discharge height: 56 inches

ANCILLARY EQUIPMENT

Hydraulic system capacity: 120 gallons, water cooled

Dust suppression system:

Water spray at each auger throat and on conveyor discharge

Water requirements:

5 gpm @ 60 psi

Fire suppression system:

Dry chemical-manual discharge

Methane detection system:

Bacharach dual-channel monitor

Lighting: 3 fluorescent area lights, 2 incandescent floodlights

Borehole Ventilation (through hollow auger stems):

Roots blower 175 cfm

REMOTE CONTROL FUNCTIONS**Discrete controls:**

Hand-controller power; auger rotational direction; carriage selector; stab jack activation; steering mode select; conveyor direction; sump direction; pump start/stop; floor and roof jack activation; emergency stop

Proportional controls:

Tram speed and direction (joy stick); auger rotational speed

Figure 2 **BIDIRECTIONAL AUGER SPECIFICATIONS**

3.2.1 Augers

Each auger (consisting of cutting head and flighting) is cradled in a trough which channels cut coal to the chain conveyor. The trough also provides support for the auger drive motor and the drive system that sumps the auger into the rib. Each trough can also be sumped up to the rib so that a tubular gasket fastened to the end of the trough seats against the rib to minimize spillage. Coal cut by the cutting head is pushed to the center of the machine by the auger flighting, where it is discharged onto the chain conveyor.

3.2.2 Conveyor

A chain conveyor lies in a trough along the bottom of the auger miner for its full length. At the outby end (discharge end), the conveyor has an upswing, enabling coal to be discharged into a shuttle car. The conveyor can be driven in reverse to loosen jammed lumps of coal.

3.2.3 Dust and Methane Control

To minimize float dust, water sprays located overhead on the end of each auger trough spray water downwards at the borehole opening. Water sprays are also located on the outby end of the conveyor.

A dual channel methane monitor shuts off electrical power to the machine when it senses the presence of methane in quantity of 1 percent or more. Methane detector heads (two total) are mounted on each auger trough near the end that contacts the rib downwind (ventilation air) of the borehole.

Ventilation of methane from the borehole is accomplished by blowing fresh air into the borehole through the hollow stem of each auger.

3.2.4 Roof and Floor Jacks

A pair of angled floor jacks for each auger stabilize the bidirectional auger by reacting cutting head thrust loads into the mine floor. These jacks are extended when the auger trough is sumped into the rib.

Roof and floor jacks provide some roof support during drilling, but the force exerted by the jacks is adjusted low to prevent localized roof failure. A pressure switch in the hydraulic circuit assures that the floor jacks extend to the floor before the roof jacks extend. Each floor jack (except angled floor jacks) and roof jack has a hydraulically released mechanical lock to prevent unexpected and sudden jack collapse.

3.2.5 Wheels, Brakes, and Steering

The auger miner is supported on four steerable wheels with foam filled rubber tires. Each wheel is driven by a hydraulic motor through a planetary gear reducer. Flow regulators in each wheel motor hydraulic circuit limits flow to each wheel; if one wheel loses traction, the remaining three wheels can still exert driving torque because the flow limiters prevent total flow going through the free wheel.

Disk brakes mounted within each wheel assembly are spring applied, but released by hydraulic pressure. Valves located at each wheel assembly allow brakes to be set in the released position. A single valve permits manual release of all wheel brakes by means of hydraulic hand pump.

Two modes of steering are provided: Four-wheel steer and crab steer. Four-wheel steer provides good mobility for turning corners from entry to crosscut. Crab steer allows the bidirectional auger to move from rib to rib or from borehole to borehole while remaining parallel to the rib.

3.2.6 Hydraulic System

All functions of the auger miner are performed by hydraulic pressure and flow. Pumps mounted to each end of an electric motor provide hydraulic power to motors and cylinders. Flow to these items is directed by intrinsically safe, solenoid controlled, pilot operated control valves. Pressure-type filters are included in all hydraulic circuits.

3.2.6.1 Pumps

A Sunstrand variable volume piston pump provides the hydraulic power to turn either auger drive motor.

A 29-gallon-per-minute gear pump supplies hydraulic power to the conveyor motor, roof and floor jacks, and the four wheel motors.

A 10.7-gallon-per-minute gear pump supplies hydraulic power to the steering cylinders, auger sumping motors, stabilizer jack cylinders and auger trough sumping cylinders, and the roof/floor jack cylinder locks.

Of two 7.5-gallon-per-minute gear pumps, one supplies hydraulic power to the pilot pressure circuits, while the second pump supplies power to the ventilation blower motor.

3.2.6.2 Fluid Motors

Gear type motors are used to drive the wheels, conveyor, and ventilation blower. Vane type motors drive each auger and auger sumping drive system.

3.2.6.3 Cylinder Locks

All roof and floor jacks have locks which lock the cylinder rod in any extended position. To release the lock, hydraulic pressure of at least 3,000 psi must be applied to the lock.

3.2.6.4 Reservoir

One reservoir serves the entire hydraulic system. Filling and replenishing the reservoir with hydraulic fluid is accomplished with an aspirator energized by flow through the stab jack circuit. Suction strainers for each pump are mounted within the reservoir. The hydraulic oil is cooled by circulating water through a plate coil installed inside the reservoir.

3.2.6.5 Hand Pump

The hand pump enables manual release of either the hydraulic cylinder locks or the wheel brakes.

3.2.7 Controls and Electrical System

The following are major components of the electrical system:

- Remote controller
- Electric motor
- Motor control box
- Emergency stop
- Lighting systems
- Fire extinguishing system.

3.2.7.1 Remote Controller

All functions of the auger miner, except the lights and fire extinguishing system, are controlled from the remote controller (see Figure 3). The remote controller is connected to the auger miner electrical system at any one of three connectors located at three corners of the machine.

Steering and tramping are accomplished at the remote controller by movement of a "joystick" type lever. Steering and tramping can be performed simultaneously either forward or backward. Tram speed increases to maximum as the tram joystick is moved off-center, forward, or backward. Tramping cannot occur if the deadman lever on the side of the controller enclosure is not depressed.

3.2.7.2 Electric Motor

The motor is a 150-horsepower, 440-VAC, 3-phase unit which drives the five hydraulic pumps.

3.2.7.3 Motor Control Box

Motor contactors and circuit breakers are contained in the permissible box mounted on the conveyor discharge end of the machine.

3.2.7.4 Emergency Stop

There are three emergency stop bars located on the auger miner, one on each side of the conveyor tail boom, and one on the opposite end of the machine. The remote controller also has an emergency stop button. Deflecting any one of the emergency stop levers sideways or pushing the emergency stop button cuts off power to the electric motor.



Figure 3 BIDIRECTIONAL AUGER REMOTE CONTROL UNIT

3.2.7.5 Lighting System

Three fluorescent type area lights are provided to illuminate the area around each end of the machine. Two lights are located on the conveyor boom, one on each side, with the third located at the opposite end of the machine.

Two incandescent flood lights are provided to illuminate each auger and the rib area surrounding the borehole.

3.2.7.6 Fire Extinguishing System

Basic components of this system are the dry powder container, nitrogen cartridges with actuators, powder discharge nozzles, and interconnecting hose assemblies. Nitrogen cartridges with actuators are located on three corners of the machine. Discharge nozzles are located near the electric motor adjacent to the hydraulic pumps and in the hydraulic valve compartment.

3.3 SYSTEM OPERATION

3.3.1 Equipment Setup

No special setup is required to operate the auger miner. All that is required is to move the machine close to and parallel with either rib and the cutterhead positioned opposite the place where a borehole is to be drilled. As an aid to positioning, the cutterhead at the borehole location marks, on which the cutterhead can be aligned, can be made on the rib at the correct borehole spacing.

Electric power and water must be supplied for operation of the auger miner. At least one shuttle car, or equivalent, must be available to haul the cut coal.

3.3.2 Supplying the Auger Miner

The auger miner has been supplied with the following utilities and consumables:

- Electric power (440-Volts AC, 3-phase)
- Water
- Rockdust
- Cutter bits
- Hydraulic oil
- Lubricating oil and grease.

Roof support supplies are not required, because the auger miner works in previously bolted entries established during panel development.

3.4 DEMONSTRATION SITE SELECTION

Prior to and early during design of the auger miner, several mine operators were contacted to promote their interest in an underground demonstration of the auger miner.

Additional contact with several mine operators was obtained through interest expressed during display of the auger miner at the American Mining Congress International Coal Show held in Chicago. A dozen representatives of companies operating coal mines asked that more information be supplied them. Each of these representatives was provided the information with a letter expressing ESD's desire to demonstrate the machine underground. Other contacts were made through previous associations established during earlier projects, or by recommendations from other contacts. Several expressed interest, but for various reasons, verbal agreement was never reached.

Later in the program, Peabody Coal Company expressed considerable interest in the auger miner and visited ESD to observe the machine tram and maneuver. Later, ESD personnel visited Peabody's Marissa Mine in Southern Illinois. They found the mine to be in excellent condition and very well run. The mine had all of the desirable features and requirements for test and demonstration:

- Minimum seam height of 72 inches
- Dry bottom
- Stable roof
- Minimum entry width of 16 feet
- Freedom from major rock inclusions in the coal.

An agreement was subsequently reached with Peabody Coal Company to demonstrate and test the auger miner for a 6-month period in their Marissa Mine.

3.4.1 Test Area

The area in the Marissa Mine selected for the demonstration was at the First Panel West (see Figure 4). Pillars in Entries 2, 3, and 4 were drilled from Crosscut 23 outby to Crosscut 9.

Most of the bottom (floor) in this area was reasonably flat. A few mounds of gob in some places had to be leveled by a scoop to permit the auger miner or a buggy (shuttle car) to pass through without high centering.

3.4.2 Mine Plan

Drilling of pillars began in Entry 2 at Crosscut 23 and proceeded outby to Entry 16. (The tail pulley of the panel belt was located between Crosscuts 15 and 16.) The auger miner was then moved to Entry 3 and Crosscut 23 for a repeat of the cycle. When Entry 4 was drilled to Crosscut 16, the panel belt was shortened to place the tail pulley between Crosscuts 8 and 9. The whole cycle was then repeated.

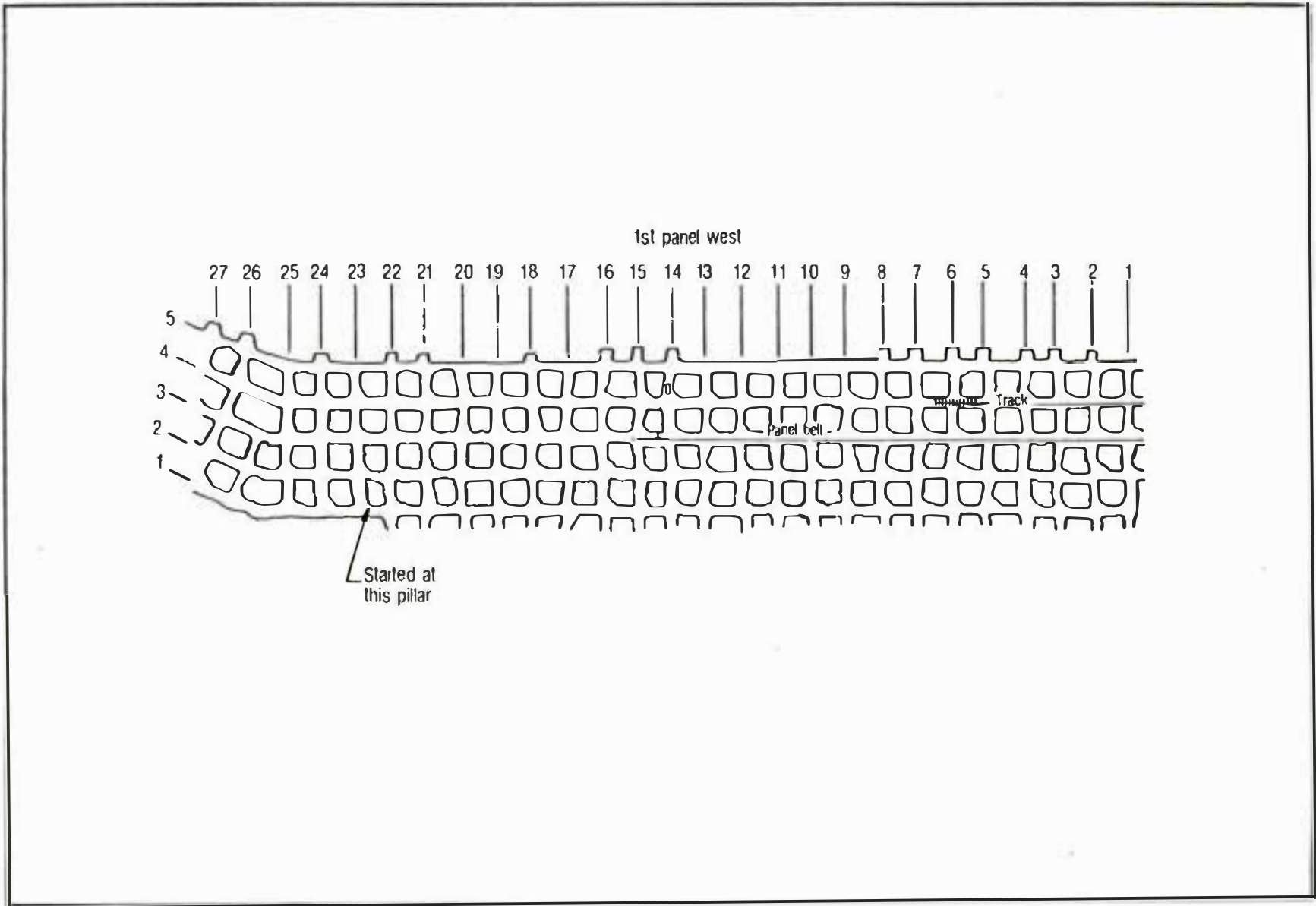


Figure 4 MINE SECTION WHERE DEMONSTRATION TOOK PLACE

The plan called for a specific drilling sequence so that the operator was outby the last hole nearest his work position. The sequence began by drilling three holes in the left pillar (when facing outby) and then, moving across the entry, drilling five holes in the right pillar. This operation continues down the entry in this five-hole "leap-frog" fashion from rib to rib for each pillar.

Toward the end of the demonstration, this "leap-frog" pattern was altered for two reasons: There was no apparent change in the integrity of the pillars that had been drilled, and maneuvering the auger miner to place it parallel to the surface to be drilled could be minimized.

Pillar surfaces were often "sawtoothed" instead of flat. Each flat area in the sawtooth pattern was roughly parallel with the others on a pillar, but these flat areas angled in the opposite direction on the opposite pillar. Less maneuvering was the result of drilling the maximum holes possible in one rib and then crossing over to the other rib to the inby corner and drilling the opposite pillar.

Proper ventilation is important to clear away dust and methane. Proper ventilation was attained by allowing some ventilation air to bleed off from the fresh air entry. After flowing past the auger miner, the air was allowed to enter the air return entry. Brattice curtains were hung across Entries 2, 3, and 4 at the inby side of Crosscut 23 (see Figure 5 for typical location of brattice curtains). Additional brattice curtains were hung in two entries outby the pillar being drilled so that ventilation air would flow past the auger miner.

Periodically, each hole drilled and surrounding rib and floor were rock dusted.

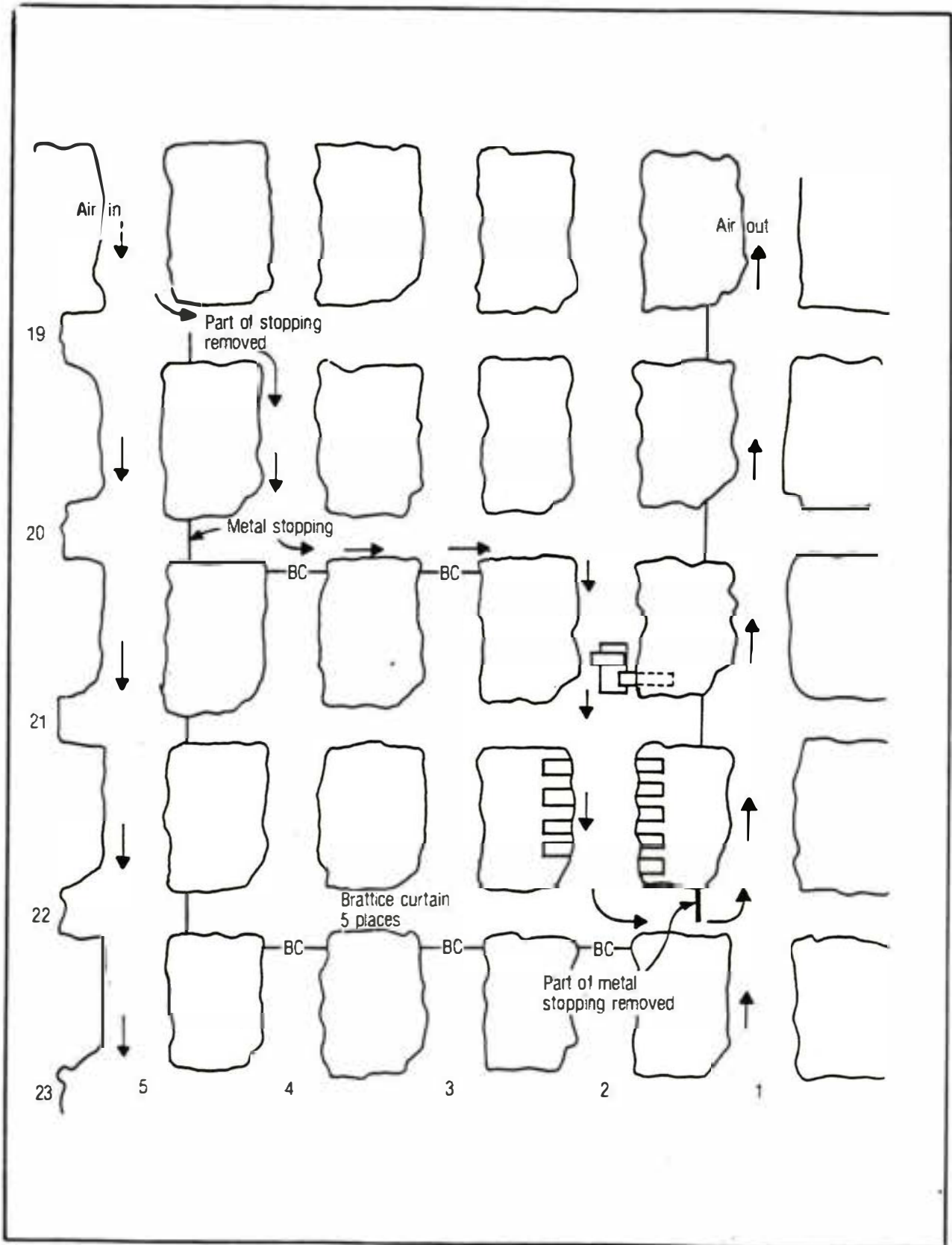


Figure 5 TYPICAL VENTILATION PLAN

4.0 DEMONSTRATION RESULTS

4.1 PREPARATION FOR OPERATION

The augers and troughs were removed from the chassis for shipment to the mine. Upon arrival at the mine, the augers and troughs were sent underground and transported to the test site. Mine personnel determined that the height of the auger miner chassis loaded on a low flatcar would exceed minimum overhead heights en route to the unloading point near the test site. With the wheels, roof jack pads, and extensions removed and the auger miner resting on the yokes, the machine was sent underground and transported to the unloading site.

At the unloading area, a ramp was constructed at the inby end of the flatcar. With electrical power supplied to the auger miner, it was raised up on its floor jacks. The wheels were reinstalled and the machine lowered to its wheels and trammed to the crosscut, where the augers and troughs were waiting to be installed.

The troughs and augers were installed, trough sumping cylinders connected, and hydraulic lines connected to the cylinders, auger sumping motors, and auger rotation motors.

Assembly was thus complete, and the auger miner was trammed to the testing and demonstration site.

4.2 PRODUCTIVITY

4.2.1 Raw Shift Tonnage

At the beginning of the project design phase, the projected raw shift tonnage was calculated to be an average of 250 tons per shift (50 holes per shift). The actual average raw shift tonnage for the entire demonstration period was 22 tons per shift, based on the number of shifts during which one or more holes were drilled. Based on the last 3 weeks of operation, the output was 46 tons per shift. The largest amount of coal produced in any one shift was 120 tons (24 holes). A total of 1,520 tons (304 holes) were drilled during the 10-month demonstration; approximately 14 weeks of this period were inactive while the auger drive motors were being consecutively repaired.

4.2.2 Tons Per Man-Shift

The productivity of the auger miner was calculated at the onset to range from 53 to 65 tons per man-shift. (See Table 1, Bidirectional Auger Proposed Contract Modifications, in Appendix C.) Based on the number of shifts during which one or more holes were drilled, the actual productivity was approximately 11 tons per man-shift (two men per shift).

For most of the shifts in which holes were drilled, the crew consisted of a mechanic/operator and one or more engineering support personnel. In addition to the mechanic/operator, a shuttle car operator was occasionally made available. Extraction of coal from pillars using the auger miner can be accomplished with two men. A third man might be advisable to tend the trailing electrical cable and water hose and to move brattice cloth so that air flow is directed past the auger miner for dust control.

4.2.3 Factors Affecting Productivity

Several factors could have resulted in or contributed to falling short of the productivity goals:

- Hard coal
- Vane motors
- Inadequate power
- High oil temperature
- Auger sump chain drive
- Cutter bit wear
- General delays.

4.2.3.1 Hard Coal

When the auger miner was being designed, the location of the demonstration site was unknown; design of the auger was virtually complete when the demonstration site was finally selected. Without specific knowledge of how hard the in-situ coal would be, the designers used field test data gained from previous similar applications to establish performance parameters and select components. Design of the auger miner was thus based on the performance of the unidirectional auger.

Auger thrust forces (see Table 1) were reduced on the auger miner, because it was to drill only 10 feet deep, as opposed to 80 to 100 feet deep for the unidirectional auger. Auger torque requirements remained about the same; the increased torque required for a larger diameter auger versus the torque required for the smaller unidirectional auger diameter and the additional resistance to turn 80 to 100 feet of auger and flight sections.

Table 1 COMPARISON OF AUGER THRUST/TORQUE

	Unidirectional Auger	Auger Miner (Bidirectional)
Auger Torque, Ft.-Lbs.	13,500 at 3,000 psi	13,500 at 2,800 psi
Auger Thrust, Lbs.	50,000 at 2,500 psi	22,453 at 3,000 psi
Production Rate, Tons/Min.	3.5	0.78

Design of the auger miner was thus based on the results of the underground test in the Pittsburgh (Number 8) coal seam at Ireland Creek Mine.

The grindability of coal is a composite property of hardness and other properties. The grindability index is thus an indicator of coal hardness. Comparison of the Hardgrove Grindability Index (HGI) number of the coal seam at each demonstration site shows that the coal at the Marissa Mine demonstration site for the auger miner is harder to some degree. The HGI for the Pittsburgh seam at Ireland Creek is 56-57 and 50-52 for the Herrin (Number 6) seam at the Marissa Mine. Coal with an HGI less than 100 requires more energy to grind than coal having an HGI greater than 100. Coal from the Herrin seam takes more energy to grind than coal from the Pittsburgh seam, because its HGI is lower (farther from 100). Engineers who were in both mines agree, however, that this comparison of grindability indexes presents a distorted picture of the comparative boring conditions. In the Ireland Mine, personnel could walk up to a rib anywhere and pull off pieces of coal with their bare hands; this could not be done anywhere at the Marissa Mine. Several thin layers of bone are in the coal seam at Marissa Mine, the thinnest being about 1/4 inch thick and the thickest being about 1-1/2 inches thick.

4.2.3.2 Vane Motors

Vane-type hydraulic motors are used on each auger to drive the mechanism that pushes the auger into the coal as it drills a hole. Since each auger is used alternately, thermal shock to a motor can occur when hot oil flows into a cold motor. Thermal shocks in excess of 50°F are not recommended. The recommended start-up procedure is to start and stop the motor until temperatures are equalized.

If the recommended start-up procedure is not followed, internal parts of the motor can become worn or damaged. This procedure was not consciously followed throughout the demonstration and, because on the average, the inby auger takes longer to drill a hole, and measured fluid flow through each motor is vastly different, it appears that the inby auger sump motor is severely worn or damaged.

The engineering decision to use the vane motor, though seldom used on underground mining equipment, was based on its ability to deliver high torque at low speed with high volumetric efficiency. Furthermore, the motor is available with a hollow shaft which lends itself to a simple connection for bore hole ventilation and a compact method of mounting the motor.

4.2.3.3 Inadequate Power

The outby auger stalled easily, with new cutting bits installed on the cutting head, indicating that there was insufficient power to turn the auger at maximum sump pressure. Sump relief pressure had to be reduced to avoid stalling; when the cutting bits dulled a little and/or oil temperature increased, the sump relief pressure was gradually increased to maximum.

The inby auger did not stall as easily. This fact could be attributed to the condition of the sump motor, which would be less efficient due to abnormal leakage, resulting from internal wear.

4.2.3.4 Oil Temperature

Throughout the early part of the demonstration, when less than five or six holes were being drilled consecutively, high oil temperatures were not recognized as a problem. Later, when six or more holes were being drilled consecutively, it was realized that oil temperatures were reaching and exceeding recommended operating temperatures. The addition of a second heat exchanger and an increase in water flow allowed reduction of oil temperatures to the recommended operating range.

As oil gets warmer, it becomes less viscous and flows more easily past internal clearances in pumps, valves, and other hydraulic components. This quality was quite evident with the inby auger sump motor, especially since it appears to be worn internally. As the oil warmed up, the time required to drill a hole increased.

4.2.3.5 Auger Sump Chain Drive

Channels along each upper edge of the trough contain a system of double-strand roller chain and sprockets which push the auger against the pillar as the hole is drilled. The design of the system requires an open slot along the side of each channel facing the center of the trough. As the pillar is being drilled, the end of the auger flight flips coal upward and toward one side of the trough. This action fills the channel on that side with coal fines and small lumps which are carried by the chain toward the end of the channel where the idler sprocket is located. Because there is inadequate provision for these fines and lumps to escape from the channel, they are compacted in the channel around and before the sprocket, causing the inward advance of the auger to cease as it nears the last one or two feet of travel. The remedy is to cycle the auger in and out of the hole a few times for 1 or 2 feet to break up the compaction of coal and clear the channel. After drilling three or four holes, 4 or 5 minutes of time were often taken to direct a jet of water into the channel at the idler sprocket to wash out coal fines.

4.2.3.6 Cutter Bit Wear

High thrust forces on the auger are a probable cause of rapid wear on the cutter bits, but coal is also extremely abrasive. As a comparison, the coal in the Number 6 seam in Illinois is approximately 1.5 times as abrasive as the coal in the Number 8 seam in Pennsylvania.

With new cutting bits, the auger miner drilled 9- to 10-foot-deep holes in 3-1/2 to 4 minutes, but once the clearance angle on the carbide tip (see Figure 6) was reduced to zero by wearing action, the tip no longer cut effectively. Loss of clearance angle caused a noticeable increase in the time required to drill a hole.

Accurate positioning of cutter bits seems to be critical to consistently cutting consecutive holes within a certain length of time. Cutter bits that cut in the same circular path should be precisely mounted with respect to their cutting plane. Otherwise, those bits that precede the cutting plane touch the coal face first and do all the work of cutting. When these are worn down until there is no clearance angle remaining, they not only rub on the coal, but also prevent those other cutters sitting back from the cutting

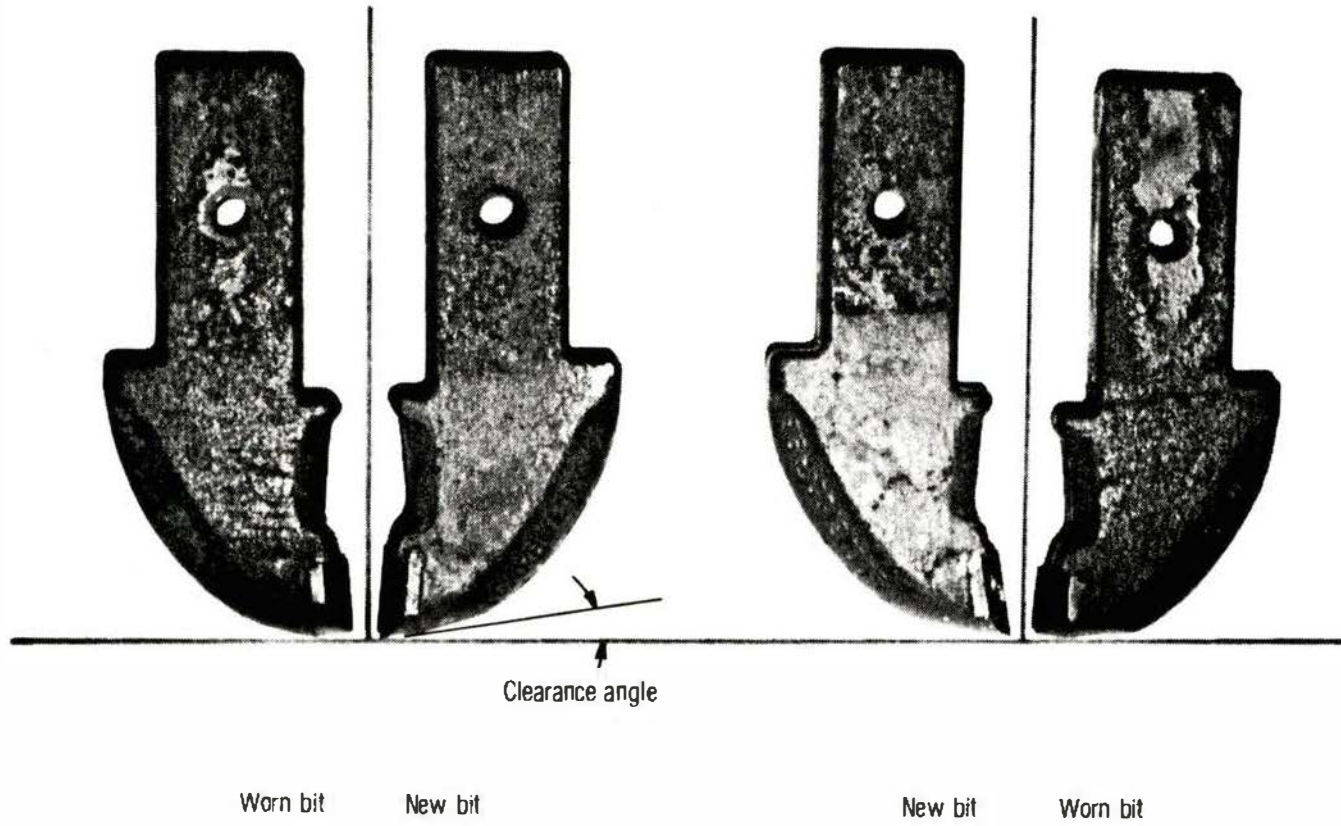


Figure 6 CUTTER BIT WEAR

plane from cutting. Drilling of the hole can stop if enough cutter bits are allowed to wear down before replacement.

4.2.3.7 General Delays

Delays in auger miner operation occur that are not directly related to the auger miner, but which nevertheless prevent drilling holes in the pillars. Some of the reasons for delays that occurred during the demonstration are listed below:

- Repairing buggy (shuttle car) cable; this delay occurred several times.
- Adding oil to buggy hydraulic reservoir; this was required several times, although the buggy had been recently refurbished.
- Cleaning spilled coal from around panel belt tail pulley; coal dumped too quickly onto the belt from the buggy spilled onto the bottom (floor). Cleaning had to be done several times.
- Replacing a drive coupling on the panel belt head pulley drive assembly.

With only a crew of two to operate the auger miner, drilling of holes stopped while the crew took care of the problem causing any one of the above delays.

Movement from pillar to pillar does not take much more time than movement from hole to hole. When removing coal from a certain number of pillars along three entries, however, two major moves of the auger miner are required, necessitating movement of the trailing cable and water hose to the next entry, and movement of the auger to the next entry, and then movement along the entry to the starting point. Relocation of the buggy trailing cable tie point is also required. Brattice curtains for directing flow of ventilating air must be moved to those pillars adjacent to the auger miner and rehung.

Using only one buggy caused some delay in the cycle time for drilling one hole, moving to the next hole location, and preparing to drill the hole. Having two buggies would have reduced the time cycle. Part of the buggy delay resulted from having to slowly feed coal onto the panel belt, because no feed-breaker was used to regulate flow onto the belt.

4.2.4 Improved Productivity

During the demonstration, several attempts were made to decrease the time required to drill a hole. Most attempts centered around changes to the cutter head and, in general, produced no significant change. The best cutting times were achieved by setting relief pressures higher than original design requirements and frequent changing of cutting bits.

4.2.4.1 Cutting Bit Pattern and Quantity

Both cutting heads have three concentric rings, and each ring has mounting blocks for attaching flat cutter bits. On each ring, every third block is angled slightly so that one third of the bits is angled in, one third is straight, and one third is angled out. One auger has a two-prong rotary

drill bit at the center of auger rotation, whereas the other auger has a semi-ring which holds three cutter bits (see Figure 7). A total of 57 mounting blocks (54 on the other auger) were provided.

The total number of cutting bits installed throughout the demonstration varied from 57 to 30. With some bits removed, various patterns of bits were tried, for example, every other cutter bit removed or every other group of three cutter bits removed. With some of the arrangements, cutting smoothness may have been lost, and the auger may have stalled more easily. There was little difference observed in the cutting speed, however.

For a brief period, full-face tip cutting bits were installed to see if a larger rake angle (see Figure 8) would increase cutting speed. No discernable difference could be observed. Otherwise, the full-face peak tip cutting bit was used throughout the demonstration.

4.2.4.2 Increased Auger Thrust

It seemed logical that increasing auger thrust would reduce the time required to drill a hole. The pressure relief setting was thus increased from 1,800 psi to 2,500 psi, the rated working pressure of the pump. This action decreased the time to drill a hole from approximately 13 minutes to about 6-1/2 minutes. Because the initial goal was to drill holes in 3 to 4 minutes, the pressure was increased again to 3,000 psi, where it stayed for the remainder of the test. This increase in pressure reduced the time to drill a hole to about 3-1/2 to 4 minutes.

4.3 EQUIPMENT OPERATION (Malfunctions, or less-than-satisfactory operation)

4.3.1 Tramming

Tramming the auger miner was not always satisfactory, although the mine has a dry fire clay bottom. Wheel spin sometimes occurred, because of the rigid frame/wheel arrangement's inability to follow the uneven floor (similar to having one of the drive wheels of an automobile on a slippery surface). Flow restrictors placed in the fluid lines to each wheel motor limit fluid flow to the slipping-wheel-motor so that some fluid pressure (and thus motor torque) is available to drive the wheels in contact with the floor. When movement of the auger miner ceases because of a spinning wheel, two techniques can be attempted to restore movement:

- Stop tramming and allow the wheel brakes to apply fully; close the valve in the brake line to the spinning wheel; resume tramming until clear, and then re-open the valve.
- With the tram lever in the tram position, steer the wheels back and forth (full steer) until traction returns and the machine starts to move (there is a slight possibility, with this method, that the wheels might dig their way into the floor until the auger miner is hung up on the center of the chassis).

When tramming from place to place, the operator, or his helper, must watch that the auger miner does not tram over the remote control cable or the trailing cable and water hose.

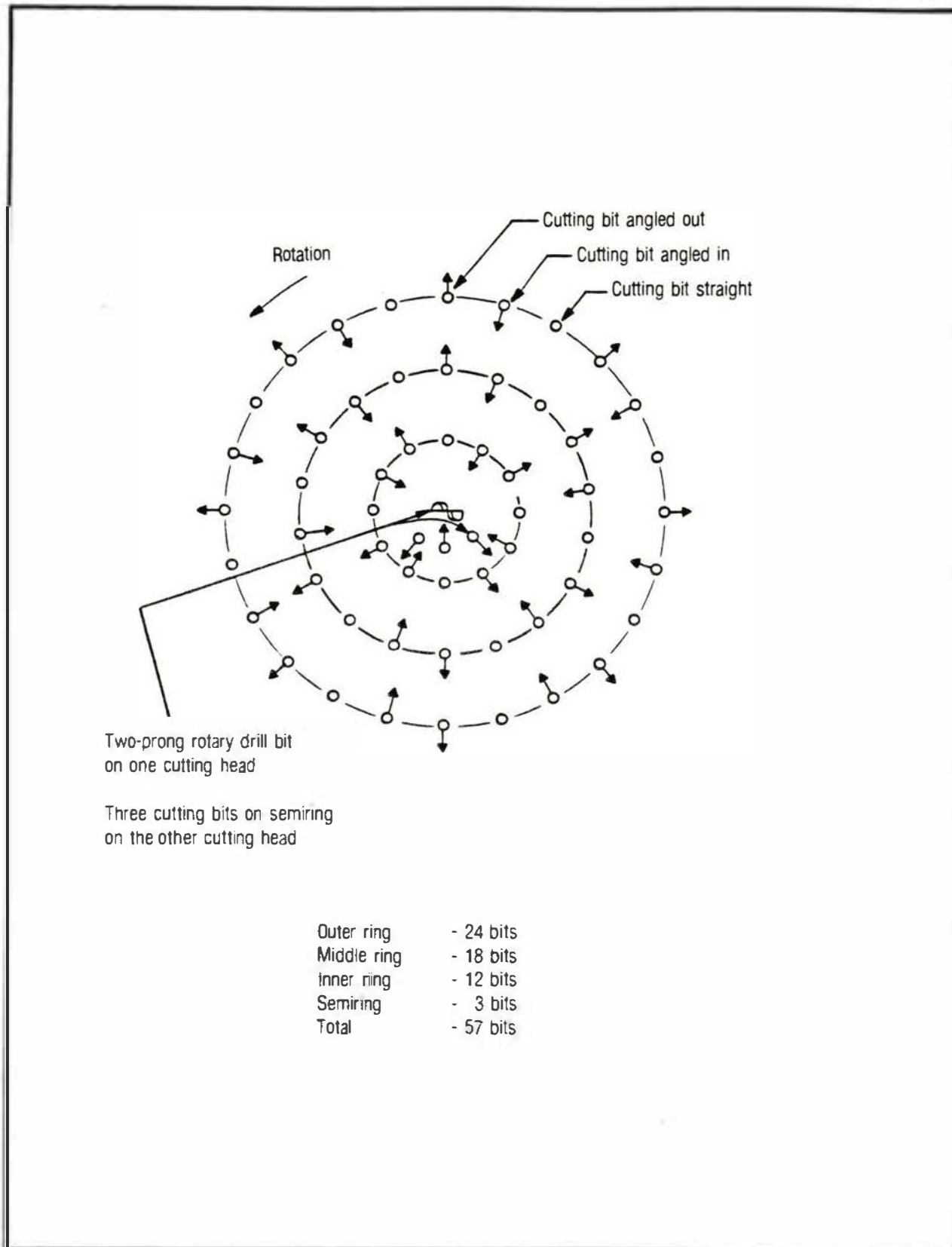


Figure 7 CUTTING HEAD BIT PATTERN

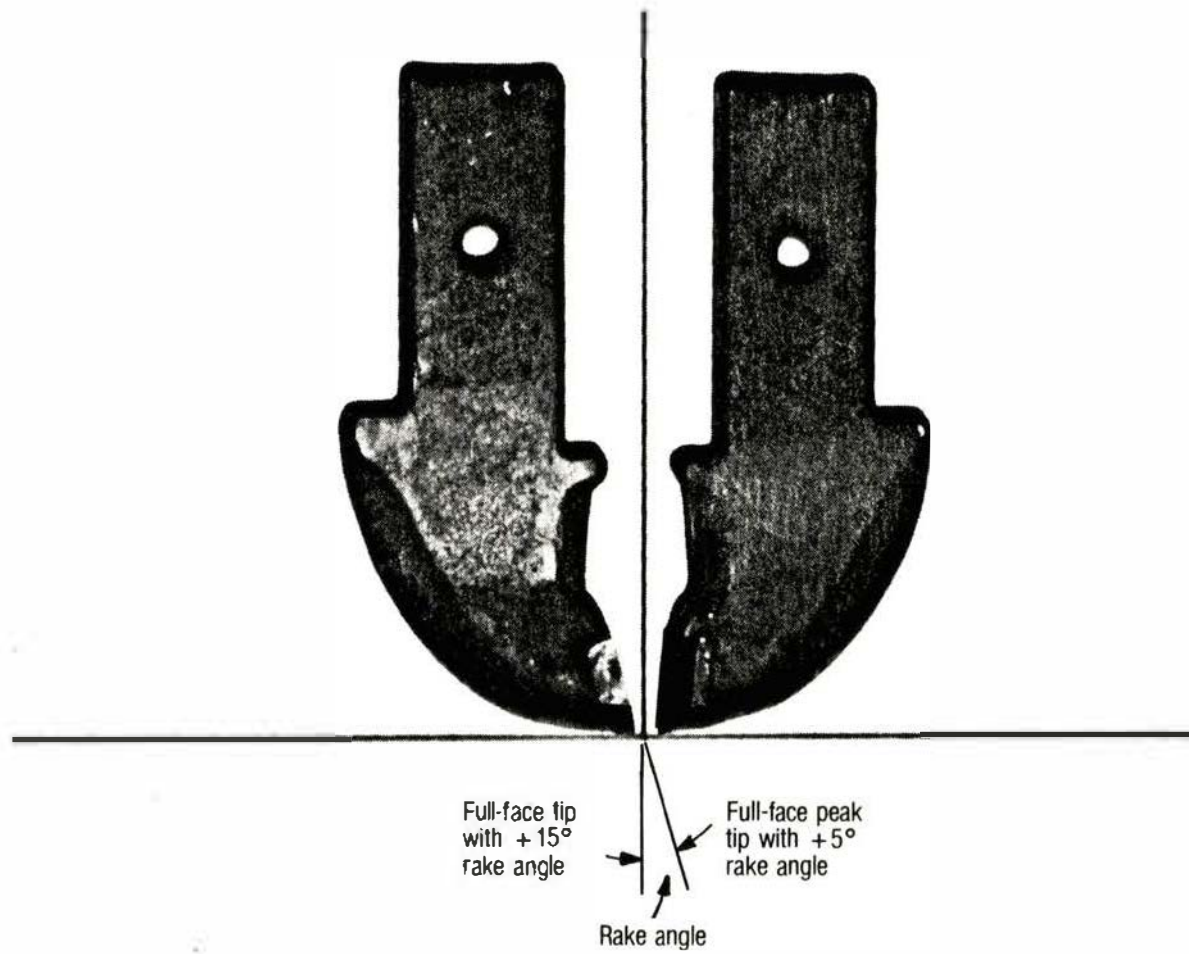


Figure 8 CUTTER BIT STYLES

4.3.2 Steering

During the early weeks of operation, it was found that the wheels inadvertently steered off of their intended course; i.e., they would steer without a command from the remote controller. This problem occurred because the fluid lines to the steering cylinders contained shuttle valves which allowed fluid to pass from one steering cylinder to the other. Removal of the shuttle valve overcame this problem.

Occasionally, the wheels lost synchronization, i.e., they did not turn to equal angles. This condition can be remedied by placing the steer/tram control lever in full steer until both pairs of wheels have reached their steering limit. To avoid this problem, changes must be made from crab steer to four-wheel steer, or vice versa, only when the wheels are at maximum steer positions.

Four-wheel steer is required to make sharp turns from entry to crosscut and vice versa. Crab steer works very well when moving from rib to rib across entry. Once the auger miner has reached the opposite rib and the trough rubber lip is close to the rib, the wheels are straightened out. The auger miner is then moved parallel to the rib until the auger is opposite the spot for the next borehole.

4.3.3 Brakes

When the auger miner went underground, the wheel brakes were installed to automatically release when the control lever was moved into the tram position, and the deadman switch was held closed. After a week of operation, it became apparent that the brakes were not holding the auger miner in place when the control lever was released; the auger miner would roll back 1 to 2 feet. To correct this problem, the brake fluid lines were separated from the tram fluid circuit. A separate solenoid operated flow control valve was added to the brake fluid circuit. This control valve was activated by an unused set of contacts in the deadman switch. With this arrangement, the brakes were released when the deadman switch lever was held down. This remedy provided little if any improvement, however.

The next corrective step entailed using a dedicated switch for release of the brakes. This switch was placed next to the deadman switch lever so that both could be operated with one hand. With this arrangement, brake control was improved by tramping into position, continuing to hold the deadman switch and the control lever in tram, releasing the brake switch and waiting a few seconds for the brakes to fully apply, and then releasing the deadman switch and the control lever. This arrangement and procedure seemed to work fairly reliably, giving the brake application spring adequate time to force the oil out of the brake cylinder and through the fluid lines. Had the fluid lines been larger (they measure 1/4 inch inside diameter), the problem might not have occurred.

4.3.4 Roof Jacks

The roof jacks retracted away from the roof immediately after being set against the roof. A time delay inherent to the design of the hydro-mechanical cylinder lock and an open center control valve allowed the cylinder rod to retract an inch or more after being set. The problem was

corrected by installing a pilot operated check valve in the roof jack fluid line circuit.

While drilling a hole, the auger miner floor jacks and wheels would settle into the mine floor to the point that the roof jacks no longer supported the roof. This problem was solved by extending the jacks to the roof again and as often as necessary.

4.3.5 Conveyor

Large chunks of coal occasionally jammed the conveyor. It was found that if the conveyor was reversed momentarily a few times, the jam could be cleared.

4.3.6 Borehole Drilling

The following is the operation procedure, when the auger miner is positioned near the rib at a point where the hole is to be drilled:

- Extend roof and floor jacks
- Set rib jack
- Sump auger trough up to the rib
- Pull valve selection lever between auger troughs to open the proper pair of auger rotation valves
- Start conveyor
- Start auger rotation
- Start sumping auger.

The reverse procedure should generally be followed when the borehole is complete, except that the conveyor is not turned off until the auger is fully retracted into the trough.

When drilling was first begun, it was found that rotation had to be slow or the rotating auger eased into the rib until the cutting bits were all cutting coal; otherwise, the auger would climb the rib.

When the borehole was about 7 feet deep, the end of the auger flighting did not effectively push the cut coal to the conveyor. From this point on, the end of the flighting helix flipped bug dust and chunks of coal up into the air, but never out of the trough. The alternative was to sump the trough out of and back into the borehole to push the coal to the conveyor. Each of these sumping cycles took time and increased the time necessary to bore a hole. Initially, the auger was cycled out and in to clear cut coal, but the operator later let the cut coal accumulate, toss, and slowly creep back to the conveyor until the borehole was completed. To resist the thrust of the auger during borehole drilling, stabilizer jacks forced hinged footplates into the mine floor. These jacks proved mostly ineffective after fluid pressures were boosted to 3,000 psi to obtain greater auger thrust. To

prevent the auger miner from moving out of the drilling position, a rib jack was placed opposite the outby auger. This rib jack was merely a roof jack with one end set into a piece of pipe welded to the machine frame. The inby auger needed no rib jack to react thrust, because the inby auger is nearer the center of gravity of the machine.

4.3.7 Augers

The auger miner was originally constructed so that rotation of either auger could be initiated at the remote controller through use of a pair of pilot operated check valves for each auger motor. Fairly early in the demonstration, it became apparent that the check valves were not operating reliably. Sometimes, when operating the other auger, the auger that had previously been in use would continue to rotate, or the auger in use might stall momentarily while the idle auger began to rotate. The check valves added considerable restriction to fluid flow. Both of these problem areas were eliminated by replacing the check valves with a pair of manually operated ball valves for each auger motor. The operating levers of each pair of ball valves were connected, and each pair of valves was connected by a link. Two operating handles were connected to that linkage arrangement, one for each side of the machine. This valve arrangement switched fluid flow from one auger motor to the other and isolated the idle motor from the high pressure of the hydraulic system.

4.3.8 Hydraulic Reservoir Refill

Originally, the reservoir was filled through a large filler placed in the top of the tank. This filler had a shallow screen in the opening which inhibited oil flow into the tank. It was realized that a miner would soon lose patience and poke a hole in the screen to accelerate oil flow.

Since some mining equipment has a system for self-filling the tank, one of those components, the aspirator, was obtained and installed on the auger miner. By allowing fluid to flow to the aspirator (jet pump), less than atmospheric pressure is created within the aspirator. Atmospheric pressure then pushes hydraulic oil out of a refill container through a hose and into the aspirator. All fluids flowing through the aspirator go into the reservoir.

4.4 EQUIPMENT FAILURES AND PROBLEM AREAS

There were failures of several major components on the auger miner, one of which occurred before leaving the ESD shop. Most components failed progressively until their performance became unacceptable. A few minor problem areas kept recurring until a satisfactory solution could be implemented. The following were the component failures and problem areas:

- Variable volume pump
- Vane motors
- Chain conveyor drive-shaft bearing
- Stabilizer jack spherical rod-end bearing.

- Steering cylinder attachment bolts
- Steering link spherical rod-end bearing
- Hydraulic oil temperature
- Auger sump chains
- Hydraulic valve bank

4.4.1 Variable Volume Pump

This pump failed three times, twice at the ESD shop and finally during the demonstration. Pump failure was noted while debugging the machine during shop assembly. The failure was determined to be internal leakage, which worsened as debugging continued. The pump was sent to a factory repair center, where it was found to have severe internal damage. Oil samples of the hydraulic system were examined and found to be contaminated with metal particles; a 3-micron filter was thus purchased and temporarily installed in the pump fluid circuit to remove the contaminants.

The second failure of the pump was damage to the rotating part of the shaft seal and was caused by a piece of metal (see Figure 9) which was inadvertently left inside the pump during the first rebuild. This piece of metal was part of the flange of the stationary part of the original seal replaced when the pump was rebuilt.

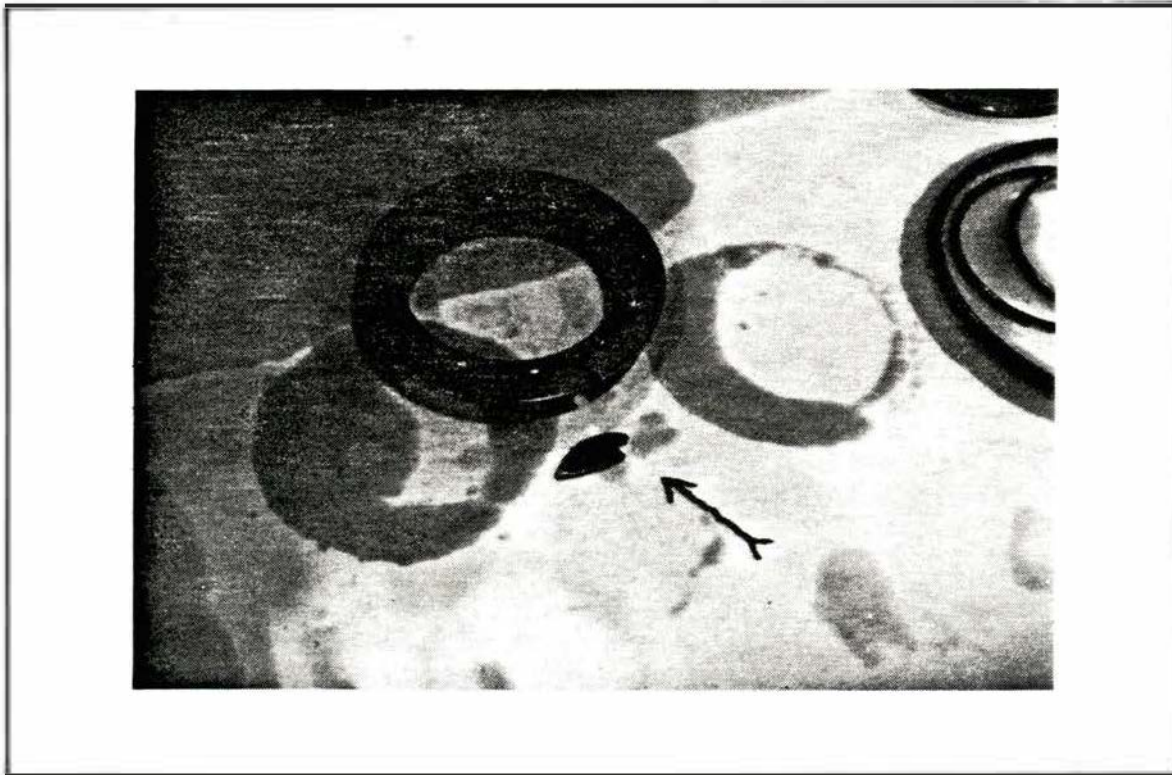


Figure 9 BROKEN PIECE FROM PREVIOUS FAILURE FOUND IN REPAIRED PUMP

Once underground and reassembled, the auger stalled when an attempt was made to drill the first borehole. Auger rotation pressure, which should be 2,250 psi at stall, dropped to less than 500 psi, and pump charge pressure dropped to 0 psi. Since the situation was identical for both augers, it was concluded that the pump was at fault. Other diagnostic tests were performed which confirmed this conclusion. The pump was taken to the factory for repair, where the diagnosis of failure was "gross contamination."

Before resuming operation, two 10-micron high pressure filters were installed in this closed-loop pump/motor circuit so that fluid returning to the pump would always be filtered.

4.4.2 Vane Motors

Both motors driving each auger failed, due to excessive wear on the end covers and the center divider plate, resulting in excessive leakage. The cause of failure could not be determined, although there were three possible reasons for the excessive wear:

- Contamination of hydraulic fluid
- Thermal shock
- Axial loading of rotor.

4.4.2.1 Contamination of Hydraulic Fluid

Following the first failure of the variable volume pump, the hydraulic fluid was examined and found to contain metal particles and other contaminants.

Contaminated fluid circulated through these motors until the pump was removed for repair (as stated above, a 3-micron filter was temporarily installed to remove contaminants from the fluid). Failure of the motors was not apparent, however, until about the thirteenth week of the demonstration. The first indication was that one auger took 3 to 4 minutes longer to drill a hole to full depth.

Numerous possible causes for this difference were investigated before being narrowed down to the motor. During the diagnosis process, it was realized that the hydraulic fluid had a "cloudy" appearance that was initially thought to be water. A sample of the fluid was sent to the FMC Corporation Materials Laboratory in Santa Clara for a qualitative analysis. The lab report (see Appendix D) stated that there were 30.9 milligrams of contaminant per 100 milliliters of hydraulic fluid, amounting to 0.036 percent of contamination on a weight basis; the fluid contained 0.25 percent of water by volume. The cloudy appearance of the fluid was the result of very fine particles suspended in the fluid. Before resuming operation after rebuild of the motors, all 10-micron filter elements were removed and replaced with 3-micron elements until filter element replacement was required. By the end of the demonstration, much of the contamination appeared to have been removed from the hydraulic fluid.

4.4.2.2 Thermal Shock

The motor manufacturer informed ESD engineering that these vane motors were sensitive to thermal shock because of the very small clearances between internal parts. Thermal shock occurs when hot fluid (140°F) is circulated through a cold motor (65°F), because it has been idle; the hot oil makes the internal parts of the motor expand, reducing these clearances to none in some places.

To prevent thermal shock, hydraulic fluid is usually continuously circulated through the end covers of each motor. External tapped ports were provided for this purpose, but required connection to the pump output by numerous long hose assemblies. One end of each of these hose assemblies had to move about 10 feet as the auger drilled a borehole. An alternate method was adopted which used short hose assemblies with no relative movement. This method allowed a small volume of fluid to drive the auger motor; the idle auger thus actually rotated very slowly while the other auger was working. This was considered to present no hazard to operating personnel.

4.4.2.3 Axial Loading of Rotor

Auger thrust loads are taken by a large spherical-roller thrust bearing attached to the auger drive motor. This bearing supports a shaft which attaches to the auger at one end and is driven by the vane motor, through splines, at the other end. Bearings of this type and for this application must be preloaded to prevent the shaft from moving in an axial direction when a heavy load is applied. Axial thrust could be transmitted to the rotor of the vane motor if the splines were transmitting torque before the thrust load was applied. Axial thrust applied to the rotor would cause rapid wear of the center and end plate.

Axial play on the thrust bearing for one auger was measured at 0.015 inch. Shims were removed from the assembly to provide the proper preload. The preload on the thrust bearing for the other auger was found to be properly adjusted.

To what extent the loose thrust bearing contributed to wear in the motor is unknown. Wear in the motor on one end plate and one side of the center plate would lead to the conclusion that the wear was caused by thrust loads, but both end plates and both sides of the center were severely worn.

4.4.3 Chain Conveyor Drive-Shaft Bearing

While drilling the first hole, after repair of the variable volume pump, the conveyor suddenly stopped as if jammed with coal. Jogging the conveyor forward and backward about 18 inches at a time cleared out the coal, but the conveyor still would not run properly.

The cause of the problem was suspected to be at the drive end of the conveyor. Observation holes were burned through the foot shaft area hold-down plates; no physical cause for the malfunction could be seen, leading to the suspicion that the hydraulic drive motor was the cause of the malfunction. The motor was removed and sent to an authorized service center, where testing indicated that the motor met manufacturer's specifications. With the motor reinstalled and conveyor running, fluid line pressures in and out

were measured and conveyor drive shaft bearing temperature monitored (by touch test); bearing temperature increased rapidly. The conveyor drive shaft assembly was disassembled; one bearing was found nearly destroyed due to lack of lubrication. Before the drive shaft assembly was reassembled, the drive shaft had to be resurfaced.

4.4.4 Stabilizer Jack Rod-End Bearing

There were several failures of the rod-end on the inner (inboard) stabilizer jack for each auger. Failure appeared to be caused by lumps of coal and coal fines packing between the hydraulic cylinder and surrounding structure. The problem ceased after a piece of rubber conveyor belting was placed over the clearance opening in the structure around the jack, and the rod end attachment was changed so that a cavity in the jack arm could no longer pack with coal or apply a moment to the rod end.

4.4.5 Steering Cylinder

The steering cylinder for the wheels at the discharge end of the machine regularly came loose from its mounting. The cause was thought to be excessive vibration resulting from the conveyor chain rubbing against the chain upturn bracket attached to the bottom of the cylinder mounting plate. Anaerobic adhesive (Loctite) was applied to the mounting bolt threads, but failed to prevent the bolts from loosening. No other action was taken to resolve the problem.

4.4.6 Steering Link Rod-End Bearing

The bolts that attach steering link rod-ends to wheel steering arms repeatedly came loose. The spring-type lockwasher was inadequate to maintain bolt torque against the frequent load reversals. No corrective action was taken except retightening each bolt.

4.4.7 Hydraulic Oil Temperature

The oil temperatures in the auger drive hydraulic circuit rose to over 190°F after drilling six consecutive holes (oil temperatures were not stabilized at this point). This temperature increase had a noticeable effect on the time required to drill a hole. The first hole drilled, at the start of the shift, took about 6 minutes, and each successive hole took longer to drill than its predecessor. The sixth hole required 10 to 12 minutes to drill 10 feet deep.

The oil temperature rose because the variable-volume pump and each auger drive motor were in a closed loop circuit. Heat was generated in the circuit faster than hoses, pumps, and valves could dissipate it. Although a small volume of oil flowed back to the reservoir from the pump and motor case drains (because of internal leakage) where it might be cooled slightly, the amount was insignificant.

In an effort to get more oil back to the reservoir, a flow control valve and check valve were connected to the low pressure leg of the circuit with a tee fitting, allowing an additional oil flow of 3 gallons per minute to flow to the reservoir. This flow also proved to be insufficient, and further

increases in flow were not possible because of the insufficient capacity of the variable volume pump charge pump.

To stabilize oil temperature in the loop at or near a desired 140°F, an oil-to-water heat exchanger was added to the low pressure leg of the loop. Water flow through the new heat exchanger is parallel to the heat exchanger in the oil reservoir. To obtain the necessary heat transfer in the new exchanger, water flow through both heat exchangers was increased by increasing the number of dust control spray nozzles for each auger and by replacing the existing water spray nozzles with new ones having larger orifices.

The tube and shell heat exchanger placed in the low pressure loop have a maximum rated working pressure of 200 psi. If an auger is operated in reverse, the pressure in the loop will exceed 200 psi and cause failure of the heat exchanger. To prevent this failure, one wire to the auger reverse switch on the remote control panel was disconnected from the switch.

4.4.8 Auger Sump Chains

A pair of double-strand roller chains are used to sump the auger as it drills its hole. These chains lie inside structural members that are part of the upper edges of the auger trough. The side of each structural member facing an auger is slotted lengthwise to provide passage for the auger drive motor mounting yoke pin. This pin fits into a block that slides along the length of the structural member when pulled in either direction by the chain (see Figure 10).

Coal fines and small lumps are flung upward and into the slot by the tail end of the auger flight once each revolution of the auger. The coal that goes into the slot gets pushed along by the chain-to-yoke block and carried by the lower strand of chain to the double-row sprocket, where it is compacted between sprockets. The entire inside space around the sprocket becomes compacted with coal. Coal compacted between the dual sprockets results in an increase in the effective pitch diameter of the sprocket and thus greater tension in the chain.

This problem was recognized early in the demonstration. Obvious corrective action was to use single-strand chain, thus avoiding the compaction of coal on the sprocket. Single-strand chain and single sprockets were purchased and delivered to the demonstration mine. The single-strand chain was not installed, however, until one of a pair of the double-strand chains broke due to overtension late in the demonstration. Compaction of coal around the idler sprocket was never effectively eliminated, although several ideas were considered and a few tried unsuccessfully.

4.4.9 Trailing Cable and Water Hose

The electrical power cable and water hose entered the machine at one outby (conveyor discharge end) corner of the auger miner, but the power cable/water hose were laid out along the rib on the opposite side of the auger miner, resulting in a loop of cable/hose trailing across and behind the auger miner, with one leg of the loop always close to or under the wheel

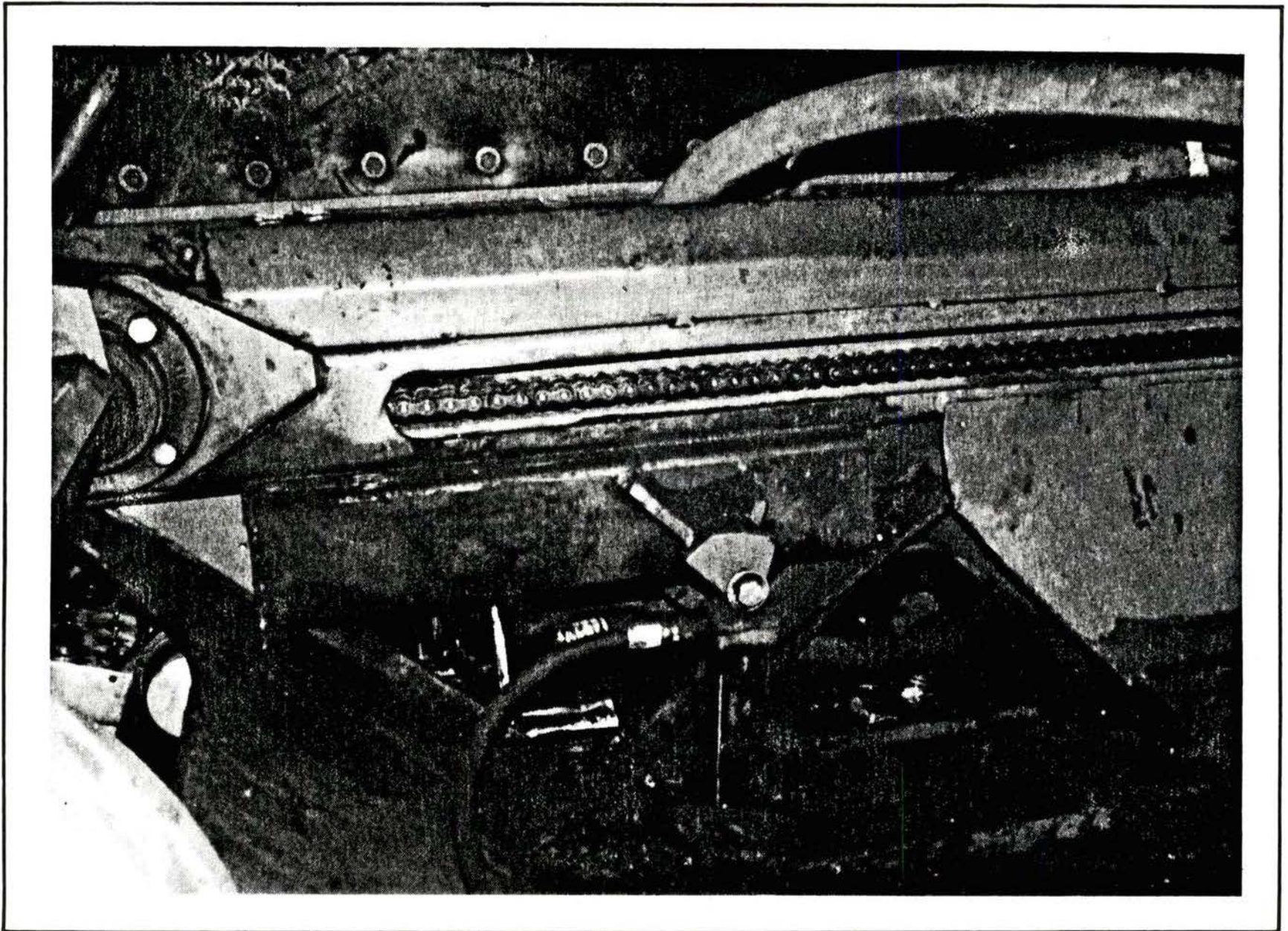


Figure 10 AUGER SUMP CHAIN BEHIND SLOT IN STRUCTURAL MEMBER

when drilling pillars on that side of the entry. This problem was greatly alleviated by attaching cable/hose support brackets to the auger miner at each corner on that side.

4.4.10 Hydraulic Control Valve Bank

One bank of five solenoid-operated control valves continuously leaked hydraulic fluid. When disassembled, one of several special bolts which fasten one manifold block to the next was found broken. These bolts are special because each successive bolt screws into the head of the previous bolt. Each bolt head has internal threads and a hexagonal recess for wrenching with an Allen wrench. The problem was eliminated by replacing the broken bolt, and then clamping the whole assembly together with threaded rods, nuts, and plates applied externally.

4.4.11 Roof Jack Extensions

Each roof jack had a 7- to 8-inch extension threaded onto the end-of-the-jack cylinder rod when delivered to the demonstration site. A 9-inch-diameter pad was fastened to the extension by ball and socket.

Quite often, the jack would not extend to the roof; the extensions were thus replaced with longer (about 17-inch) extensions. With the longer extensions, the jack would nearly always reach the roof. A few places were encountered, however, where the roof-to-bottom distance was markedly less, and then the roof jack pads scraped along the roof. On one occasion, the jack cylinder rod broke off at the threads.

If other means of locking the jack cylinder rod had been used, instead of the hydromechanical lock, there may have been enough additional cylinder stroke available to accommodate most of the roof-to-bottom variations.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The auger miner demonstrated its potential as a viable and economic method of extracting coal from underground pillars, particularly where surface subsidence cannot be permitted.

The auger miner configuration demonstrated at Marissa Mine eliminates or overcomes many of the problems experienced with previous augers which drilled deep holes. Because this auger moves about on four steerable wheels, it can be quickly repositioned to drill the next hole. No precision alignment procedures are necessary. It is only necessary to position the auger miner parallel to the face so that the rubber cuff on the auger trough seats against the coal face. Setup time for each successive hole is less than 5 minutes on the average. With hole spacing on 5-foot-minimum centers, breakthrough into adjacent holes does not occur.

The primary reasons for not meeting the projected production of 250 tons per shift were inadequate power to turn the augers, insufficient thrust on the auger, and high machine downtime for unscheduled maintenance. Cutter bit wear due to imprecise location of cutters relative to a common cutting plane and following the same circular cutting path were also definite contributing factors to reduced cutting rate.

5.2 RECOMMENDATIONS

In view of the large worldwide interest expressed in the auger miner (see Appendix E) and the optimism expressed by individuals within Peabody Coal Company (see Appendix F), we recommend further development of a viable auger miner for extraction of coal from underground pillars.

This program has provided the data to permit design and fabrication of a new model auger miner meeting a majority of mine operators' requirements and incorporating several design changes to improve mobility, durability, productivity, and machine cost. These changes would include, but not be limited to, the following:

- Replace the fixed wheel-to-frame mounting with a wheel mounting that allows all wheels to remain in contact with the ground.
- Replace the roller chain drive system which sumps the auger into the pillar with a more satisfactory system, such as rack and pinion.
- Replace the angled floor stabilizer jacks with jacks that react the auger thrust load against the opposite rib.

- Replace the vane type motors which rotate each auger with electric motors and speed reducers.
- Increase the power available to the rotation drives.
- Replace the hydromechanical cylinder locks on roof and floor jacks with pilot operated check valves commonly found on mining equipment.
- Provide a method of rapidly replacing cutter bits.
- Consider a unidirectional auger design as a means of simplifying the machine and reducing initial cost.
- Eliminate some "nice-to-have" features to simplify the design.

Figure 11 depicts an auger configuration that incorporates most of the recommended changes listed above. A pivoting beam axle has been incorporated to maintain four-wheel contact with the mine floor. Tram drive is by two DC electric motors connected by driveline to front and rear wheel gear reduction drives. Four-wheel and crab steer are provided as before. The auger is driven by a 150-horsepower 900-rpm electric motor through a double-reduction roller chain drive. Two high-torque low-speed gear-type hydraulic motors drive pinions on two inverted racks to sump (advance) the auger into the coal face. A rib jack, which can be pivoted about one end, is provided to react auger thrust into the opposite rib. Machine control, roof jacks, dust control (by water spray), and bore hole ventilation, are like those on the bidirectional auger. One 36-inch-diameter auger, rather than two 48-inch augers, is proposed to reduce machine cost, weight, and height. At an overall height of 52 inches, the auger should have a broader marketing potential for recovering coal from pillars. With the conveyor arranged for discharge at either end, the auger has capability to work pillars on both sides of an entry or crosscut.

Specific output of the 36-inch auger would be increased so that total output per shift will be 200 to 250 tons per shift.

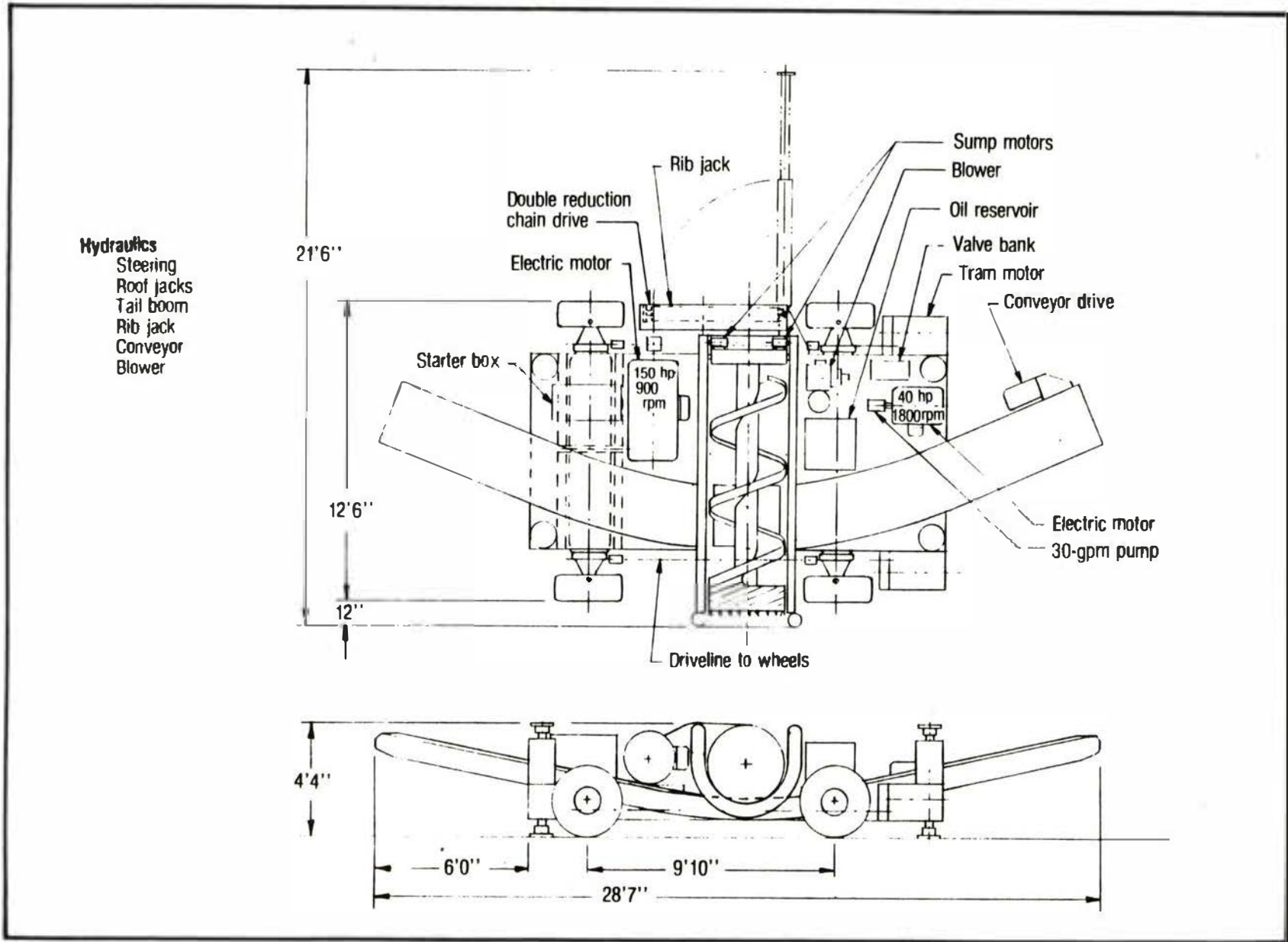


Figure 11 SINGLE AUGER CONCEPT

6.0 SUBJECT INVENTIONS

By definition, "Subject Inventions" means any invention, discovery, improvement, or development (whether or not patentable) made in performance of the experimental, developmental, or research work under this contract.

No subject invention claims are being made by ESD.

Appendix A

**DIARY OF PROJECT
ACCOMPLISHMENTS**

APPENDIX A

DIARY OF PROJECT ACCOMPLISHMENTS

ACCOMPLISHMENTS DURING OCTOBER 1978

- The bulk of this period was devoted to creating the organizational regime for the program. Several project control documents were drafted and finalized.
- The bidirectional reports and proposals which formed the basis for this contract were reviewed.
- The model of a bidirectional auger configuration which had been developed in an earlier program was displayed in FMC's exhibit at the American Mining Congress International Mining Show in Las Vegas, Nevada, on October 9 through 12. The model was explained to interested parties by the several members of the project staff in attendance. Interest in the model and in the concept of underground augering was high, and several mining companies indicated that, as the project progressed, they would consider mines under their control as possible demonstration sites. The following are some of the constructive criticisms or suggestions offered by those reviewing the model:
 - The mining industry appears to view augering as having more appeal in low coal - 60 inches or less.
 - They are also interested in full-seam extraction; they view leaving a band of coal at the seam bottom or leaving a thick web as a weakness of the system.
 - Several comments were voiced that the separate drill and extractor vehicles appeared cumbersome and added expense to the system.
 - The concept of deep drilling was disputed by most operators, who viewed the major utility of the machine as the ability to recover coal from their normal pillars - generally 40 feet by 60 feet or smaller.
 - Most reviewers indicated that if the cost of the auger system was not substantially less than that of a continuous miner, they would prefer to purchase the more versatile miner to rob pillars.
 - Only a few visitors indicated an interest in using the auger purely to drill airways.

We are currently reevaluating our two-machine concept in light of these comments and the unidirectional auger demonstration findings. The unidirectional auger now operating at the Ireland Mine is providing valuable information on auger handling guidance and ventilation and on machine maneuverability and setup.

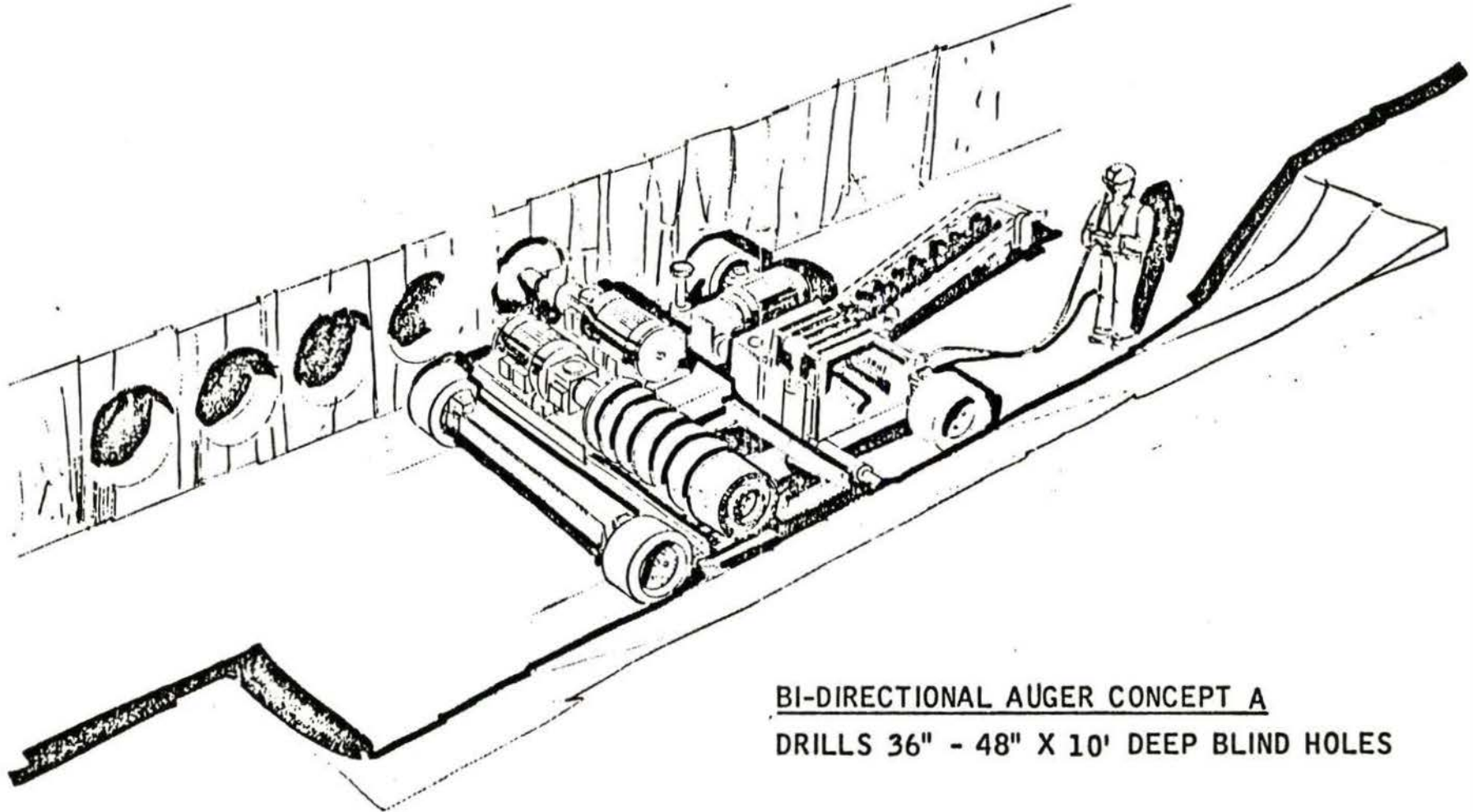
We expect to further contact several of the mining companies who expressed an interest in the project while at Las Vegas to determine their desires and specifications if a system were to be fabricated for demonstration in one of their mines.

ACCOMPLISHMENTS DURING NOVEMBER 1978

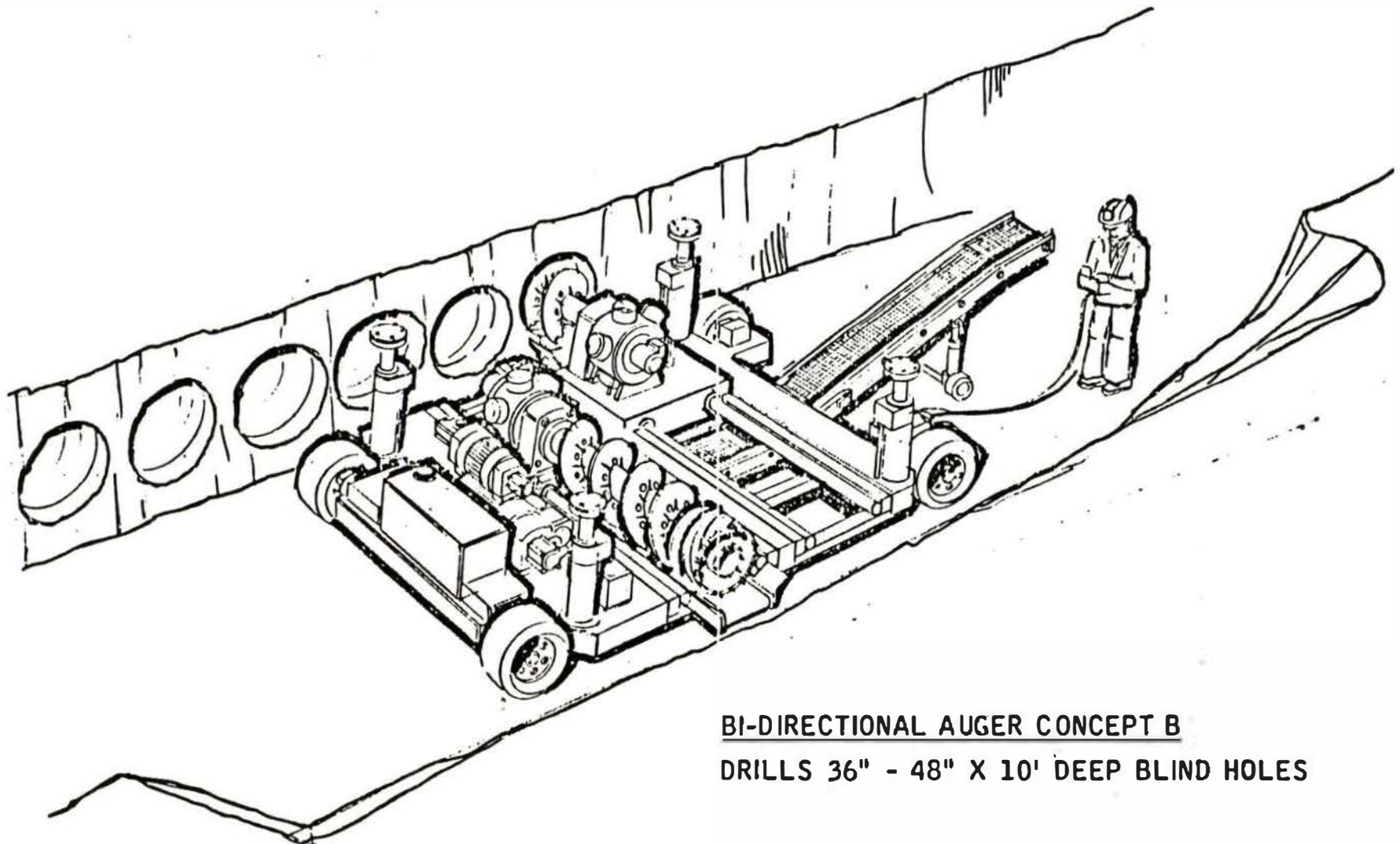
- Several new concepts for bidirectional augering machines are being evaluated, the more viable of which are machines which function independent of specialized ancillary equipment.
- The unavoidable delays incurred with our unidirectional underground auger are the time required to reload flights, moving and setting up the auger machine to start the next hole, and shuttle car changeout. It has become apparent that if boring is an uninterrupted process while loading a shuttle car to capacity, then the only mining delay is experienced during shuttle car changeout, meaning that the time required to set up for boring the next hole must be included within the shuttle car changeout time. Augered holes should then be sized in diameter and depth to match the capacity of the face haulage equipment.

If an augered hole does not break through the pillar to establish ventilation, a specialized ventilation plan must be designed to resolve that problem. Such a ventilation plan has been prepared for submittal to MSHA.

- Upon evaluation of the time study data taken from the underground auger program in the Ireland Mine, two promising machine concepts have emerged (see attached illustrations). These machines will require further "brainstorming" in the areas of tramability, coal conveyance, and power requirements.



BI-DIRECTIONAL AUGER CONCEPT A
DRILLS 36" - 48" X 10' DEEP BLIND HOLES



BI-DIRECTIONAL AUGER CONCEPT B
DRILLS 36" - 48" X 10' DEEP BLIND HOLES

ACCOMPLISHMENTS DURING DECEMBER 1978

- A review meeting was held at the Ireland Mine, at which the two bidirectional auger concepts shown in last period's report were revealed and discussed. Attendees were:
 - Mr. Norbert Becker - General Superintendent, Ireland Mine
 - Mr. W. G. Yavelak - Chief Mine Engineer, Ireland Mine
 - Mr. Bruno Bettinazzi - Safety Superintendent, Ireland Mine
 - Mr. Don Yoders - Superintendent, Rosbys Rock Portal Ireland Mine
 - Mr. Hestle Riggle - Assistant Mine Foreman, Ireland Mine
 - Mr. James Glendenning - Section Foreman (Current Auger Test Section)
 - Mr. Joe Ritchey - Auger Program Manager, FMC

Both concepts were favorably received, but the concept which was seen as plainly superior was the remotely controlled chassis which mounted to two rigidly attached augers designed to drill 10-foot blind holes. The Ireland Mine views this concept as being ideal to work in their normal roomed-out areas where the pillars are only 34 feet wide. This concept would offer a true increase in recovery not presently provided by the unidirectional auger because of MSHA restrictions on the hole patterns and the incidence of intersected boreholes. Although no demonstration agreement was solicited at this time (and none volunteered), it appears that the Ireland Mine will have a strong interest in demonstrating one of these two new concepts (preferably the blind hole borer).

- An operating scenario utilizing sequential artist drawings or model movements, along with narrative for each step, is being prepared prior to approaching MSHA for their pre-approvals of the mining and ventilation plans.

ACCOMPLISHMENTS DURING JANUARY 1979

- All of the drawings and most of the text for the operating scenario of the current bidirectional auger concept have been completed. Additional calculations are being made to determine such factors as additional tonnage recoverable from pillars, total time of exposure of the equipment in an entry, etc.
- Staff officials of MSHA in Arlington, Virginia were contacted and invited to a concept review meeting at FMC at the end of February. At this time, we are hopeful that an exact set of criteria for all of the operational and safety issues can be resolved.
- Design work has been initiated for those areas which are not strongly dependent on the exact concept, such as the tram system, to the extent that commercial components are being evaluated and vendor data is being accumulated. One interesting investigation is the possibility of using a low-speed, high-torque electric motor to power the auger drill drive. There is some possibility of a space saving.

ACCOMPLISHMENTS DURING FEBRUARY 1979

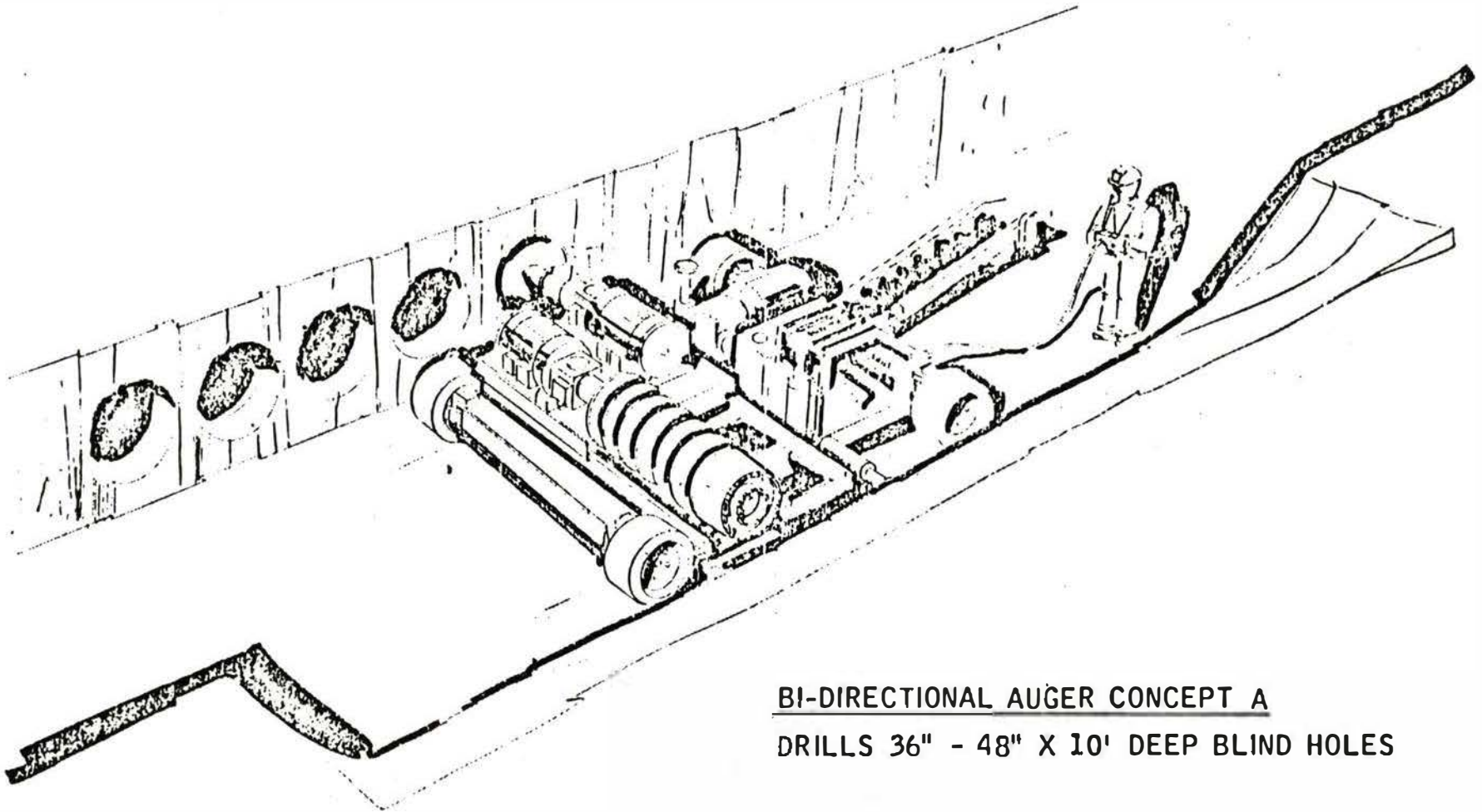
- The operating scenario for the bidirectional auger and concept drawings and pillaring plan drawings were completed and used as the basis for discussions with MSHA. They are attached to this report.
- A concept review meeting was held between FMC and MSHA at FMC's Engineered Systems Division office in Santa Clara on February 27-28. MSHA personnel in attendance were:
 - Mr. Robert Elam - Arlington, Virginia
 - Mr. Paul Componation - Arlington, Virginia
 - Mr. Mike Lawless - Morgantown, West Virginia

All configurational and operational aspects of the concepts were explained and discussed. We are awaiting a memorandum of understanding from MSHA indicating their recommendations, but in general it appears that the concept is viable, specifically:

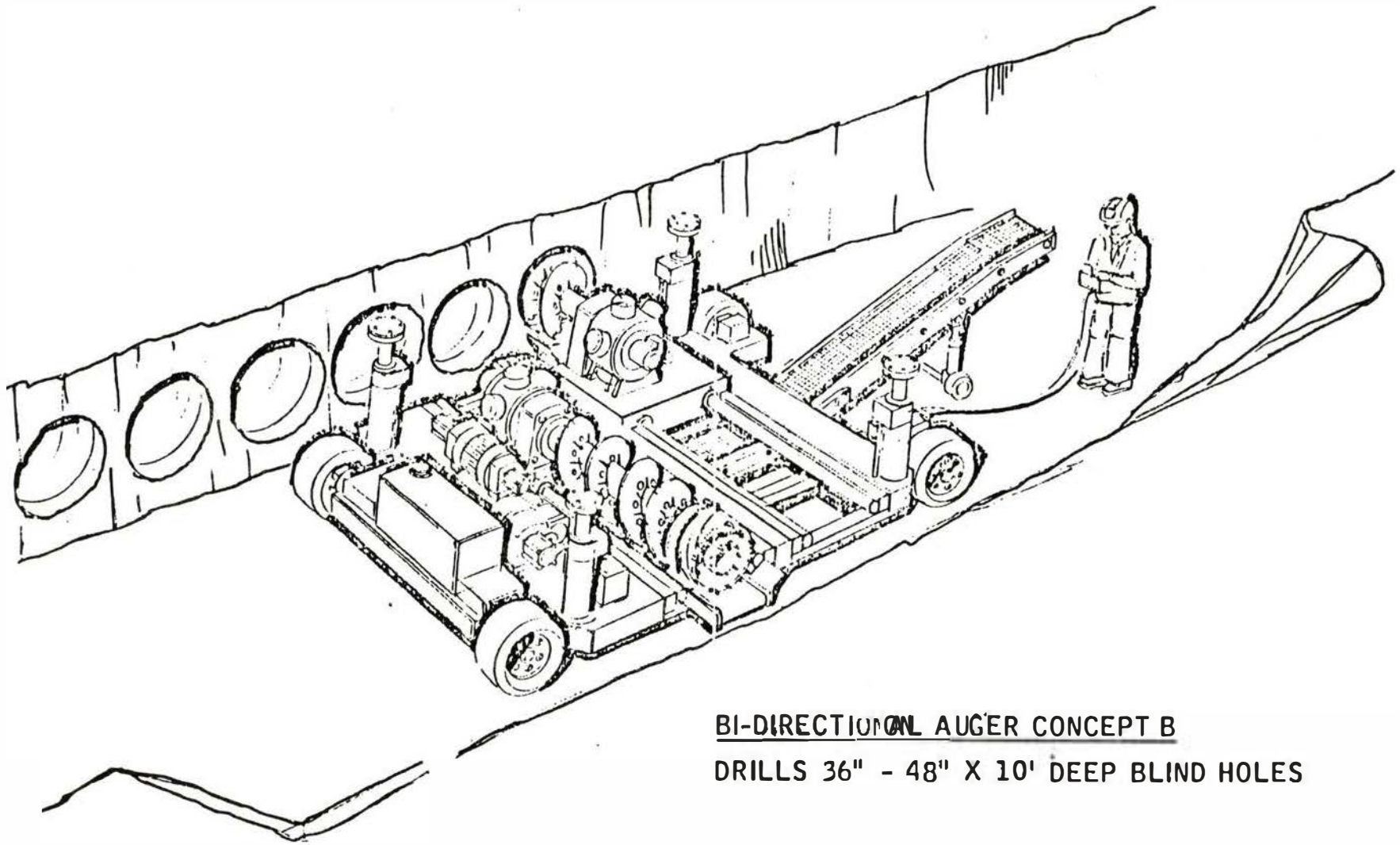
- Short blind holes will be allowed without sealing, but with subsequent area rock dusting.
- Ventilation must be maintained in the borehole during drilling, both natural and forced. The amount of forced ventilation can be determined by the specific liberation of methane encountered, but in general, an on-board blower-type system (100 to 200 SCFM) should be sufficient.
- Water sprays are encouraged.
- Posting behind the machine, if required at all, can consist of a line of breaker props, which may be hydraulic if desired, and retrieved by lanyard and reset. The machine's roof jacks may also suffice for this function.

Some topics were not resolved, including the use of an umbilical control box for remote control in lieu of an on-board operating station. The requirements for service and parking brakes were also in question. We were referred to others in MSHA who have interpretative experience in these matters.

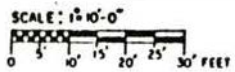
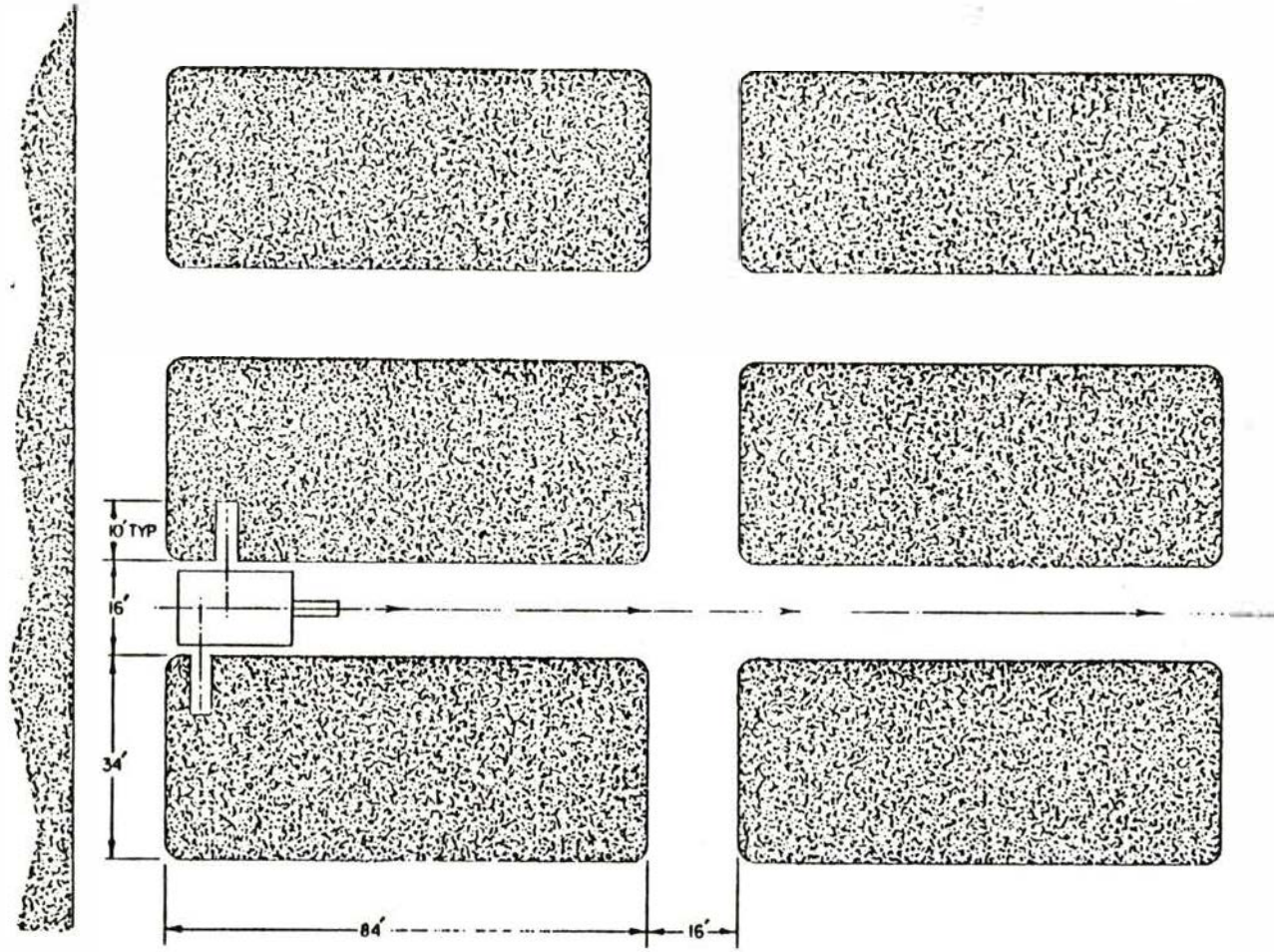
- Design work continued on power train, frame, and steering systems. Recent horsepower experiments on the auger machine now at the Ireland mine are being reviewed to aid in selecting bidirectional auger components.



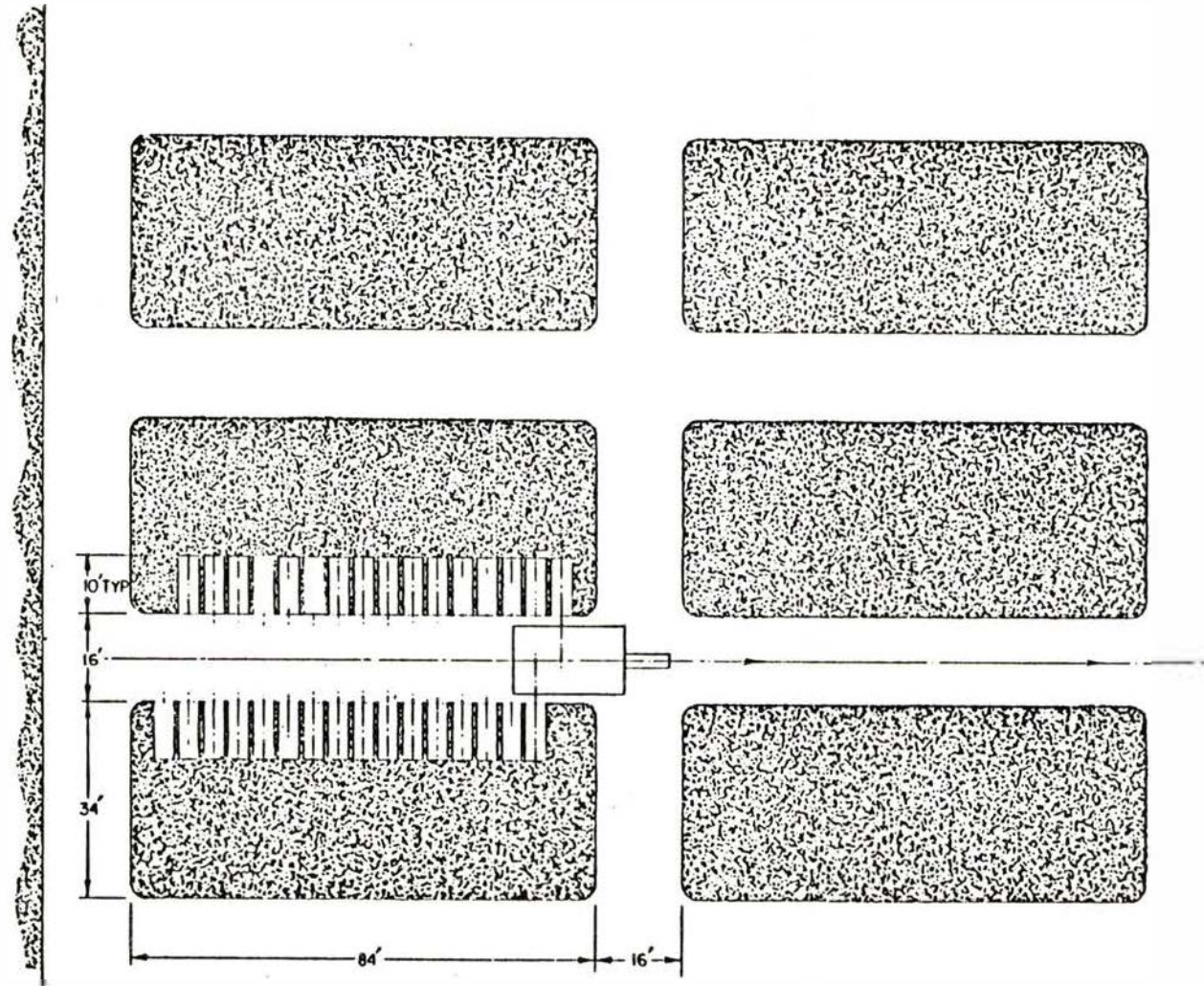
BI-DIRECTIONAL AUGER CONCEPT A
DRILLS 36" - 48" X 10' DEEP BLIND HOLES



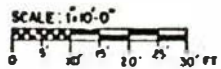
BI-DIRECTIONAL AUGER CONCEPT B
DRILLS 36" - 48" X 10' DEEP BLIND HOLES

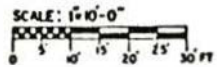
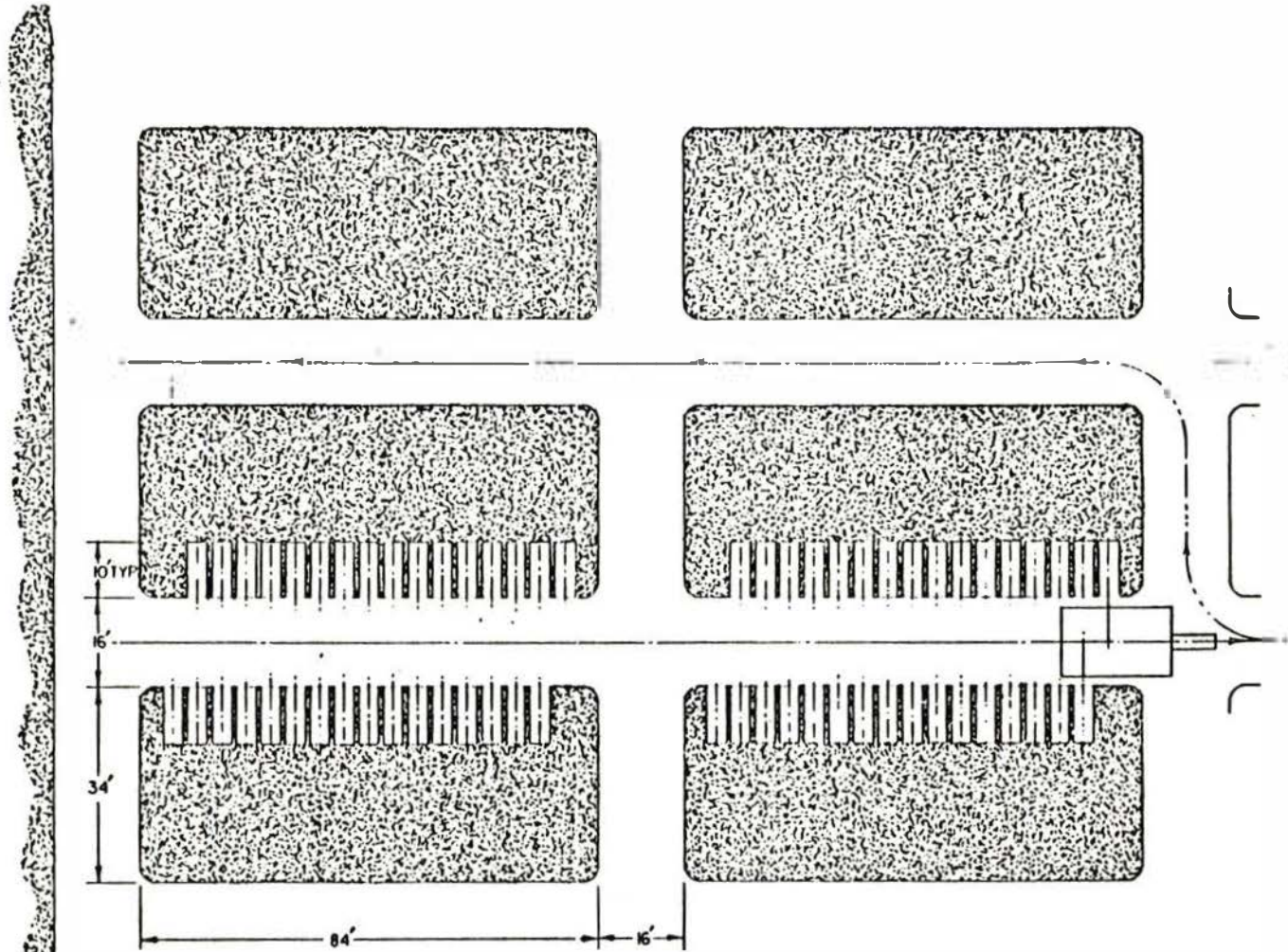


1 START OF PILLAR EXTRACTION, BOREHOLES DRILLED SEQUENTIALLY.

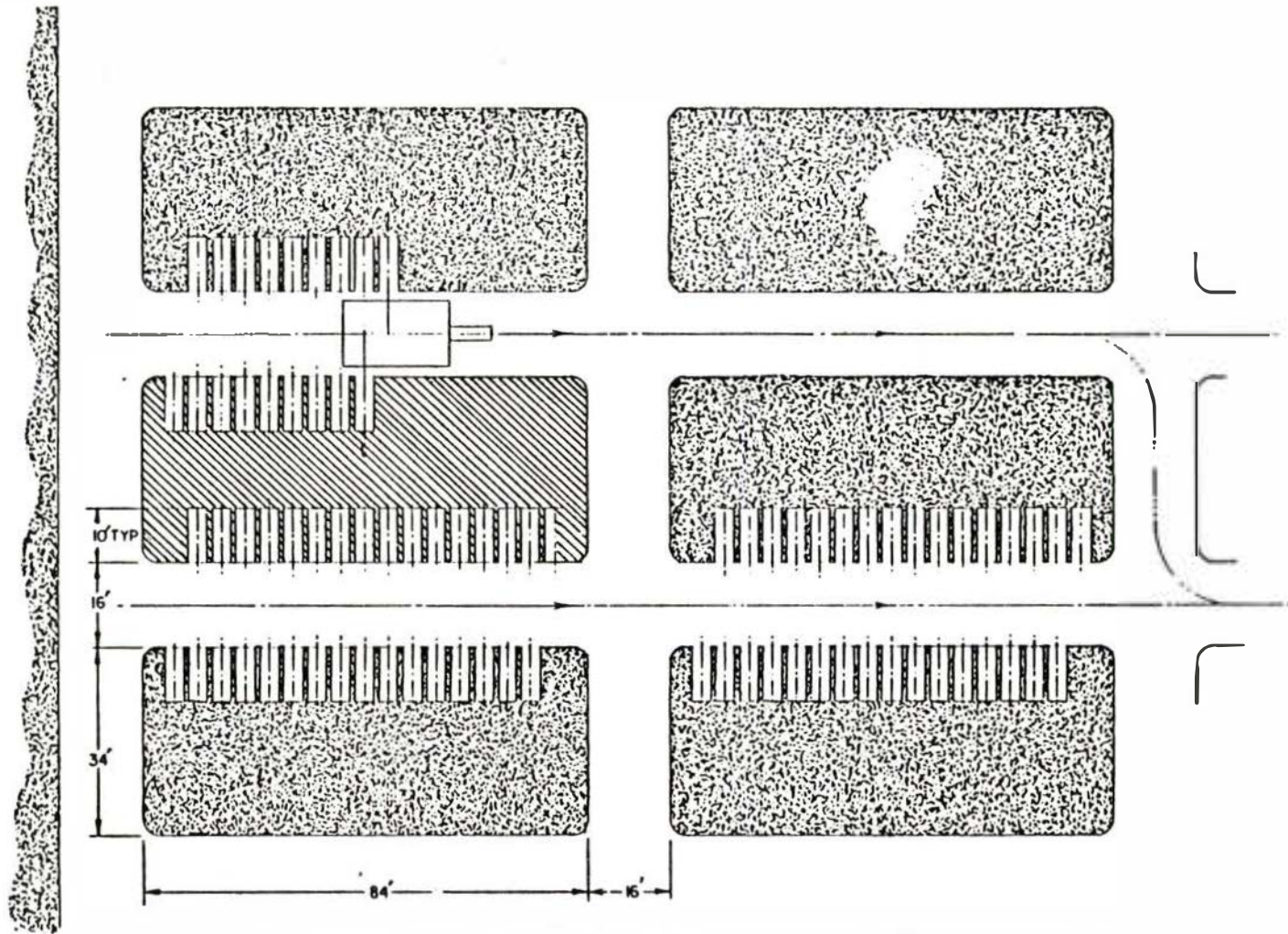


2 FIRST PAIR OF PILLARS TOTALLY DRILLED.
APPROXIMATELY FOUR TONS PER BOREHOLE.





3 SECOND PAIR OF PILLARS TOTALLY DRILLED.
READY TO MOVE TO ADJACENT ENTRY.



4 THIRD PAIR OF PILLARS BEING MINED. SHADED PILLAR WILL BE THE FIRST TO BE TOTALLY EXTRACTED.

SCALE: 1" = 10'-0"

ACCOMPLISHMENTS DURING MARCH 1979

- On March 13, a meeting was held at MSHA's technical support center at Bruceton, Pennsylvania, to discuss FMC's concept of remote control of the bidirectional auger versus an on-board operator's station. The following people were in attendance:
 - Tony Escover - FMC, Advanced Mining Systems Manager
 - Joe Ritchey - FMC, Bidirectional Auger Project Manager
 - Jack McCormack - Chief, Division of Safety Technology PTSC, MSHA
 - Tony Zona - Chief, Roof Control Branch, PTSC, MSHA
 - Bill Debevec - MSHA, Roof Control Branch
 - Joe Cybulski - MSHA, Roof Control Branch
 - Glen Springer - MSHA, Roof Control Branch
 - Robert Crumrine - MSHA District 3, Supervisory Coal Mine Technical Specialist (roof control)
 - Robert O'Neil - CMI, MSHA District 3, Roof Control
 - John Bogus - Bureau of Mines, PSMRC Industrial Safety

The meeting was lengthy and detailed and included a scenario of operation, time study information, etc. The question of remote control for reasons of visibility, removal of an operator from hazardous location, etc., was not challenged; however, the application of roof jacks onboard the machine was insisted upon as supplemental roof support when performing routine or emergency repairs or maintenance. Ultimately, no conclusions could be made until FMC submitted a scale, plan-view drawing of the machine showing operator locations, roof jack locations, and capacities and the positions the machine could take in the entries when drilling. No official recommendation on our remote control scheme could be made until this drawing had been submitted.

It was suggested that, in addition to considering umbilical remote, we investigate radio remote control. We have located several vendors of permissible radio remote equipment, one of which seems promising if enough channels are available to control all of the machine's functions.

- A plan view drawing containing the information mentioned above was made and sent to MSHA for their review and recommendations.
- A meeting was held at the offices of Associated Mine Management, Inc., in Belle Vernon, Pennsylvania, regarding use of one of their mines (the Shannopin Mine, now owned by J & L Steel) as a test site for the bidirectional auger. They approached FMC after reading an article on

our auger work in Coal Age Magazine. They will be sending an official letter of interest in April, and arrangements are being made to visit the mine at that time.

- Significant progress was made on the designs of the tram, sump, conveyor, and electrical systems on the basic machine. A concept for a semicylindrical auger trough with a center-mounted conveyor is being modeled in 1/8 scale. If successful, it will offer such advantages as reduced spillage, lighter machine weight, better maneuverability, and the probable elimination of an entry conveyor.

ACCOMPLISHMENTS DURING APRIL 1979

- MSHA has not yet reached any conclusions on our request to operate the bidirectional auger by remote control. They are expected to have an official comment on our proposed system by mid-May.
- Associated Mine Management, Inc., is behind schedule in its planned acquisition of the Shannopin mine, but continues to have a strong interest in the project. When takeover of the mine is complete, they will formalize their interest in a letter. We will be able to visit the mine at that time.
- The electrical system for the auger machine is 70-percent complete. One roof/floor jack is nearing completion for physical test. One wheel unit is being fabricated also for physical test.
- The 1/8-scale model of a semicylindrical auger trough was completed and test run. It appears that, by using a sump and retract cycle, all coal can be removed from the borehole. The model is being fitted with a small conveyor, at which time we should know whether the design is suitable.

ACCOMPLISHMENTS DURING MAY 1979

- A meeting was held on May 9, with members of MSHA's Technical Support group in Pittsburgh, regarding our request to operate the bidirectional auger by remote control. Their review of our drawing had raised some questions regarding the safety of the operator from being run over or bumped by a shuttle car. We agreed to modify our drawing to show an entry (second stage) conveyor or a "surge buggy" operation, wherein one shuttle car is parked behind the miner and acts as a transfer car only (i.e., trams only when the miner trams). These plans are now being considered by MSHA.
- With reference to the above, it was discovered that, with our desired tailboom arrangement, the bidirectional auger would not negotiate a 90-degree, three-way intersection, a stringent design requirement. We have now developed a concept for a short tailboom on the miner with a special second-stage conveyor permanently attached to the nose of a "surge buggy" shuttle car. We now envision the bidirectional auger system as including such a specially outfitted shuttle car.
- The 1/8-scale auger drive train model has been completed and test run with a variety of materials, including crushed and graded volcanic rock, pea gravel, coal, and dried beans. The dried beans feed from the bin best and may also best represent the lay of the coal, due to their low density. The scale conveyor appears adequate to carry the coal away under all circumstances. It appears that, by adding a sideboard approximately 1 foot high at the forward end of the auger trough, the auger may be sumped continuously into the coal face without the previously expected stopping and reverse sumping. If the same is found to be true on the full-size machine, it will save 15 to 20 seconds on the hole-to-hole cycle and mean a theoretical 10 to 15 extra tons of coal production per shift.
- Personnel from Moog visited ESD with their radio-control unit. We discussed the interface requirements between their unit and our electrical system. There seem to be no major problems.
- One wheel unit has been completed, and a test procedure is being developed. Only the spindle unit will be tested, due to the long lead time of the wheel/tire units.
- Several major long-lead-time items have been ordered, and several others (including the 150-hp electric motor) are in preparation.
- The main frame/conveyor is approximately 30-percent designed. Some structural fabrication should begin in late June or early July.
- Associated Mine Management, Inc., maintains a strong interest in the bidirectional auger for the Shannopin Mine. CF&I Steel Company, the Allen Mine, was visited to observe its new underground auger just purchased from Fairchild, Inc. They are not interested in pursuing any new auger projects, at least until their present machine is evaluated.

- We have tentatively scheduled a project review meeting at ESD for DOE personnel during the last week of June.

ACCOMPLISHMENTS DURING JUNE 1979

- On June 21, we received a call from a representative of the MSHA Technical Support office in Pittsburgh. They had reviewed our roof support system and general operator's area for using radio remote control on the auger miner and could find nothing which would preclude its use out-of-hand. This review does not constitute an approval, however, as the MSHA District Manager could still object to the machine's being used in a given mining plan (in this respect, the auger is no different from any other underground equipment). For this reason, it was suggested that FMC send a representative to meet with a representative of the MSHA Technical Support office and a representative from District 2 (Pennsylvania). We agreed to attend such a meeting in the latter half of July.
- On June 8, we applied to MSHA for an investigation of the intrinsically-safe circuits to be used on the bidirectional auger. We were advised that the lead time between receipt of an intrinsic safety investigation request and the start of the investigation is currently running 9 months. From our prior experience, the actual investigations take from 4 to 6 weeks, with the approval letter taking another 2 to 3 weeks. We can thus figure on an 11-month (minimum) leadtime for intrinsic safety approval.

Physical inspection for machine approval can be scheduled to be performed at FMC at the end of the assembly phase.

- The auger frame is essentially complete, except for the numerous mounting brackets, which will be added as the assembly continues.
- About 90 percent of the long lead items, including the 150-hp motor, have been ordered. About 30 percent (in dollars) of the total purchased parts have now been ordered. Certain small items such as environmentally-sealed electrical switches and military-type electrical connectors are proving to have annoyingly long lead times. As yet, no serious delays due to parts availability are predicted.
- We have no new leads on potential demonstration partners for the machine. Associated Mine Management is still a possibility (the Shannopin Mine). If necessary, we plan to contact and visit a number of mining companies. New artists' concept drawings and mine plan schemes are being prepared to show the attractiveness of secondary recovery by auger.
- Mr. Dick Farrar, the project TPO, visited ESD to attend a progress review of the project.

ACCOMPLISHMENTS DURING JULY 1979

- A member of the FMC project team traveled to Joy Manufacturing Company in Franklin, Pennsylvania, to obtain consulting and design assistance from Joy personnel in the design of the center-lying chain conveyor on the bidirectional auger.

We have decided to use Joy components wherever possible for two reasons: (a) It frees FMC of the detailed redesign of already existing components, and (b) Most mines stock Joy repair parts or have a quick source of supply in the event of breakdown. The design layouts were completed at Joy, and most of the Joy buy-outs have now been received.

- Virtually 100 percent of the long-lead items and approximately 60 percent (in dollars) of the total purchased parts have now been ordered. One major item (not considered long lead) which has yet to be ordered is the Moog radio control system. Their system proposal and quote are due to us in early August.
- One wheel unit spindle assembly of the auger chassis was sent to FMC's materials and testing laboratory in Santa Clara to be durability tested. A special fixture is now being designed and, when completed, the wheel unit will be subjected to a simulated 6 months of mine duty. Assuming that no structural failures occur, the wheel unit will be torn down at the end of the test and the component parts checked for wear. Four additional wheel units with design changes, if warranted, will then be fabricated.
- A representative of United Coal Company was again contacted regarding the company's interest in demonstrating the auger. They have at least one property where the auger could be beneficial, but their seam height is only 60 inches, necessitating a drastic reduction of the auger diameter to physically fit in their entries. We agreed to continue to communicate with United, but see little possibility of a demonstration match-up.
- Associated Mine Management, Inc., continues to be positive about demonstrating the auger in the Shannopin Mine if their plans to acquire the mine are consummated. They do not presently have a reliable schedule of when that acquisition may actually occur.
- A representative of MSHA in Arlington who had participated in an earlier design review at ESD was contacted and given an update of our current design status and rationale. There appears to be no conflict between our concept of the machine and its operation and MSHA's concept of what is acceptably safe and in compliance with the law.

ACCOMPLISHMENTS DURING AUGUST 1979

- The center-lying conveyor structure is now about 80-percent complete. All buy-out components from Joy Manufacturing Company have been received. The conveyor drive has been designed. The longest lead-time items remaining to complete the conveyor assembly are two splined shafts being made by the Fairfield Company which will not be ready until December.
- Work on the frame and suspension of the machine was very slow during this period, due to the combination of a heavy influx of work into the shop and the temporary reduction of shop manpower due to vacations. We have been promised extra manpower for the months of September and October.
- The one-wheel unit which is to be durability tested is mounted on the test stand, but no test has begun, due to the late delivery of several hydraulic and electric components.
- A cursory survey has been taken which shows that about half of the major machine components ordered so far have been received late or are still back ordered. We are analyzing this trend to see if and where interference with shop work will occur and what impact it may have on the program schedule. We are also attempting (with some success) to expedite late suppliers.
- American Mine Management, Inc., which is attempting to acquire the Shannopin Mine from J & L Steel, is supposed to reach a milestone in negotiations during the month of September. AMMI is still very interested in using the bidirectional auger to recover pillars in the Shannopin Mine.

ACCOMPLISHMENTS DURING SEPTEMBER 1979

- The drawing package for the center-lying conveyor is complete, and fabrication is approximately 90-percent complete. Final assembly and test running cannot take place until certain purchased parts arrive in December.
- Work on the main frame and major subassemblies is progressing satisfactorily with a full shop crew.
- The two auger troughs were completed and stress-relieved. They will now be sandblasted and painted, and the assembly of the drive units can begin.
- Many purchased items are still behind in delivery, although we are successfully expediting a great many of them.

Louis-Allis Company, which is supplying the 150-hp permissible electric motor, has experienced a seven-week strike at its plant, thus slipping delivery. Since it is now the major long-lead item, this delay may offset the project schedule.

- We are in the process of assessing the relative merits of the Moog radio control system versus our original umbilical control system. Moog cannot supply the control station exactly to our specifications without a lengthy and expensive development effort. Also, their back-up umbilical cord has not yet been approved for use underground in the face area. It now appears that some of the original advantages of the radio system are not available in the present technology. A decision on controls will be made in the next reporting period after consultation with MSHA.
- MSHA was recontacted regarding the positioning of the operator and the shuttle car during drilling. We expect that MSHA will agree with our proposal for remote control, or will propose a viable alternative.
- Consol's Ireland Mine, where the previous unidirectional auger was tested, was contacted to determine their possible interest in demonstrating the bidirectional machine. Those at the mine actively involved with the last machine were encouraging, but the decision must be handled at a higher management level. A letter is in preparation.
- There is no change in the status of American Mine Management, Inc., and its acquisition of the Shannopin Mine.

ACCOMPLISHMENTS DURING OCTOBER 1979

- The two auger troughs have been chemically cleaned and painted, and some assembly work on the drive units has been done.
- We have decided not to pursue the Moog radio control unit on the auger at this time. Having Moog design a control set to our specifications is not within the present schedule and funding constraints of the program. FMC's redoing the existing Moog handset (for a National Mine Service continuous miner) would result in a less-than-totally-acceptable package.

We have mocked up a handset for the umbilical controller which appears functionally adequate.

- Several major machine components are still behind in their delivery, and our attempts to expedite them have met with only limited success. A long strike at Sperry/Vickers has just been settled, but has seriously delayed the delivery of the sump drive motors.
- All electrical schematic drawings, both power and control, have been completed and are ready for review by MSHA. Our request for investigation on the intrinsically-safe portion of the system was submitted on June 8, 1979 and, as expected, we completed our drawings before MSHA was ready to review them. For reference, we were advised by MSHA to allow 9 months from the time of submission to the time of beginning the investigation. This remains one of the pacing items in the project.
- The first fabricated wheel unit for the auger successfully completed 10,000 test cycles on October 31. The test included lock-to-lock cycling at normal load and 1.3 times normal load with 2g shock loads applied every 100 cycles, the equivalent of 6 months of actual underground service. There were no structural failures. The unit will now be disassembled to determine the wear on the moving parts.

Fabrication of the four-wheel units, which had been held up pending the testing results, will now begin.

ACCOMPLISHMENTS DURING NOVEMBER 1979

- The wheel unit, which had undergone 10,000 test cycles (the equivalent of 6 months of continuous usage), was torn down and inspected for signs of wear. No significant wear was observed, except for one area of the lower kingpin which had come loose during the test and worked about half way out. Even the wear on this part was not so great that it needed replacement. Tab washers will be added on the kingpin retaining bolts on future assemblies to prevent the kingpins from working loose. The wheel unit was reassembled and tested for an additional 5,000 cycles at a load of 15,000 pounds, or approximately 1-1/2 times the normal static loading. There were no structural failures or undue wear.
- The conveyor was completed and test run using an auxiliary hydraulic power source. Some minor corrections in the shroud surrounding the drive unit were necessary to prevent jamming. Sound level tests were made (at the operator's station) which ran 108-1/2 dB, a scale, slow response. We intend to run the conveyor intermittently for 2 to 3 hours to allow the sprockets and chains to wear in, at which time we will recheck the noise level. We are also investigating various methods of noise abatement, although the conveyor will run more quietly when it is loaded with coal.
- Late delivery of components by several of our suppliers continues to be a problem, necessitating the substitution or delay of work to effectively utilize the available components and labor. The Louis-Allis motor delivery slippage continues to be a major pacing item, as are the York hydraulic cylinders. Neither company has been able to meet its originally quoted delivery date, and both have slipped their schedules several times.
- We have been informed unofficially that the workload at MSHA has caused longer lead times for intrinsic safety investigations than we were advised of in June 1979, at the time of our application for investigation. We had been expecting the investigation to begin in March 1980, but it may actually take until June 1980. It is unknown whether we may somehow be allowed to operate the machine underground in advance of the investigation.
- The auger cutterheads are under construction at W & S Welding in Neal, West Virginia and are scheduled to be completed in February 1980.
- We have been unable to make telephone contact with United Coal Resources regarding its possible acquisition of the Shannopin Mine. We believe that this indicates that the acquisition attempt was unsuccessful and that the Shannopin Mine is no longer a very likely demonstration site.

ACCOMPLISHMENTS DURING DECEMBER 1979

- The conveyor was test run continuously for approximately 2 hours at rated speed. Noise level was measured at approximately 110 dBA. We have jury-rigged two noise reduction features which, it appears, will lower the noise level to about 103 dB, and we are investigating other techniques which should, in the aggregate, bring the noise level to 100 dB or less.
- A visit was made to W & S Welding in Neal, West Virginia, to discuss the general construction of the auger cutterheads. The cutterheads will be completed on schedule, in early February.
- We visited the Ireland Mine to observe the old test panels left from FMC's prior auger experiment. There has been essentially no degradation of the panels, leading us to believe that no degradation should be expected with the new machine making shorter, blind holes. The superintendent at the Ireland Mine said that he would recommend to his management that they demonstrate the bidirectional auger if they begin retreat mining in a time frame compatible with our needs. They are presently mining only in support of their longwall.
- We have been invited to make a presentation on the bidirectional auger to CF&I Steel Company in Pueblo, Colorado. Its Allen Mine is a desirable test site, and we will visit the mine in mid-January.
- There has been some limited success in expediting component suppliers, and some late hydraulic components have been received. At the present time, late deliveries are not expected to have a serious effect on the manufacturing schedule.
- A visit was made to MSHA, Technical Support Group, in Bruceton, Pennsylvania, to discuss the latest general arrangement of the auger and the operator's remote control stations. We have basic agreement from MSHA that what we have proposed is safe and will be approved.

ACCOMPLISHMENTS DURING JANUARY 1980

- We visited CF&I Steel Company in Pueblo, Colorado, where a presentation was made to its Manager of Mines. They are quite interested in secondary recovery by auger and currently own an underground auger built by Applied Mining Equipment and Services Company of Huntington, West Virginia, which they have not yet put into service. CF&I was interested in the mobility and productivity advantages of the FMC bidirectional auger, and we were invited to visit its Allen Mine in Trinidad, Colorado, about 110 miles from Pueblo.

Accompanied by the Mine Superintendent and General Superintendent, we made an inspection tour of the mine to typical areas which they would like to auger. Our general conclusion is that the Allen Mine is very well run, practices good housekeeping, and has generally good roof and bottom conditions. In a great number of areas, however, roof support is supplied not by roof bolts, but by steel cross beams supported by wooden posts at the ribs. These cross beams are interconnected by heavy wooden timbers parallel to the entry. The net result is reduced entry height, which in numerous areas is too low for the bidirectional auger (with 28-inch diameter cutterheads) to tram beneath. In addition, to auger these areas would require a complicated procedure of removing and replacing the wooden posts in localized areas along the ribs. The net result would be production/productivity greatly diminished from the machines' projected capability.

The Allen Mine is now determining just what bolted entries of adequate roof height exist in the mine. If there are enough pillars/entries to support a 6-month demonstration, we believe that the Allen Mine represents a viable test site.

Discussions with CF&I/Allen Mine personnel are continuing.

- Sound-deadening vinyl material supplied by the EAR Company is now being applied to the upper and lower pans of the auger's conveyor. An applications engineer from EAR, after reviewing the machine, predicted a sound reduction of about 6 dBA. Application of the material will increase the weight of the machine by about 1,200 pounds.
- Fabrication of all major weldments comprising the machine has been completed. The last items to be finished were the hydraulic reservoir, the drive gimbals, and the steering yokes and spindles. The major fabrication work remaining consists of the hydraulic plumbing, electrical wiring, fire suppression system installation, and miscellaneous brackets and mounts. We anticipate that some system testing can begin in mid-March.

ACCOMPLISHMENTS DURING FEBRUARY 1980

- A visit was made to Consolidation Coal Company headquarters in Pittsburgh. We made a presentation on the bidirectional auger to Mr. Bill Poundstone, Executive Vice President. Mr. Poundstone expressed a great deal of interest in the machine and requested additional information with which he would have his industrial engineering staff compute the auger's theoretical production. This information is being gathered, and new cycle time charts and mine plan drawings are being prepared.
- Application of EAR vinyl damping material was completed. The conveyor has not been test run to check sound level. When the machine's own motor/pump is connected, the conveyor will be checked.
- The machine is now in the final stages of assembly. About 80 percent of the bolt-on subassemblies have been completed. The bulk of the remaining work is hydraulic plumbing and electrical wiring.
- MSHA has not yet responded to our request for electrical (intrinsically safe) investigation, which was projected for March. Any delay on MSHA's part could have a detrimental effect on the program schedule. Several members of MSHA are scheduled to visit ESD in mid-March to discuss problems and new procedures for obtaining machine approvals in a timely manner.

ACCOMPLISHMENTS DURING MARCH 1980

- Machine Fabrication

The assembly and installation of mechanical and electrical components are virtually complete, including brackets and holders typically left until the end. Although the main components of the hydraulic system have been mounted on the machine, the plumbing itself is only about 85-percent complete. This task is taking longer than anticipated, largely because the stock of local vendors who handle fittings and hose ends is inadequate to meet our demands. All of the necessary parts have been ordered and will most certainly arrive while the machine is being displayed at the coal show.

- Surface Testing

The auger is scheduled to undergo thorough testing in the shop, once it returns from Chicago, and the plumbing completed. Several systems have, however, been briefly checked for function during the construction process. The auger sump and conveyor systems have been powered by a hydraulic flow bench and have performed at the desired rates without deleterious effect. The proportional control on the remote control box which governs auger rotational speed was electrically tested to determine the resolution capability. The characteristic was deemed to be inadequate and will be corrected to provide the operator with a more linear response from that control.

- Coal Show

The machine was cleaned and prepared for display at the American Mining Congress Coal Equipment Show to be held in Chicago, Illinois, on May 5-8, 1980. Due to the incomplete hydraulic plumbing, the machine will be displayed statically.

- MSHA Approvals

Although MSHA has yet to act on our request for an intrinsic safety investigation, they inform us that they anticipate a start date of some time in May. Several members of MSHA visited FMC to discuss problems associated with obtaining approvals in general, but we were informed that no new procedures have been implemented to hasten the process.

A package is being prepared for submittal to gain an electric machine approval, of which the previous request will become a part. We hope to have the machine physically inspected for that purpose by MSHA officials in late May or early June.

- Contract Modification

A proposal has been prepared to redirect efforts toward the single chassis, short hole auger version, and away from the originally proposed concept. The proposal also includes activities and costs associated with the coal show.

ACCOMPLISHMENTS DURING APRIL 1980

- American Mining Congress Coal Show

The bidirectional auger was prepared for shipment during the early portion of the month and departed for Chicago by truck on April 15. Although the machine arrived in Chicago on the 21st, it was not off-loaded and moved into McCormick Place until the 28th. The equipment survived the journey without reported damage, and representatives from FMC who happened to be on site conducting independent business stated that the auger is in excellent condition for the display.

- Demonstration Preparation

During the machine's absence from FMC, activity has been directed to the formulation of support materials for the underground demonstration. Included in this effort are operation and maintenance manuals, a copy of the complete drawing package, and an inventory of all spare parts to be provided as support for the demonstration. The weeks that the machine is away from FMC facilities provide an opportunity to concentrate on these required tasks.

- MSHA Approvals

The application for electrical machine approval has been prepared and will be sent to the Technical Projects Officer for submittal to MSHA. MSHA regulations state that the application must be submitted by the TPO for all government-funded projects. Due to our recent experiences with other government projects, we will closely monitor the progress of the application.

- Contract Modification

The proposal to redirect efforts toward the single-chassis, short-hole version of the auger and away from the concept originally proposed was submitted to DOE early this month for approval.

ACCOMPLISHMENTS DURING MAY 1980

- American Mining Congress International Coal Show

Our participation in the coal show (May 5-8) was very interesting and educational, but its value in attracting prospective demonstration partners remains to be seen. The bidirectional auger did represent one of the more popular displays in the show, mainly because of its unique concept and intriguing configuration, which aroused more general curiosity than bonafide interest. As a result of the show, we have compiled a list of 12 possible demonstration mines, but many factors must be considered before any of them become viable candidates, i.e., seam height, mine plan, enthusiasm of management, type of roof support, current state of mine development, etc. Of course, mine owners/operators are preoccupied with the currently depressed market and are thus less approachable. Letters thoroughly explaining the status of the project and the terms of the likely demonstration agreement have been sent to each of the 12 mines, but no responses have been received. Briefer, less revealing letters have been sent in response to 12 other inquiries from parties unlikely to aid in the search for a cooperating mine, i.e., foreign mines, professors, and vendors.

- MSHA Approvals

The application for electric machine approval has been sent to the Technical Projects Officer for submittal to MSHA. MSHA regulations state that the application must be submitted by the TPO for all government-funded projects.

MSHA had informed us that it planned to begin the intrinsic safety investigation sometime in May. No contact was made with us during the month regarding the application that was submitted exactly one year ago. Further delay on MSHA's part could delay the electric machine approval and, ultimately, the entire program schedule.

- Underground Demonstration

Consolidation Coal Company was sufficiently interested in the bidirectional auger last February to request more information so that the industrial engineering staff could analyze the production potential of the machine. Although we have not been able to contact the Executive Vice President himself, we have been able to talk with the industrial engineer who headed the study. He informed us that his investigation was based on time data from their McElroy Mine and resulted in a projected production rate of 265 tons per shift. Much of the data he used is proprietary to Consol, making him reluctant to divulge all of the details. Based on our experience in the Ireland Mine, we had projected a production rate of 294 tons per shift. We are anxious to speak with the Executive Vice President to see if he feels that the productivity of the machine is adequate for their operation and if he is now willing to provide a demonstration site.

ACCOMPLISHMENTS DURING JUNE 1980

- Machine Fabrication and Functional Testing

Fabrication of the machine has been completed. The auger is capable of accepting electrical power via the trailing cable and directing the various subsystems to perform tasks dictated by the remote control box. Functional testing was then begun to insure proper operation of each subsystem individually and collectively. The testing operation is nearly complete and, although several oversights were discovered in the design or assembly of the system, all were quickly isolated and resolved either hydraulically or electrically.

- The smooth and rapid pace of the debugging phase has been overshadowed by the premature failure of the variable displacement hydraulic pump used to rotate the cutterheads. Internal leakage within the housing was diagnosed after just a few hours of operation as the failure steadily grew worse. The manufacturer of the pump will prepare a failure analysis and repair the unit, all of which is expected to be covered by its warranty policy. The local distributor has been advised of the situation and will attempt to expedite the rebuild effort so that the pump may be returned within possibly two weeks. In the meantime, functional testing will continue on subsystems not dependent on that component.

- MSHA Approvals

No action has been taken on either the intrinsic safety investigation or the electric machine approval since their submission to MSHA. These approvals are mandatory before the machine goes underground, to avoid serious repercussions. Further delay by MSHA may deleteriously affect the program schedule.

- Underground Demonstration

Contact has been made with the Crescent Hills Coal Company of Smithdale, Pennsylvania, regarding a demonstration mine. This company has provided an underground test site for at least one other government-funded project which was evidently a mutually fruitful experience. Their interest in general is high, but interest in the bidirectional auger in particular can be described as mild.

ACCOMPLISHMENTS DURING JULY 1980

● Functional Testing

The variable displacement hydraulic pump, which failed shortly after initial startup of the machine, has been repaired and reinstalled on the auger. Since the pump had experienced severe internal damage, oil samples from the auger hydraulic system were examined and found to contain metal particles and other contaminants as a result of the failure. A large-flow, 3-micron filter was purchased and temporarily placed in that circuit to cleanse the oil before the rebuilt pump was exposed to potentially harmful foreign chips.

This same hydraulic circuit was observed to have another serious fault, independent of the variable displacement pump. Pilot-operated check valves designed to isolate one torque motor from high pressures while the other carriage is being driven do not remain open when the circuit pressure rises higher than pilot pressure. As the cutterhead rotation meets resistance, the induced pressure rises to 2,500 psi, overriding the 300-psi pilot pressure, the open P.O. checks slam shut, and rotation stops. An obvious solution to the problem was to increase the pilot pressure to 2,500 psi, but this method was not chosen for two reasons. First, the pilot line is common to several other functions, including rotary actuators incapable of surviving pressures greater than about 400 psi. Second, the horsepower loss would increase more than 8-fold, possibly increasing oil temperature beyond the cooling capability of the reservoir heat exchanger.

The corrective action ultimately chosen was to purchase high-flow P.O. check valves capable of controlling a 2,500-psi system with a 300-psi pilot. Those components have been ordered and are expected to arrive for installation by mid-August.

Additional subsystems, including the roof and floor jacks, have been modified to satisfy functional requirements. Minor changes are required in the blower circuit (used for in-hole ventilation), but the remaining subsystems listed below now operate properly:

- Tram
- Steer
- Stab jacks
- Roof/floor jacks
- Sump
- Conveyor
- Water spray

The dual-channel methane monitor, a purchased subsystem, failed to maintain a constant zero reading in a methane-free atmosphere. The malfunction was due to thermal breakdown of an IC in the display unit. That portion of the subsystem has been returned to the manufacturer for warranty repair.

- Performance Testing

The design of the roof and floor jacks incorporates a unique mechanical captive mechanism to maintain support, rather than the more common method of hydraulically locking the cylinder. A fixed sleeve around the cylinder rod is incorporated as an interference fit. This clamping force supports the load, which can only be released when hydraulic pressure (3,000 psi) is applied between the sleeve and rod, causing the sleeve to expand. Spare units, available for support during the demonstration, were tested in the laboratory to verify the rated load holding ability of the jacks. In both cases, the jacks withstood loads greater than their rated capacity before initial breakaway of the sleeve was realized. This test report may be of value in the future, should MSHA decide to challenge the use of these jacks for application on the auger.

- MSHA Approvals

The intrinsic safety investigation has begun, and after reviewing the auger electrical drawings, MSHA has informed us of their preliminary findings. Several sample components will be sent to them for testing as requested, as well as supporting documentation and updated electrical schematics. At this point, no serious shortcomings have been detected which would result in further delay or difficulty in meeting MSHA requirements.

ACCOMPLISHMENTS DURING AUGUST 1980

- Functional Testing

All machine functions have been tested and now operate properly, except for the pilot-operated check valves in the cutterhead torque circuit and the magnetic pause switch in the sump circuit. The P.O. check valves cannot be successfully utilized in the present design, and replacement valves have been ordered and are overdue from the vendor. Upon receipt, the valves will be installed and tested. The magnetic switch used to temporarily delay the cutterhead sump midway through its stroke cannot function, due to its proximity to massive steel parts. An attempt is being made to isolate the switch from materials which destroy the magnetic field.

The methane-detector readout unit which was received from the factory with a defective component has been replaced in its entirety under the warranty guarantee and has been reinstalled on the auger and calibrated.

- Performance Testing

Under its own power and control, the auger has been trammed outside the shop building to a rough, near level soil area simulating what might be expected underground. While the machine was negotiating this terrain, three tram/steer characteristics deserving of additional attention became evident.

The power provided to the steer cylinders is insufficient, unless the machine is simultaneously tramping. The spring applied, fail-safe wheel brakes prevent wheel rotation when not tramping and cause the tires to scrub when a stationary steer is attempted. The hydraulic pressure available is insufficient to overcome this scrubbing force, thereby causing the steering function to stall. When the brakes were locked in the released position via the manual override, however, the steer function operated satisfactorily. To remedy this shortcoming, the brake release circuit will be hydraulically plumbed to the steer control as well as the tram, thereby allowing free tire rotation during steer operations.

- On several occasions, while maneuvering in the field, the auger became "high-centered," causing one or more wheels to leave the ground and reduce the flow and pressure available to the remaining wheels which remained tractive. Although this situation is not anticipated to occur frequently in the mine, a slight modification to the machine was deemed necessary to maintain adequate mobility characteristics. Ball valves will be installed at each wheel which, when closed, will prevent brake pressurization and act as a brake release inhibitor. The machine operator then has the ability to manually lock any or all wheels and maintain full tractive effort on the others.

The bidirectional auger control box allows the operator to automatically choose either four-wheel or crab steer for maneuvering from rib to rib. It was felt that during long continuous trams down the entry or from one section to another, the ability to convert to two-wheel steer would be advantageous. For this reason, ball valves will be installed at each steer cylinder to allow manual conversion to this mode when desired.

- MSHA Approvals

The intrinsic safety investigation is near completion, as all questionable components have been sent to MSHA for testing as requested. Several electrical components or settings have been changed as a result of the investigation, but none has been physically significant.

To more quickly and easily gain certification from MSHA, the electric machine approval application has been changed to reflect its being for one machine on an experimental basis only.

ACCOMPLISHMENTS DURING SEPTEMBER 1980

● Surface Testing

The bidirectional auger has been assembled to its final configuration and tested in an outside area adjacent to the shop facilities, affording a valuable opportunity to characterize and debug the system in a convenient environment before going underground for the demonstration. Six operational shortcomings have been discovered during the surface testing phase; a description and status of each problem is listed below.

1. The pilot-operated check valves in the cutterhead rotation circuit were incapable of controlling a 2,250-psi circuit with only a 300-psi pilot pressure. Replacement valves of a different internal design were purchased and installed to rectify the condition. Initial testing has indicated satisfactory operation, although performance at stall pressures has yet to be verified.
2. The magnetic proximity switches in the sump circuit would not function, due to nearby steel components. One switch mechanism has been redesigned to obtain magnetic isolation, but its function has not been tested.
3. A plumbing modification to allow the fail-safe wheel brakes to release during all steering operations is partially complete. The necessary hydraulic lines have been installed, but the shuttle valves have not been received from the vendor.
4. The wheel brake release inhibitors (ball valves) have been installed and perform satisfactorily. The operator now has the capability to manually lockout any or all wheels, should the machine become high centered.
5. Two other ball valves have been installed and tested which permit manual conversion to two-wheel steer for long, continuous trams.
6. The pilot-operated check valves required to maintain activation pressure on the stabilization jacks have failed. An effort was made to redesign the valve cartridge by machining a deeper groove to accept a larger retaining ring. One of the two modified valves failed again, so both valves were removed from the machine. Contact with the vendor will determine the required remedial action.

● MSHA Approvals

The control circuitry has been assigned an intrinsic investigation (approval) number by MSHA, and the machine permit is expected to be granted shortly after the auger is physically inspected. The MSHA inspection has been tentatively scheduled for the last week in October.

- Underground Demonstration

Three representatives from the Indiana district of Peabody Coal Company visited FMC to observe the auger in operation and discuss possible demonstration arrangements. They displayed a genuine interest in the machine and felt that it would fit in well with their current mining practices. Unfortunately, they need a smaller machine, possibly a 36-inch cutterhead, able to function in a 48-inch seam. They did, however, offer to promote the bidirectional auger with their Illinois operations personnel who have a similar need but in higher coal (6 feet). Further communication with Peabody Coal Company is not expected for 3 or 4 weeks.

ACCOMPLISHMENTS DURING OCTOBER 1980

● Surface Testing

Five problem areas were corrected in the closing stages of the surface testing phase of the program, as summarized below:

- A plumbing modification was completed to allow the fail-safe wheel brakes to release during all steering operations.
- The failed pilot-operated check valves required to maintain activation pressure on the stabilization jacks have been replaced by components with a different internal design. Satisfactory operation has been restored, and no further problems are anticipated.
- The 100-gpm variable displacement hydraulic pump that experienced serious internal damage in July failed a shaft seal this month. During the installation of a replacement seal, a broken piece from the seal retainer was found in the case and was responsible for the failed seal. The existing seal retainer had not failed, indicating that the metal piece (about the size of a dime) was not removed when the unit was rebuilt by the manufacturer in July. Both the distributor and manufacturer met at FMC and dismantled the pump to insure that additional metal pieces were not present. The pump was subsequently rebuilt with a vendor-supplied seal kit, resulting in satisfactory operation.
- Two of the three fluorescent lights failed to function, because incorrect ballasts and power control modules (integral fixture components) were supplied by the vendor. Those items, designed for 300 VDC, have been returned to the manufacturer in favor of 120-VAC versions which had been originally ordered.
- The remote-control umbilical cable failed when it inadvertently became tangled in the wheel during trammig operations. Although the connector was easily repaired, the incident exemplifies why radio remote control is becoming more popular in the mining industry.

● MSHA Approval

On October 21, an MSHA investigator visited FMC and physically inspected the auger to determine compliance with MSHA regulations. A significant documentation effort was required to fully describe components and specifications in the drawing package, but none of the electrical hardware required change or modification. MSHA did request that guards be emplaced around the sump drive shafts to avoid personnel injury; that safety feature has been incorporated, and photographs depicting the shaft guards have been sent to MSHA.

Underground Demonstration

The visit last month by Peabody Coal Company to observe the bidirectional auger has sparked hope that a demonstration partner may soon be found. In conversations with Peabody late in October, we were informed that they are considering their newest property, the Marissa Mine in Southern Illinois, as a potential site. The Operations Manager of that district and the Mine Superintendent are currently reviewing the prospect of demonstrating the machine. We expect to hear from them early in November.

The rolling resistance of the machine was measured at 2,300 pounds. Approximately 1/3 of the currently available tractive effort is thus required to initiate motion on loose, level soil.

- Underground Demonstration

The Executive Vice President of Consolidation Coal Company has informed us that, after dispersing information regarding the bidirectional auger throughout the Company, no positive responses were received. It was suggested that we concentrate our solicitation efforts in the Ohio Valley, where the seams and mine plans are more conducive to the auger's requirements. This area served as a demonstration site for the previous unidirectional auger program and has already been thoroughly canvassed for a demonstration site for this project.

Peabody Coal Company has not yet decided whether or not to demonstrate the machine. Interest in the machine remains firm and represents the lone viable candidate for a demonstration partner.

ACCOMPLISHMENTS DURING NOVEMBER 1980

Surface testing of the bidirectional auger has now been completed, as major system performance characteristics have been measured directly. The table below shows the results of those tests, each of which is then briefly discussed.

<u>Performance Characteristic</u>	<u>Value</u>		<u>Theoretical Maximum</u>
	<u>Measured</u>	<u>Expected</u>	
Cutterhead Torque	8,400 lb-ft at stall	8,750 lb-ft	8,750 lb-ft at 53 rpm
Cutterhead Sump	6,800 lb at stall	10,000 lb	10,000 lb at 10 fpm
Tram Speed	89 fpm	88 fpm	88 fpm
Tractive Effort	6,350 lb at stall	6,700 lb	9,600 lb at 88 fpm
Rolling Resistance	2,300 lb	2,000 lb	

Cutterhead torque is provided by a low-speed, high-torque hydraulic vane motor which exhibits near-rated torque regardless of speed, even at stall. The measured value was obtained by wrapping two cables around the circumference of the cutterhead and attaching the ends to deadmen, 180-degrees apart. Tension on one cable was monitored and simply doubled to calculate the induced torque. The second cable was necessary to form a pure couple, thereby balancing the force vector of the first cable. The measured torque of 8,400 lb-ft is 96 percent of the design target.

Sump force of the cutterhead drive was significantly less than expected, but is nevertheless felt to be satisfactory. The measurement was taken without the cutterhead attached so that static friction between the flight and trough did not dilute the available force. The weight of the gimbal-mounted drive unit on the supporting slides in the trough did, however, result in undesirable friction which contributed to the discrepant (low) measurement.

Tram speed of the machine was measured on a slight incline, so an average was taken of an equal number of trials in each direction.

The relatively low tractive effort displayed is due in large part to the typical behavior of hydraulic gear motors. Torque ratings of gear motors are only valid at nonzero speeds as torque capacities at stall are generally 30 percent less. It is felt that mobility characteristics of the machine may in fact represent a serious shortcoming during the demonstration, but that, of course, is heavily dependent on the conditions of the mine floor. Although the hydraulic system pressure is currently set at maximum (per component manufacturers literature), the specific application may permit a pressure increase (and accordingly torque increase) of about 20 percent after consulting with the manufacturers.

ACCOMPLISHMENTS DURING DECEMBER 1980

- The bidirectional auger has been fabricated and tested within the shop facilities of FMC. Additionally, extensive performance testing has been conducted on natural soil terrain adjacent to the shop building. As a result of testing, several shortcomings were noted and corrected, and components failing in an infant mortality mode were experienced and replaced.
- The machine has been debugged and is now ready for demonstration in a cooperating underground coal mine.
- The contract for the auger program expired at the end of December 1980, thereby ceasing project activities. A proposal to extend the schedule has been submitted, and we have been unofficially informed that the request will be granted. Until confirmed authorization to proceed is received, however, no further costs will be incurred.
- The bidirectional auger was displayed at the International Coal Show in Chicago in May for the expressed purpose of securing a cooperating underground coal mine willing to demonstrate the machine once fabrication and surface testing was completed. Due in large part to the generally depressed coal market at that time, serious interest was not immediately evident. The condition of the industry remains poor, and recent communications with mine owners/operators met at the show produced no positive results. In October, however, representatives from Peabody Coal Company asked if they could visit FMC to review the machine which was introduced to them at the Chicago show. During their visit, they seemed to be impressed with the operational characteristics of the auger and, though more interested in a smaller version for low coal, promised to discuss the proposed demonstration with the appropriate Peabody operations group. The three people from Peabody who visited (entirely at their own expense) included the Vice President of Operation Service, the Chief Project Engineer, and the Chief Electrical Engineer.
- This month, Peabody has asked to again review the auger at FMC for possible placement in their Marissa Mine in Southern Illinois. Three or four representatives are expected on January 28, including the Director of Underground Operations (Illinois) and the Marissa Mine Superintendent. The Government Technical Representative has also been invited to attend this meeting and surface demonstration.

The interest shown by Peabody has been very strong and presently represents the only viable candidate for a cooperative agreement.

ACCOMPLISHMENTS DURING JANUARY 1981

The program contract, having expired on December 31, 1980, was modified on January 26, 1981, to include a schedule extension through February 1982. During the first three weeks of this reporting period (to the 26th), there were no project activities, as the contract extension was neither continuous nor retroactive.

On January 28, 1981, a meeting was held at FMC with representatives of Peabody Coal Company to discuss possible underground demonstration arrangements for the bidirectional auger. A physical inspection of the machine, as well as a functional demonstration, were provided during the visit. Personnel in attendance from Peabody Coal Company included the Vice President of Operation Service, the Director of Underground Operations, and the Mine Superintendent and Chief Electrician of the Marissa Mine in Southern Illinois. The technical project officer from the DOE was also present, as well as appropriate FMC personnel.

The decision reached during the presentation and discussion was that Peabody Coal Company would participate in the demonstration phase of the project. They plan to place the machine in their Marissa Mine in Southern Illinois, which they feel represents the most advantageous site within the Company. Peabody will immediately begin drafting a formal agreement with FMC to delineate liability responsibilities and other legal requirements.

Additionally, they will begin coordination with the local MSHA office regarding implementation of the auger into their current mine plans, including ventilation, rock dusting, haulage, posting, and other site-specific considerations.

In the meantime, FMC will address three tasks required to place the machine underground. Since the experimental machine permit recently issued for the auger by MSHA is based on a 4/0 trailing cable, an application for a snap approval will be submitted to change to a 2/0 cable. The Marissa Mine will supply the trailing cable, and the smaller size is preferred by the mine.

Two machine characteristics were thought to be potentially troublesome and in need of upgrading. The tram power may be insufficient in certain situations, and the machine - rib interface may permit unwanted spillage of coal on the mine floor. Both items will be rectified in the shop facilities of FMC prior to shipment to the mine.

It is anticipated that the bidirectional auger will be shipped to the Marissa Mine in the latter part of March for demonstration commencement in April.

In the interim, FMC will communicate regularly with the Marissa Mine to assure that our activities are coordinated.

ACCOMPLISHMENTS DURING FEBRUARY 1981

All project activities during the month focused on preparation for the underground demonstration at Peabody Coal Company's Marissa Mine.

- Improved Tram Characteristics

Larger gear motors have been installed at each wheel and the hydraulic system pressure increased in an effort to increase available wheel torque, particularly at stall. These changes require a proportionately larger oil flow to maintain maximum tram speed. Additional modifications to the hydraulic circuitry will increase flow to the wheels, but maximum tram speed will still be slightly slower. All required design changes have been delineated and all components ordered. The net result of the effort will increase torque at each wheel by 120 percent but decrease maximum tram speed by 25 percent.

Another aspect of the tram system which concerned Peabody Coal Company was the inability to maintain power to three of the wheels when one loses traction and spins freely. Restrictors have been ordered which, when installed, will prevent any given wheel from accepting more than 30 percent of the total available flow. If the machine becomes high-centered and one or two wheels begin to spin, full design torque is thus maintained at the other two-wheel units, although at a slightly reduced flow.

- Coal Spillage at the Rib-Machine Interface

Activity during the month has also been directed at developing viable concepts to prevent spillage of coal at the rib while augering. If the machine is not properly positioned against the rib before a hole is begun, any gap between the end of the auger trough and coal face will allow a pile to form on the floor which is unacceptable to Peabody Coal. Several concepts have been developed and illustrated, and each will be discussed with Peabody Coal to reach a mutually acceptable solution.

ACCOMPLISHMENTS DURING MARCH 1981

All project activities this month were directed toward incorporation of improvements prior to preparation for shipment to the underground demonstration site.

- Improved Tram Characteristics

Following the installation of larger gear motors at each wheel and increasing hydraulic system pressure, flow restrictors have been plumbed into each of the wheel motor ports. These restrictors prevent any given wheel from receiving more than 30 percent of the total available flow. In the event of machine high centering or loss of traction of one or even two wheels, full design torque is maintained at the other two-wheel units, although at slightly reduced flow.

All hydraulic circuitry modifications required to supply increased flow and pressure to the wheel motors were accomplished. This modification required the installation of a pilot-operated, pressure-reducing valve to protect the low-pressure pilot circuit when gear pump section flows were combined. Gages were installed at appropriate points prior to start-up and test. It was immediately noted that the new pressure-reducing valve was fluctuating and was deemed unreliable in its ability to protect downstream hydraulic components. Testing was discontinued, and a direct-acting, pressure-reducing valve was ordered. As of this date, the replacement valve has not been received.

- Tour of Proposed Demonstration Site (Peabody Marissa Mine)

An aboveground and underground tour of the Marissa Mine was made by FMC personnel and the DOE Technical Projects Officer. The Marissa Mine is located between St. Louis, Missouri, and Carbondale, Illinois. The operation was opened in 1979, and development is 40-foot by 40-foot pillars on 60-foot centers (20-foot entries). Seam height is 6 feet 6 inches to 7 feet, the bottom is dry fire clay, and the top is shale.

Mine conditions are exceptional; both the development itself and the surface facilities are clean, well maintained, and well managed. Mine management is enthusiastic about the auger and is confident of success. The underground demonstration is scheduled to commence in May, providing that the current UMW contract dispute is settled.

- Coal Spillage at the Rib-Machine Interface

Following the tour of the Marissa Mine, a meeting was held in the Mine Superintendent's office to discuss our proposed solutions to unwanted spillage of coal on the mine floor. All in attendance agreed that the device must be active, not passive, and either a sumping nose cone or a trough presump. It was decided, upon returning to FMC for additional in-house discussion, that the trough presump concept with a soft nose would be executed. The design was finalized and detailed, material purchased, and released to the shop.

- Mine Supplied Electrical Power Cable

We were informed that the Marissa Mine would supply electrical power to the machine with 2/0 four-conductor cable. The current MSHA machine approval was granted, specifying 4/0 three-conductor cable. This change will require the preparation of an appropriate Stamped Notification Acceptance Programs (SNAP) form. Contact was made with an MSHA electrical engineer for assistance in preparing the forms and necessary backup documentation for submittal to DOE.

- Remote Control Boxes

Two additional machine remote control boxes and electrical cables were assembled to accompany the auger as spares during the underground demonstration.

ACCOMPLISHMENTS DURING APRIL 1981

All project activities this month were concentrated on updating machine documentation and follow-up on purchased parts required to complete machine modifications prior to shipment to the underground demonstration site.

- IAM Strike

There was no shop activity this month, due to a strike by the IAM union local representing all FMC divisions in the Santa Clara valley.

This strike will cause completion of machine modifications and commencement of the underground demonstration at the Marissa Mine to slip by at least one month. The anticipated shipping date is now the first week in June, providing that the shop returns to work during the first week in May.

- Mine-Supplied Electrical Power Cable

The MSHA Stamped Notification Acceptance Program (SNAP) form, along with revised drawings and parts list adding an alternate 2/0 four-conductor power supply cable, was prepared and submitted to DOE for approval. This data package will in turn be submitted to MSHA for final review and approval.

- Safety Interlock Switch

A second MSHA SNAP package was prepared and submitted to DOE for approval. This change adds a switch to the auger rotational control to prevent machine start-up, unless the control is in the off position. The primary purpose of this switch is to protect personnel performing such tasks as cutterhead bit changeout. Second, the Sunstrand hydrostatic transmission which supplies power to the auger drive motor is protected from internal damage due to start up under load.

- DOE Review of Current Projects

Rick Markley, assistant to William Schmidt, Director of Coal Technology Branch DOE, visited FMC to attend a series of presentations reviewing the status of FMC's current underground coal mining projects. The projects are the flywheel-powered shuttle car, the hopper-feeder-bolter, and the bidirectional auger.

Mr. Markley is currently gathering information on six DOE projects for Mr. Schmidt's upcoming presentation to Congress, one of which will be the hopper-feeder-bolter. During an informal review of mining equipment under construction in our shop facility, Mr. Markley stated that "the bidirectional auger is the only DOE project that seems to have a finished product appearance and commercial market value."

- Coal Spillage at the Rib-Machine Interface

Some of the material required to accomplish the presumping of the auger trough modifications was received this month. The trough soft nose design was finalized and all material purchased. This cushioned interface will be a crescent-shaped length of large-diameter, thick-walled, soft rubber hose.

ACCOMPLISHMENTS DURING MAY 1981

All project activities this month were directed toward following up the purchased parts necessary to complete the machine modifications and releasing the required documentation.

- IAM Strike

There was no shop activity again this month, due to the strike by the IAM union local, which represents ESD and all FMC divisions in the Santa Clara valley. This strike will now cause the completion of the machine modifications and the subsequent date of shipment to the demonstration site to be postponed by 2 months. It is now anticipated that the machine will be ready for shipment during the first week of July, providing the shop returns to work on the first of June.

- Coal Spillage at the Rib-Machine Interface

With the exception of the rubber hose used on the soft nose, the balance of the material required to complete the presumping of the auger trough modification was received.

Several of the large components used in the design were fabricated from material which was drop-shipped to outside vendors. These items will be picked up when the shop returns to work.

- Start-up and Service Procedures Manual

During the month, some of the vendor catalog and maintenance data was gathered, and several of the maintenance charts were prepared.

About half of the machine operation text was written.

ACCOMPLISHMENTS DURING JUNE 1981

All project activities this month were directed toward the completion of the machine modifications required prior to shipment to the demonstration site.

- IAM Strike

With settlement between ESD Corporation and the IAM bargaining unit, shop activity resumed this month, commencing on June 2. Call back of all shop personnel was completed during the third week of June.

- Coal Spillage at the Rib-Machine Interface

All major changes to the machine main frame and auger troughs to implement the presuming of the trough modification were completed this month. The remaining loose ends, such as plumbing the sump cylinders and modifications to the stabilization jacks, will be completed during the first week of July.

- Tram System

All hydraulic system component changes and plumbing modifications were completed during the month. The system has been test run in the shop prior to tractive effort tests to be conducted outdoors behind the ESD shop facility.

- Start-up and Service Procedures Manual

During the month, the balance of the vendor catalog and maintenance data was acquired. The machine operation and electrical maintenance text was completed.

- Foreign Interest in Underground Augers

Hikosuke Onishi and Ryuichi Nishio of the Taiheiyo Coal Mining Company of Tokyo, Japan, along with T. Tohriyama of the Far East Mercantile Company, visited ESD on June 15.

During the course of this meeting, we learned that Japanese health and safety regulations regarding underground augering are far less stringent than U.S. regulations. A significant variation from U.S. law would allow boring deep (over 10 feet) blind holes without ventilation, rock dust, and masonry seals. This difference alone should increase productivity 25 percent.

Their primary interest lies in boring deep holes in longwall barrier pillars, but they appear quite enthusiastic over all concepts of underground auger mining for secondary recovery.

ACCOMPLISHMENTS DURING JULY 1981

All project activities this month were directed toward the completion and testing of the machine modifications required prior to shipment to the demonstration site.

- Coal Spillage at the Rib-Machine Interface

The changes required to complete the trough presuming modification were completed. During tests under actual boring conditions performed at the ESD facility, it was noted that no spillage occurred at the bottom of the hole. Because we are limited to conducting our drilling tests in a sloping dirt embankment, some spillage did take place toward the center line on the left side of the auger trough. All in all, it is felt that the modification will keep spillage to a bare minimum and has accomplished the desired results.

- Tram System

After being reassembled in the unpaved area behind the shop facility, the machine was run through a series of tractive effort and stall torque tests. The first of these not-so-scientific but realistic tests was to prepare a series of random holes. The holes varied in depth from 6 to 8 inches and 2 to 4 feet in diameter. The machine traversed this area with no difficulty whatsoever. The second test consisted of blocking all four wheels with wooden four-by-fours and attempting to climb over them. The machine would not do this, seemingly indicating a lack of power. Upon calculating the upward angle represented by these blocks, it was determined that this test was the equivalent of ascending a 90.4-percent slope. The third test was simply to run the machine up against a solid object and apply tram power until a wheel spun. This testing was completed and, although there is a slight reduction in speed, the overall tramping characteristics are greatly improved and will be more than adequate for any mine floor condition.

- Peabody Coal Company Inspection of the Machine Modifications

Three representatives of the Peabody Coal Company visited the ESD facility on July 14 to observe the performance characteristics of the machine with its completed modifications. In attendance were Charlie Bollier, Chief Industrial Engineer; Denney Robinson, Chief Electrician, Marissa Mine, and Ross Shelledy, Project Engineer for the auger underground demonstration. The machine was put through its paces and, during the course of boring several holes in the dirt embankment, the sump drive became jammed. With closer inspection, it was determined that small pebbles were being carried into the idler sprocket on top of the lower strand of the drive chain. This chain is double-strand 80, which will not self-clean because of the center dead band and corresponding absence of center sprocket teeth. To overcome this

condition, single-strand 100 chain will be substituted. The chain, necessary sprockets, and related hardware were ordered. In addition, scrapers were installed ahead of all sprockets that will remove any material which is too large to drop between the chain rollers. On July 17, Peabody Coal Company requested via letter that we make arrangements for shipment at the earliest possible date.

ACCOMPLISHMENTS DURING AUGUST 1981

Project activities this month were directed toward preparing the machine and spare parts for shipment and mine site reassembly prior to the underground auger demonstration.

- Machine Shipment and Preparation for Underground Test

The machine was disassembled and readied for shipment, leaving the ESD facility loaded aboard two trucks on August 14. These trucks arrived at the Marissa Mine on August 20. At time of arrival at the mine site by an ESD representative on August 25, both auger troughs and cutter-head along with the spare parts box had been taken underground.

Mine personnel determined that the chassis, when placed on a lowboy, exceeded minimum height requirements, and it was decided to remove the roof jack pad extensions and wheels. The chassis now resting on the steering yokes was brought into the mine during the afternoon shift.

The following day, August 26, electrical power was applied to the machine and the chassis raised on the floor jacks to facilitate reinstalling the wheels.

A ramp was constructed at the inby end of the lowboy, and the machine was then lowered onto its wheels and trammed up to a crosscut where the troughs would be installed.

Upon returning to the surface at the end of this shift, Bill Opolka, the Mine Superintendent, stated that our onboard automatic water spray system regulated to 60 psi was inadequate. He insisted that, to provide the necessary dust control, the sprays must receive full mine-supplied water pressure, which is 260 psi.

Since the spray system receives its water from the discharge of the hydraulic reservoir heat exchanger, rated at 60 psi, it was decided to divide the sprays into three circuits.

To supply the heat exchanger with low-pressure water, a tee was installed downstream of the automatic shutoff valve ahead of the carriage select valve. The heat exchanger discharge was plumbed to the conveyor sprays, and the carriage sprays would now run on high-pressure water. This change necessitated replumbing the carriage sprays with high-pressure hoses. Shift Number 4 on August 28 continued work on water sprays and installed both troughs on the machine frame. The troughs and cutterheads were lifted as assembled units by chaining the cutterhead end into a scoop bucket. Using both auger tram and scoop tram and twist, the troughs were aligned within the main frame guide rails and pushed across the machine using the scoop bucket ram.

- On August 29, the auger trough presump cylinders and stab jacks were installed and plumbed. The machine was then trammed over two crosscuts and up eight blocks (600 feet) to a site that will be both a test area and the start of the auger demonstration boring plan.

At the start of shift Number 6 on August 31, we attempted to bore the first of a series of test holes. With auger rotation at approximately 25 rpm and repeated shallow sump advances, a 6- to 8-inch-deep starter hole was bored. With advancement of the auger rotation control to full speed and actuation of the sump switch, the cutterhead would stall. Rotational pressure, which at stall should have been 2,250 psi, was reading less than 500 psi, and charge pressure would drop to near zero. These conditions were identical on both of the boring carriages, thereby indicating malfunction of the Sunstrand variable displacement pump. After numerous calls to the Sunstrand factory representative and performing all possible onsite diagnostic tests, it was decided to remove the pump and take it to the factory in Ames, Iowa.

ACCOMPLISHMENTS DURING SEPTEMBER 1981

Project activities this month were concentrated on diagnosing the Sunstrand variable displacement pump malfunction and commencing the underground demonstration.

- Sunstrand Pump

The variable displacement pump was removed from the machine and delivered to the Sunstrand factory in Ames, Iowa, by an ESD Corporate representative. It was found, after total disassembly, that the valve plates and piston slippers were heavily scored, thereby causing excessive internal leakage and almost total loss of system pressure. The pump was rebuilt and, after discussing the probable cause of this failure with a Sunstrand Applications Engineer, we were informed that "gross contamination" was to blame. At this time, it was recommended that we install two high-pressure 10-micron filters in this closed loop circuit between the auger torque motors and the pump high-pressure ports. Two Canflo Model CFHP-5020 filters were purchased and air-freighted to the mine site. Additional plumbing components and the rebuilt pump were returned and reinstalled on the machine.

- Sumping Rate

When attempting to bore the first series of test holes, the fixed 0.74 foot-per-second sump rate proved to be much too rapid for the available rotational cutting torque and would stall the cutterhead. This speed was gradually reduced by means of a flow restrictor until a rate of approximately 1 foot per minute resulted in an uninterrupted, continuous drilling operation.

During the boring of the first two holes, the sump pressure began to climb and ultimately would no longer move in the forward direction. The channel-shaped track in which the chain-driven yoke shoe travels had become packed with wet coal fines, thus preventing any forward movement. This condition is aggravated if an excess quantity of water is applied to the throat of the bore hole.

- Delay in Brake Application

As the machine was trammed adjacent to the rib to start a bore hole, the brakes would not apply rapidly enough to stop the machine within several feet of the desired point.

The brake units are spring applied and hydraulically released, actuated by both tram and steering circuit pressure. When the tram steer joy stick control is returned to the neutral position and the machine is on a level surface, the brakes will apply. If, however, the machine is on a slope, the tram wheel motors will act as pumps when the machine is coasting, thus preventing brakes from applying.

An additional spring-offset, pilot-assisted valve has been assembled to be installed in the system. This spring-offset valve opens when tram or steer pressure is released and will allow the brake circuit to bleed directly to tank, facilitating a very rapid application.

Conveyor Jamming

With the auger drive again functioning properly, a test hole was attempted. During the cutting of this hole, the conveyor suddenly stopped as if it had become jammed with coal. Jogging it forward and backward with chain movement of 18 inches to one-half a full revolution cleared all of the coal with still no improvement. Suspecting the drive end as being the source of the trouble, several observation holes were burned in the foot shaft area hold down plates. This inspection revealed no obvious problems; the conveyor drive motor was thus assumed to be the cause of the erratic behavior. The motor was removed and taken to a factory-authorized rebuild facility in St. Louis, Missouri. The motor was disassembled for visual inspection, new seals were installed, and the motor was tested on a dynamometer. The motor conformed to the manufacturer's specifications and was ruled out as a possible cause of the problem. Due to an acute shortage of underground repairmen (we had a qualified repairman during three of the first 25 shifts), it was decided to idle this machine during the last week of September. We were guaranteed by mine management to have adequate coverage by above-average repairmen if we worked the afternoon shift during the first week of October. The mine rotates their shifts every four weeks, with the second week of October putting the afternoon crew on days, returning the situation to normal.

ACCOMPLISHMENTS DURING OCTOBER 1981

Several problem areas and equipment failures were corrected.

- Jammed Conveyor

As reported last month, the conveyor repeatedly seemed to jam. The drive motor was reinstalled, and by taking line pressures into and out of the motor and noting a rapid rise in bearing temperature, it was determined that a conveyor drive shaft bearing had failed. Disassembly confirmed the diagnosis; cause of failure was lack of lubrication. New bearings were installed and the assembly reinstalled into the machine. (It was necessary to resurface the bearing shaft.)

- Steering

The wheels would sometime steer from the intended path without command when a wheel trammed into a hold or lump. Removal of a shuttle valve from the steering hydraulic circuit cleared the problem.

- Trimming

Sometimes a wheel would spin while trimming, causing the machine to stop. This would happen when one wheel had little resistance to turning because the wheel was over a hole, off the bottom (floor), or in soft bottom, and caused all of the oil to flow to the wheel having little or no resistance, preventing the other wheels from getting enough oil pressure to make them turn. To improve the condition, 12-gpm flow control valves at each wheel were replaced with 9-gpm valves. A more positive means of preventing wheel spin is to manually close a valve in the hydraulic line at the wheel which is spinning, so that its brake remains applied.

- Braking in Place

Once the machine was trammed into place for boring a hole, the machine would often roll back one or two feet. This happened because the brake and tram circuits are activated by the tram control; there is also a time delay for the hydraulic brake pressure to delay to zero.

By holding the tram control level in tram and turning off the pump motor, the machine will remain in place. This is not a desirable operating procedure. The problem was improved by separating the brake and tram hydraulic circuits.

- Miscellaneous

Hoses to the auger rotation motors sagged into the hopper area and got pinched and abraded when the auger was fully retracted. Supports were fabricated and installed to prevent this condition.

The floodlights (2) were relocated to provide illumination of the auger and face. In the previous location, illumination was blocked by the rubber skirts on each side of the auger trough.

Filters previously added to the auger rotation hydraulic circuit were permanently mounted to the machine with brackets.

Addition of hydraulic oil to the reservoir was extremely slow, because of the restriction caused by the fine mesh screen in the filler neck. Since it is likely that a hole would be punched into the screen to facilitate filling, an aspirator was plumbed into a stab jack hydraulic circuit. With the stab jack hydraulic circuit running over relief, the aspirator will draw oil from a drum and discharge the oil into the hydraulic system reservoir.

Hooks were added to one outby corner of the machine to help keep the trailing power cable and water hose off the bottom (floor) around the area of the wheel.

- Augering Holes

Bored approximately 15 holes during the month. Auger Number 2 seems to bore a hole faster than Auger Number 1 by two to four minutes. The reason(s) for this is unknown, for there are several conditions that can be the cause for differing cutting rates. The time to bore a nine-foot hole averages about 13 minutes for the Number 2 auger.

Pressure gages were being added to measure pressures developed by pump and at sump and rotation hydraulic motors.

ACCOMPLISHMENTS DURING NOVEMBER 1981

All effort during this period was directed toward reducing the time required to bore a hole and to correction of hydraulic equipment operating malfunctions.

The operating malfunctions centered around operation of the two augers. Sometimes Auger Number 1 would begin rotating when the selector switch was moved to Number 2 and the rotation level advanced. Also, when the working auger was boring a hole, the idle auger sometimes rotated in short impulses. Occasionally, when the working auger stalled momentarily, the idle auger began rotating.

By measuring hydraulic fluid flow and pressure and finally bypassing one pilot-operated check valve in the auger rotation motor hydraulic circuit, it was determined the the malfunctions were caused by erratic operation of the pilot-operated check valves. These were removed from the machine and replaced with four ball valves. The ball valves are interconnected and operated manually by handles accessible at each side of the machine. With this change, only the selected auger turns when boring a hole, and operation has been much smoother and more positive.

The time required to bore a hole has been varying between 9 and 15 minutes; a 5-minute hole is the goal. In our efforts to improve on the time to bore a hole, many combinations of cutting bit numbers (quantity) and arrangements within each ring of cutting bits were tried. (Hydraulic pressure relief valves were adjusted to the lowest working pressure rating of the hydraulic components.) With some combinations, there was slight improvement and with others, none. Two flat plates with beveled and pointed leading edges were welded between cutter bit mounting rings. These increased the time to bore a hole, but broke off more of the core rings of coal left at the end of the hole. Plumb bob bits (three) welded to the rings also broke off the core ring, but had no measurable effort on the time.

The original full-face peak style cutting bits with positive 5-degree rake angle were replaced with full-face style cutting bits having positive 15-degree rake angle. It was thought that these would cut faster, but they proved no better than the originals.

When relief valve settings were raised to about 2600 psi, the time to bore a hole decreased to about 6-1/2 to 10 minutes. Higher hydraulic pressure to the sumping motor, it is rated for 3000-psi working pressure, could reduce the time even more. A hydraulic component in another branch of the system requires 3000 psi. The hydraulic system plumbing was jury rigged to deliver 3000 psi to the sumping motors. Unfortunately, the pressure loss through one of the components was high, resulting in only 2700 psi being delivered to the sump motors.

Auger Number 1 (inby auger) has consistently taken longer to bore a hole than Auger Number 2 (outby auger). The reason for this is not known, but steps to determine the cause will be undertaken during the early weeks of December.

ACCOMPLISHMENTS DURING DECEMBER 1981

During this reporting period, all work was directed to decreasing the time to bore a hole and determining the reason why one auger took longer to bore than the other auger.

Flow meters and pressure gages were installed temporarily in the hydraulic circuit. These verified that pressure loss through the pressure intensifier would not provide 3000 psi to the auger sump motors.

An alternative means of providing 3000 psi was tried. The valve bank which directs fluid pressure to steering cylinders, carriage/stab jack cylinders, and sump motors had an 1800-psi maximum relief valve. This relief valve was removed from the valve bank and a 3000 psi maximum relief valve added inline to the valve bank. This provided 2950-3000 psi to the sump motors. With this pressure at the sump motors, a hole was bored in 6:07 minutes. Considering the hardness of the coal (relatively hard for bituminous), a six-minute hold appears to be the best time that can be achieved with the present bidirectional auger design.

The remaining time was spent trying to determine why the one auger was slow at boring a hole. First, the two augers were compared dimensionally. Measurements across the cutting bits (diametral) were within 1/8" of each other. Both augers cut holes that were approximately 47-3/4" in diameter.

Because one conveyor chain drive shaft support bearing had not initially been lubricated, our attention was directed to the bearing assembly that supports the tail end of the auger scroll and its rotation drive motor. We found that the sintered bronze breather had been broken off, allowing some coal dust to enter the housing. Upon disassembly, we found a trace of oil and some contamination. (The oil probably leaked through a nongasketed mounting face.) The bearing appeared to be undamaged. A dimensional check of the housing parts was made; all parts met drawing requirements. As recommended by the auger drive motor manufacturer, a relief cut was made on the bearing housing motor mounting face to eliminate any possible binding within the auger drive motor.

The bearing and housing were reassembled, remounted to the drive motor, and filled with grease (grease is suitable, since shaft speed is only 60 rpm and will not leak out). A plug with vent hole replaced the sintered bronze breather.

When operated under no load and not connected to the auger, the assembly ran smoothly. When under load, however, the motor ran roughly at 1500 psi and above.

The auger drive motor was returned to the manufacturer during the week of December 14, 1981. They found the side plates severely scored, and the oil (the motor was shipped full of oil) contained what was thought to be water. They also found that the motor ran smoothly under no load, but poorly at 1500 psi.

The manufacturer advised ESD that these motors are sensitive to thermal shock, and that the hydraulic circuit should be revised to permit a small amount of oil to circulate through the idle motor(s).

A sample of oil was returned to ESD Corporation for analysis. The results of the analysis, performed by FMC Corporation's Materials Laboratory, are that for every 100 milliliters of oil, there are 30.9 milligrams of contaminant consisting of dirt and varying chemical compound particles containing magnesium, aluminum, calcium, copper, zinc, lead, and potassium. A small amount of fine steel particles was also present. The oil contained 0.25 percent per volume of water. The contaminant particles are very fine and remain suspended in the oil, giving it a milky appearance similar to emulsified oil. Filters on the outlet of each pump are rated at 10 microns.

ACCOMPLISHMENTS DURING JANUARY 1982

Repair of the damaged auger drive motor was completed and the motor put in transit to the mine on January 27. As of January 29th, the motor reached St. Louis and was on the shipper's dock awaiting pickup by the trucking company that will deliver the motor to the mine.

Because of the contamination in the oil, 3-micron filters have been ordered and shipped to the mine. These will replace the 10-micron filters now in use until the 3-micron filters require replacement.

Engineering has designed several hydraulic circuit changes. A cylinder lock check valve will be added to the roof jack extend circuit to prevent relaxation of the roof jack (1 to 2 inches) immediately after they have been extended to the roof and the valve closed. A flow regulator and check valves will be added to the auger rotation motor circuits to provide a small flow of oil which will keep the idle motor warm, thus preventing or reducing thermal shock. A modular system relief valve will be installed on one valve bank to replace a temporary inline relief valve installed to obtain 3000 psi. These items have been procured and will be hand carried to the mine.

A request for extension of completion date to June 30, 1982 has been submitted to the DOE contracting officer.

A rough draft of several sections of the final report were written.

ACCOMPLISHMENTS DURING FEBRUARY 1982

Installation of the repaired auger drive motor was completed. Auger thrust bearing preload for both augers was checked and adjusted to eliminate shaft end play. This was done as a precaution to prevent possible motor end rotor wear caused by auger drive shaft thrust loads being transmitted to the rotor of the auger drive motor.

Two holes were bored using the auger having the rebuilt motor Number 1; operation was normal, but when the other (Number 2) auger was started rotating, it stalled after several turns. (Warm or hot oil had been switched to flow through a cold motor.) The machine was allowed to sit for several minutes, and then Auger Number 2 rotated without further incident.

Because the auger motor manufacturer says that these motors are sensitive to thermal shock, as when hot oil is directed into a cold motor, a flow regulator and four check valves were added to the hydraulic circuit. These parts permit a small flow of hydraulic oil to circulate through the idle motor to keep it warm.

A pilot operated check valve was added to the roof jack hydraulic circuit. The check valve was added to eliminate the cylinder rod retraction of approximately one inch that had been occurring, because the cylinder locks were not engaging immediately.

The temporary hydraulic plumbing changes made during November to get 3000-psi sump pressure were returned to the original configuration. The inline relief valve was replaced with a permanent 3000-psi relief valve installed between the unloader solenoid valve and the manifold assembly.

After installation of the new items above, file holes were bored with the Number 1 auger. The Number 2 auger seemed to stall momentarily while rotating in the trough. The auger was disconnected, and the motor operated independently, but momentary stalling still occurred. The motor was removed and sent to a hydraulics repair shop for partial disassembly. There was evidence of scoring on the end plates and center plate, but in an area near the rotor drive spline. Because the repair shop did not have a honing machine large enough to accommodate this motor, the motor was reassembled and reinstalled on the machine. When operated now, the auger would stall completely, and pump charge pressure and auger rotation pressures would drop to zero. A flow meter was installed in the motor case drain. With auger rotating freely in the trough, flow was 3.5 gpm and over 15 gpm at stall (normal flow should be about 0.75 gpm). All of these symptoms were related to the manufacturer. It was decided that the motor needed repair and was shipped on February 27.

ACCOMPLISHMENTS DURING MARCH 1982

The vane motor was received by the manufacturer and disassembled. Both end plates and the center plate were worn, although not as severely as the other auger drive motor. Surface cracks, caused by heat, were found in the case hardened surfaces of the rotor.

Repair of the motors consists of the following:

- Resurface end plates and center plate.
- Send end plates, center plate, and cam rings to Parker for "Lubrite" coating. ("Lubrite" is a phosphate base anti-wear coating.)
- Add "blips" to end plates and center plate. ("Blips" are circular depressions ground to a depth of about 0.001 inch which retain oil.)
- Reassemble using a new rotor.
- Test.

At the end of March, the motor was expected to be delivered to the mine by April 5.

Engineering activity for this period was directed toward completing more of the final report rough draft.

ACCOMPLISHMENTS DURING APRIL 1982

Repair of the hydraulic vane motor was completed, and the motor was shipped back to the mine and reinstalled on the auger. Operation was much improved, with both augers performing nearly equally. The time required to drill a hole took longer with each successive hole, however. Increasing oil temperature was suspected as being the cause.

Oil temperatures in the auger drive circuit increased rapidly because this is a closed circuit between pump and auger drive motor. Oil at a lower temperature is drawn from the reservoir by the pump to replace oil lost by internal leakage through pump and motor case drains. This makeup oil is of insufficient flow to provide any cooling of the oil in the auger circuit.

To increase the flow of colder oil into the auger circuit, a flow regulator and relief valve were added to the return side of the auger circuit loop. This arrangement returned about 3 gallons per minute to the reservoir, but was not sufficient to stabilize the temperature within the recommended range for satisfactory life of the oil and component seals. Temperature in the auger circuit exceeded 190°F after drilling only six holes consecutively.

An oil-to-water cooler was added to the return side (low pressure) of the auger circuit. (Reverse rotation of the auger cannot be used, because it would apply excessive pressure to the cooler. Experience has shown that reverse is not necessary for this auger.) Additional spray nozzles (for dust suppression) were added to increase water flow and provide more cooling.

With these changes, oil temperatures were reduced considerably so that temperatures reached between 150°F and 160° after drilling 12 holes. Delays caused by problems unrelated to but directly affecting the auger prevented drilling more than 12 holes during that shift. It appears, however, that temperatures may stabilize near 160°F.

Because the auger drive vane motors are very sensitive to temperature change, to drill holes in the shortest possible time, oil temperatures in the auger circuit should not exceed 140°F. Additional increase (relatively small) in water flow through the cooler is expected to provide the additional cooling required to maintain an oil temperature stabilized at about 140°F.

ACCOMPLISHMENTS DURING MAY 1982

During this reporting period, 116 holes were drilled. During one shift, 24 holes were drilled, the most drilled in any one shift to date. Without delays unrelated to the auger, there is the potential for drilling 30 to 35 holes per shift.

Two changes to the machine seem to have contributed to the drilling of 24 holes; one was increasing the flow of water through the heat exchangers and the other was exchanging new cutter bits for the old ones and adding more bits (some bits had been removed months ago).

Three equipment failures occurred. While tramping the auger to the new starting point, a roof jack pad caught on the roof, breaking off the jack cylinder rod at the threads where the jack extension attaches. The broken cylinder was replaced with a spare cylinder.

Broken double-strand roller chains forcing the auger into the coal were other failures. Chain failure results from over-tension of the chain caused by coal fines compacting between rows of teeth on the idler sprocket. The compacted coal increases the effective pitch diameter of the sprocket. Efforts to prevent coal fines getting into this area, or letting them out, have not been successful.

The pair of chains for one auger and their drive and idler sprockets were replaced with single-strand chain. With a single-row sprocket, compaction of coal should not occur on the sprocket. Because we are near the end of the demonstration and it takes at least a full shift to change the chains and sprockets, the broken chain strand for the other auger will be repaired.

Appendix B

MSHA REQUIREMENTS

U.S. DEPARTMENT OF LABOR
MINE SAFETY AND HEALTH ADMINISTRATION

4015 Wilson Boulevard
Arlington, Virginia 22203



March 27, 1979

Mr. Joe Ritchey
Project Manager
FMC Corporation
Santa Clara, California

Dear Mr. Ritchey:

This letter is to confirm our discussions during meetings of February 27 and 28, 1979, concerning design and development of a bi-directional coal auger for use underground. The primary concerns of MSHA are those features that should be incorporated into the machine design to provide for the safety and health of the miners and for compliance with the requirements of the Act. Requirements expressed in our discussions should be construed to be minimums and where conditions warrant, additional requirements may be necessary.

As per our discussions, the machine will be operating in entries previously driven. The augering of the pillars will be considered second mining. A minimum of 9,000 cubic feet of air a minute shall be provided in the entry at the intake end of the pillar being mined as described by 30 CFR 75.301-3. The auger machine shall be equipped with a method for providing positive ventilation at the inby end of each borehole as it is being drilled. No quantitative value was established for the volume of air in each borehole; however, the system must be capable of providing sufficient ventilation in each hole to dilute, render harmless, and carry off any methane that may be liberated during augering.

The Face Ventilation System adopted by the operator as required by 75.316-1, shall be approved by the District Manager before operation of the machine. Air quantity requirements of this plan could vary on a mine-to-mine basis. The Auger machine shall be equipped with a water spray system to allay dust created during augering. The methods of dust control are also a requirement of 75.316 and 75.316-1.

The machine shall be equipped with an approved methane monitor. The sensing device of such monitor shall be so located to monitor the methane content of the air current ventilating the borehole in order to maintain the methane content to less than one (1) percent. The methane monitor shall meet the requirements of 30 CFR 75.313.

The auger machine should be equipped with an integral automatic roof support system consisting of a minimum of four (4) jacks for support of the roof immediately over the auger machine. A roof control plan required by 30 CFR 75.200 for the control of the mine roof, including the use of breaker, line

and turn posts, where necessary, shall be adopted by the operator and approved by the District Manager for the Auger machine on a mine-to-mine basis.

Inasmuch as there were questions concerning the cab or canopy requirements of 30 CFR 75.1710 for the Auger miner operated by remote control and on which operators' controls were not provided, it was recommended this subject be discussed with John McCormick, Chief, Division of Safety Technology, Pittsburgh Technical Support Center.

Rockdust will have been applied to the surfaces of entries in which the machine will be operated; however, coal surfaces will be exposed and dust created by the augering operations may be deposited on the floor and ribs in by the machine. Thus it will be necessary that some means be provided to apply rock dust to these areas. It was suggested that a rock dust machine be provided as an integral component on the augering machine. This would allow rock dust to be directed into the mouth of the holes and onto surrounding areas after the machine advances.

If there are any questions concerning our discussions please do not hesitate to call.

Sincerely,



Robert A. Elan
Mining Engineer



Paul J. Compton
Coal Mine Safety Specialist

Appendix C

**BIDIRECTIONAL AUGER PROPOSED
CONTRACT MODIFICATIONS**

FMC Corporation

Engineered Systems Division
328 Broadway Road Box 450
Santa Clara California 95052
(408) 289 0111

April 11, 1980



U. S. Department of Energy
Office of Procurement Operations
400 First Street, N.W. MS 400RB
Washington, D.C. 20585

Attention: Contracting Officer

Subject: Contract Number ET-78-C-01-3150,
Bidirectional Auger

Serial Number: ESD G-240

Gentlemen:

Since award of the subject contract, the concept of the bidirectional auger has been improved upon and revised from that which was presented in FMC's proposal, which served as the basis for contract award.

The impetus for improvement of the original bidirectional auger concept resulted chiefly from three sources:

- Evaluation and recommendations made by mine operators
- Experience gained from the operation of an underground auger in an operating coal mine
- MSHA requirements.

The impact of the above factors is detailed in the enclosed technical rationale, Enclosure A. FMC feels that the concept as presented in the enclosure will result in the development of a mining machine which will offer optimum performance, be more readily accepted by the mining industry, and accomplish the above while meeting MSHA's requirements.

April 11, 1980

While FMC recognizes that only the Contracting Officer can redirect the scope of work, it should be noted that the improvement and changes to the original concept were pursued with the concurrence of both the DOE Technical Project Officer and the DOE Washington Staff Engineer. Recognizing this, FMC hereby requests the following changes be made to the subject contract:

- Article 1.2 of the subject contract, under the provisions of Article 8.2, references FMC's proposal wherein is described the original "deep-hole drilling bidirectional auger concept." FMC requests that all references to this concept be deleted and that the concept of a "blind-hole drilling bidirectional auger," as described in Enclosure A, be substituted in their place.
- FMC has agreed to display the bidirectional auger at FMC's exhibit area at the 1980 American Mining Congress Coal Show in Chicago in May. Further, FMC has agreed to pay all expenses associated with the display area at no charge to the government. It is FMC's feeling that the exposure gained at this exposition will benefit the project by attracting a larger number of potential demonstration partners to review the equipment than would otherwise be possible within the time and funding constraints of the contract. Freight to and from the Coal Show will be an allowable contract expense. Placards and literature describing the bidirectional auger will credit the Department of Energy as the sponsor of the project. FMC requests that the display of the bidirectional auger be incorporated into the contract.
- In view of the change in concept and the additional task of displaying the auger at the Chicago Coal Show, FMC requests that the program schedule be revised as shown in Enclosure A and the completion date of the contract be extended to 31 January 1982.

At this time, FMC's assessment of these proposed modifications indicates the extra cost of the design effort associated with the concept changes has been approximately offset by the fabrication economies of the single-chassis design and that the balance of the program can be completed within the funding currently authorized.

U. S. Department of Energy

Page 3

April 11, 1980

Your prompt review and incorporation of the above items into the contract will be appreciated. If you should have any questions concerning this matter please contact Mr. J. Ritchey at (408) 289-3275 on technical matters, and the undersigned at (408) 289-3685 on contractual ones.

Sincerely,



Terence M. Bunker
Senior Contract Administrator

Encl: Proposal

cc: Mr. R. Farrar
Technical Project Officer
DOE, Carbondale

Mr. H. Reese
Washington Staff Engineer
DOE, Germantown

Mr. J. O'Neal
Contract Administrator
DCASPRO/FMC

Mr. J. Ritchey
Project Manager
FMC

FMC Corporation
Engineered Systems Division

FMC Document P-3891
April 11, 1980
Enclosure A

Proposal for
BIDIRECTIONAL AUGER PROPOSED
CONTRACT MODIFICATIONS
Contract ET-78-C-01-3150

Submitted to
U. S. DEPARTMENT OF ENERGY
Washington, D. C.

BACKGROUND

In August 1977 FMC submitted a final report entitled Feasibility Studies of a Bidirectional Auger System and a Machine Mining Plan under Bureau of Mines Contract J0265029. The report introduced the concept of an underground boring-type auger machine which would have the capability of drilling relatively deep, large-diameter holes into coal pillars on either side of an entry from the same setup or with a minor maneuver (i.e., a lateral shift as opposed to a complete turnabout). The study had concluded that such a machine -- or actually a pair of machines, since the drill and the extractor were on separate chassis -- could, in certain mine circumstances, produce coal in an economically acceptable manner. However, when compared with a continuous miner used in a plan of full or partial pillar extraction, the auger operated at a disadvantage of about 62 cents per ton (1977 dollars).

FMC determined that the auger could provide a benefit to the mining industry in bad roof areas or in locales where traditional pillar extraction was not allowed. Therefore, FMC proposed to the Bureau of Mines a project in which we would design, fabricate, and test a bidirectional auger based on the concept developed in the study. During the evaluation period of FMC's proposal, the authority for advanced mining systems research and development was transferred to the Department of Energy, and in September 1978 a Department of Energy (DOE) contract was let to FMC for the design, fabrication, and test of a bidirectional auger under Contract ET-78-C-01-3150.

In October 1978 FMC displayed, with Government approval, a model of the bidirectional auger which had been built under the prior USBM contract at the American Mining Congress International Mining Show in Las Vegas, Nevada. The model drew a considerable amount of interest; however, there were a great many negative comments on its operation from mine operators.

Specifically, they pointed out the following:

- The problems of coordinating the operations of the two chassis
- The difficulties which the operators would have in seeing where they were going and seeing one another
- The need to begin drilling on an angle of attack above the horizontal on both faces, i.e., the need to rock the machine from side-to-side
- The problem of crossing an intersection or moving to a new set of blocks whereby all the auger sections would have to be unloaded and transported
- The obvious fact that the machine(s) would be very expensive to purchase and difficult to maintain.

These and other negative comments caused us to begin to review the concept developed in the USBM study.

Simultaneously, FMC was operating a unidirectional underground auger at the Ireland Mine of Consolidation Coal Company. This demonstration was a part of DOE Contract ET-75-C-01-9100 (also a USBM carryover) and was the second stage of a two-prototype test.

Although the production from that second prototype had improved over that of the first machine, there were several discouraging aspects of the data being acquired.

The second prototype machine, although it was equipped with an attitude control system for setting the initial trajectory of the drill, was unable to reliably auger deep holes without wandering into the floor, roof, or an adjacent borehole. When these drilling errors caused a borehole to be aborted, the effects on production and recovery were devastating.

Also, it was found that the borehole ventilation system required by MSHA was so cumbersome that it in itself was responsible for a great deal of lost production.

These facts along with the previous comments from members of the mining industry convinced us that a total reassessment of our bidirectional auger concept was in order.

In December 1978 members of FMC's bidirectional project staff met with the DOE staff engineer (at the time no DOE Technical Project Officer had been appointed) to review the status of the project.

At that meeting the need for a concept reevaluation was discussed, and three potential concepts were reviewed. FMC was instructed to assess the benefits of a concept change and to coordinate with MSHA to determine whether the new concepts would ultimately gain MSHA approval.

In February 1979 FMC again met with the DOE staff engineer and reported that we had high confidence in the new concepts and that we had received endorsements from Ireland Mine personnel on any concepts which avoided deep drilling and the use of a separate blower for borehole ventilation.

In March 1979 FMC hosted a concept review meeting with several MSHA staff members in attendance. At that meeting a concept of a single-chassis bidirectional auger which drilled boreholes only 10 feet deep was presented. FMC proposed that, for this short depth, the boreholes be unventilated during drilling. We proposed that the machine be remotely controlled, or as an option, the operator could be positioned under a canopy. Artist's renderings of these two concepts are shown in Figures 1 and 2.

We received a great deal of design guidance from MSHA, and at the conclusion of the meeting it was clear that the concept we had proposed did not violate the basic current interpretations of the 1969 Coal Mine Health and Safety Act.

In March 1979 FMC received a letter from MSHA reviewing their findings from the previous meeting. The following features were required of the machine and the mine plan:

- Minimum air ventilation over the machine would be 9,000 cubic feet per minute.
- Boreholes would have to be ventilated while drilling with a sufficient amount of air to abate the methane hazard.
- A water spray dust suppression system would be required.
- A methane monitor for detecting the methane content of the air ventilating the borehole would be required.

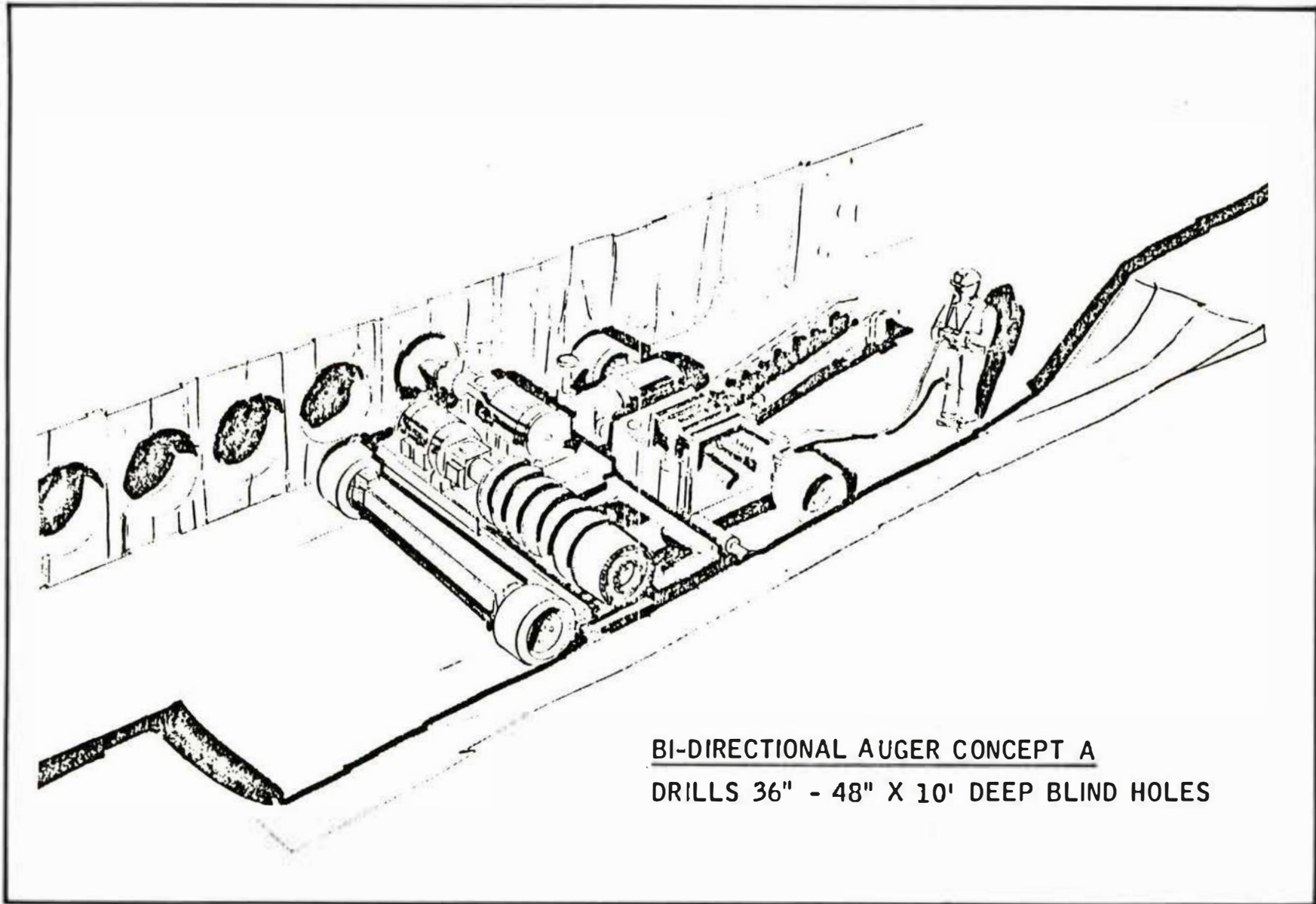


Figure 1 BIDIRECTIONAL AUGER, CONCEPT A

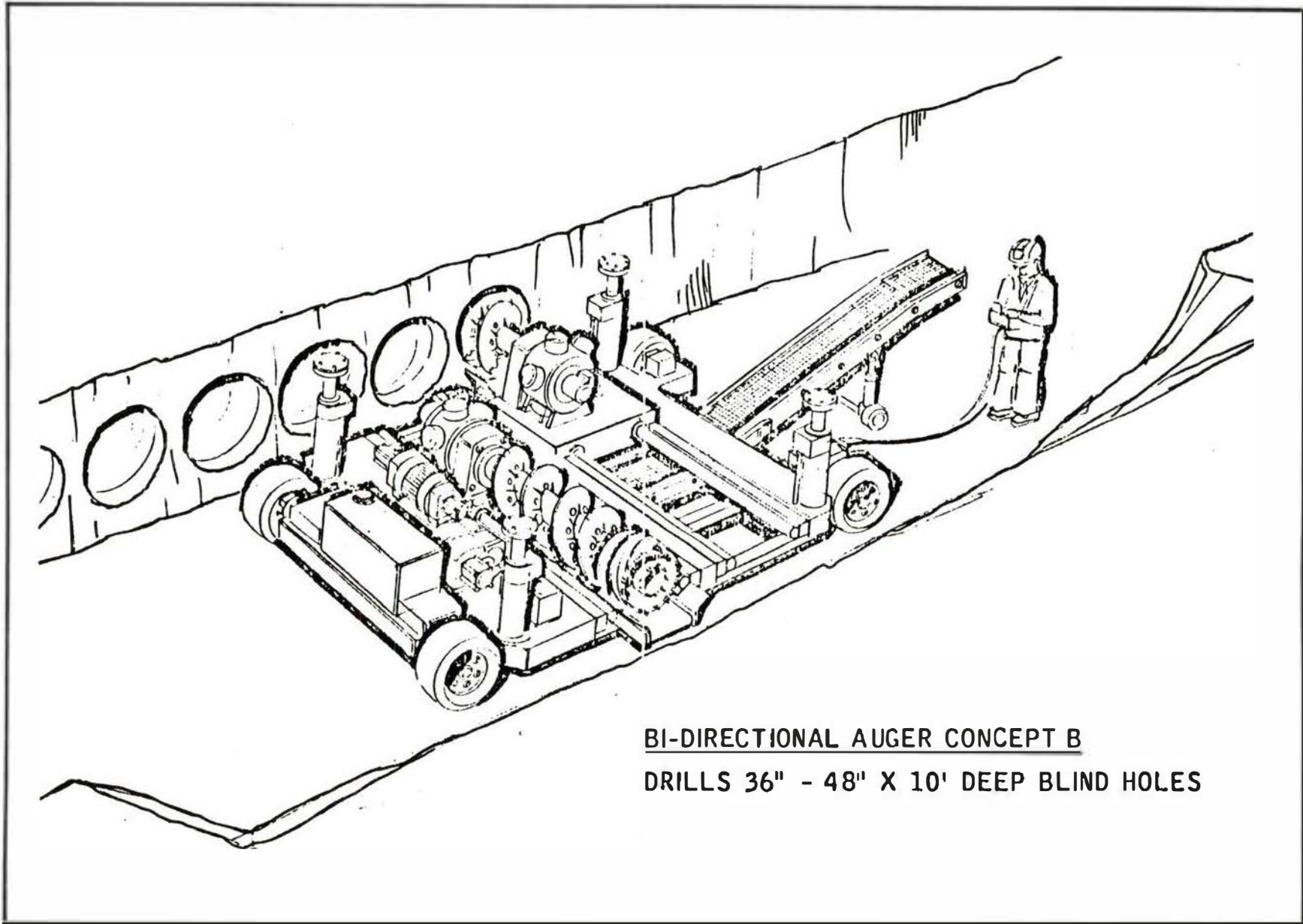


Figure 2 BIDIRECTIONAL AUGER, CONCEPT B

- The machine should have a minimum of four roof jacks to support the roof immediately over the machine.
- Rock dusting behind the machine would be required.
- The question of using remote controls in lieu of a cab or canopy was referred to MSHA, technical support.

At this point with the knowledge and consent of the DOE Technical Project Officer and the Washington Staff Engineer, FMC began the design of the improved bidirectional auger concept.

In a series of meetings with MSHA at the Pittsburgh Technical Support Center from April to December of 1979, the following factors were determined:

- Remote control of the auger was acceptable to MSHA.
- Four 13-ton capacity roof jacks positioned at the corners of the machine were acceptable to MSHA for roof control.
- A bumper was required to prevent a shuttle car from striking the auger operator.

During this same period of time several production, productivity, and recovery calculations were done to assess the merit of the new concept. Table 1 shows the results of these calculations. In brief, based on data collected during the auger experiments at Ireland Mine, the new blind-hole bidirectional auger concept was predicted to be superior to the old through-drilling concept both in production (raw shift tonnage) and in productivity (tons per man per shift).

As the scope of this proposed contract modification, FMC recommends and requests the following changes to the contract:

- Article 1.2 of the basic contract, under the provision of Article 8.2, references the FMC proposal, Document P-3678, wherein is described the original deep-hole drilling bidirectional auger concept. FMC requests that all references to the original concept be deleted and that the concept of a blind-hole drilling bidirectional auger, as described in this proposal, be substituted in their place.

- FMC has agreed to display the bidirectional auger at FMC's exhibit area at the 1980 American Mining Congress Coal Show in Chicago in May. Further, FMC has agreed to pay all expenses associated with the display area at no charge to the government. It is FMC's feeling that the exposure gained at this exposition will benefit the project by attracting a larger number of potential demonstration partners to review the equipment than would otherwise be possible within the time and funding constraints of the contract. Freight to and from the Coal Show will be an allowable contract expense. Placards and literature describing the bidirectional auger will credit the Department of Energy as the sponsor of the project.
- In view of the change in concept and the additional task of displaying the auger at the Chicago Coal Show, FMC requests that the program schedule be extended as shown in Figure 3 and that the contract completion date, including delivery of the final report, be changed to January 31, 1982.

It should be noted that this schedule is predicated upon FMC's receipt of MSHA approvals in a timely manner. The investigation of intrinsically safe circuits, requested by FMC in June 1979, is expected to commence in May 1980 and machine approval is expected in July 1980. These dates are based upon estimates by FMC and MSHA.

At this time, FMC's assessment of these proposed modifications indicates the extra cost of the design effort associated with the concept changes has been approximately offset by the fabrication economies of the single-chassis design, and that the balance of the program can be completed within the funding currently authorized.

Table 1 BIDIRECTIONAL AUGER SYSTEM COMPARISONS

Specification	Blind-hole auger 2 buggies, tripping	Blind-hole auger 2 buggies, 1 surging, 1 tripping	Through-hole auger 2 buggies, tripping
Raw shift tonnage	294 tons	214 tons	275 tons
Crew size	1 Foreman 1 Auger operator 2 Buggy operators Half-time mechanic	1 Foreman 1 Auger operator 1 Buggy operator 1 Mechanic and surge buggy operator	1 Foreman 1 Auger operator 1 Extractor operator 2 Buggy operators 1 Mechanic and entry conveyor helper
Productivity (tons per man-shift)	65.3	53.5	45.8
Productivity if crew size increases by one helper (tons per man-shift)	53.5	42.8	39.3
Labor cost per ton (1979)	\$1.39	\$1.75	\$1.92
Cost with one extra helper	\$1.64	\$2.09	\$2.18
Recovery per block (34 by 84 feet)	159 tons	159 tons	234 tons

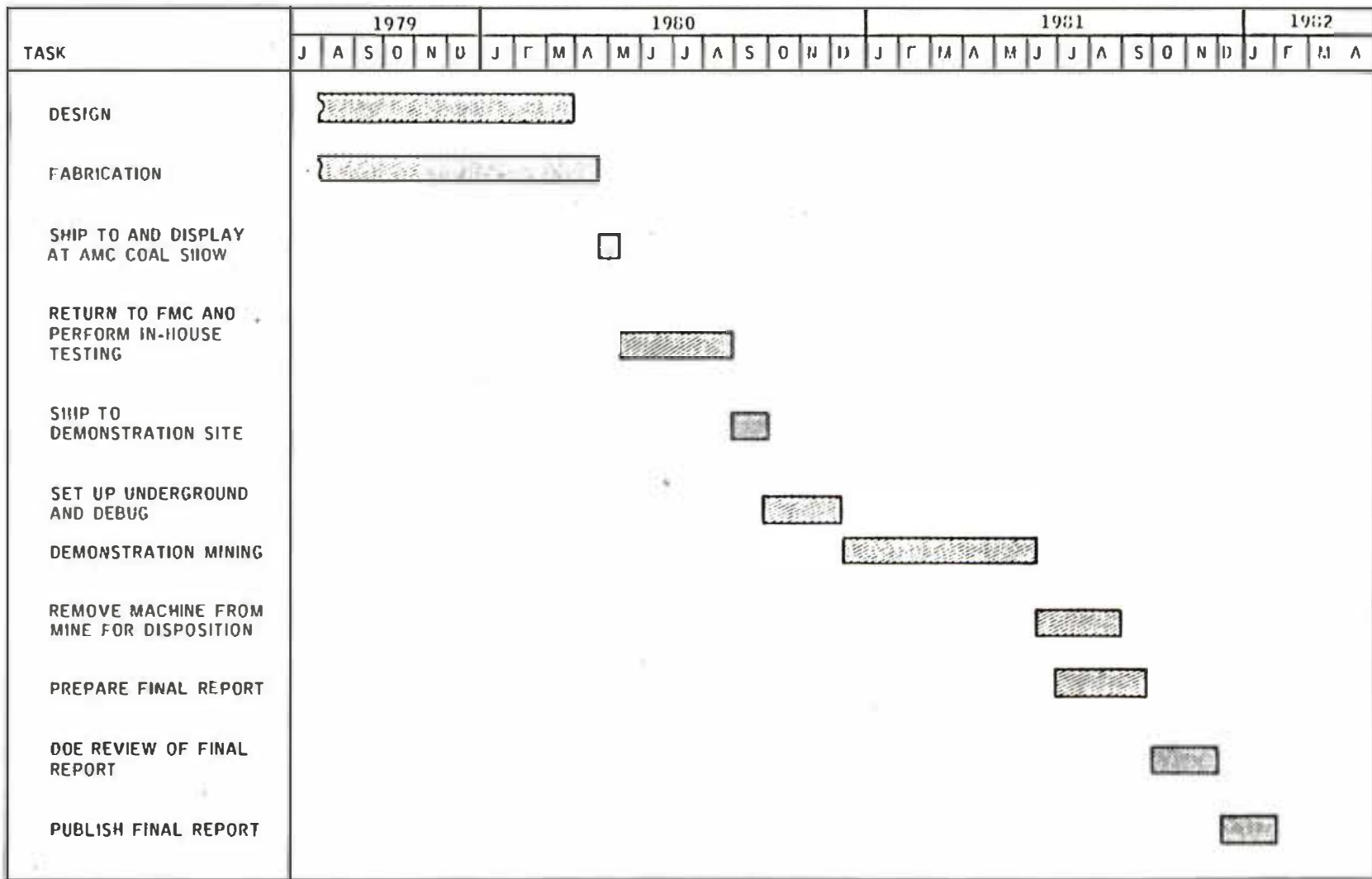


Figure 3 PROGRAM SCHEDULE

Appendix D

**MATERIALS ENGINEERING
LABORATORY TEST REPORT**

FMC Corporation

Central Engineering Laboratories
1185 Coleman Avenue Box 580
Santa Clara, California 95052
(408) 289-2731



**MATERIALS ENGINEERING LABORATORY
TEST REPORT**

<u>TARGET DATE:</u>	<u>RESPONSIBILITY:</u>	<u>CHARGE NO:</u>	<u>WP DOCUMENT NO:</u>	<u>LAB NO:</u>
	6 G3R	287500215	8983a	814079

REQUESTOR: L. Jack/Giroux 21 December 1981
DIV/CO. NAME: ESD-SJ
TELEPHONE: 2603

SUBJECT/PART NAME:

SUBJECT: Hydraulic Fluid

SUPPLEMENTARY INFO:

BACKGROUND: From auger (Illinois).

INFORMATION DESIRED:

Other - water, dirt, etc. - contaminants.

KEY WORDS:

RESULTS:

22 December 1981

Test results of the hydraulic fluid were:

Total contaminant per 100 ml. of fluid: 30.9 milligrams, consisting of dirt, and varying chemical compound particles containing magnesium, aluminum, calcium, copper, zinc, lead, and potassium; and a small amount of fine steel turnings.

The fluid also contained 0.25%/volume of water.

The "milky" appearance is from the very fine contained suspension of particles.

Beryl Rogers
Beryl Rogers
la

Appendix E

LIST OF INFORMATION REQUESTS

LIST OF INFORMATION REQUESTS

<u>Name</u>	<u>Company</u>	<u>Country</u>
John Tinklepaugh	North River Energy Co.	USA
R. Miller	Shell Co. Aust. Ltd. Coal Division	Australia
R. Jeffcoat	Southern Engineering Services	Australia
J. H. Blythe	KBC Pty. Ltd.	South Africa
K. A. Sweet	Technical Education Department Mining Lecturer	West Australia
T. Watroea	Bechtel Pacific Co., Ltd.	Australia
R. Peters	Johns Perry Ltd.	Australia
I. S. McIntosh	Ministry and Energy, Mines Division	New Zealand
I. D. C. McLean	Bellambi Coal Co.	Australia
T. Barnos	ESCOM	South Africa
Geoff Carter	Inspiration Coal Inc.	USA
M. Savich	Elliot Lake Lab	Canada
L. Fairbank	U.S. Bureau of Mines	USA
J. Davis	Utah Mines, Ltd.	Canada
Dr. Horvath Laszlonge	Koxponti Banyaszatíf	Hungary
Ing. Josef Hajek	Dum Techniky	Czechoslovakia
J. Iden	Mobil Research and Dev. Corp.	USA
P. Coxhead	Southern Cross Collieries	
Lubomir Hajek	Main Mine Rescue Station	Czechoslovakia
Mr. Naka	Tokiwa Co. Ltd.	Japan
J. L. Manka	Katowice Colliery	Poland
M. Cicovacki	Energoprojekt Geomine	Yugoslavia
Sabahudin Moranric	Amalisa	Yugoslavia
Thomas Bobick	U.S. Bureau of Mines	USA
J. C. Nelson	Elmac Corporation	USA
Frank M. Heinze	Turner Elkhorn Mining	USA
T. S. McCabe	Shell Oil Co. Mining	USA
Timothy Hawkes	Utah Fuel Co.	USA
Anthony G. Wibisono	Andacindo Calif Corp.	USA
Rebecca Goforth	Imperial Clevite Inc.	USA

<u>Name</u>	<u>Company</u>	<u>Country</u>
G. Ranganayakulu	Sinagreni Col. Co. Ltd.	India
C. A. Venkateswarlu	RIY CMPDI Ltd. Coalestate Civillines	India
Jorge Correa	Centromin Peru	Peru
P. Ridolfi	M & Jeng. Pty. Ltd.	South Africa
Joe B. Beam	Carbon Fuel	USA
A. Chaudhuri	CMPDIL R I II	India
Jose Avila	Centromin Peru	Peru

Appendix F

LETTER FROM PEABODY COAL COMPANY

PEABODY COAL COMPANY

MARISSA MINE
RURAL ROUTE #1, BOX 135D
MARISSA, ILL. 62257

July 27, 1982

Mr. William E. Will, Vice President
Operation Services Underground
Eastern Division
1951 Barrett Court
Post Office Box 1981
Henderson, Kentucky 42420

RE: Comments on bi-directional auger
machine demonstrated at Peabody Coal
Company's Marissa Mine.

Dear Bill:

Having had the opportunity to work with and observe this machine in operation, I was greatly enthused with the mining concept of augering chain pillars to gain an additional portion of coal without causing undue stress on remaining pillars and the overlying strata. A great deal of study and effort was put into a working plan that would be accepted by all factions in this project.

From the outset after having seen the machine initionally at the F.M.C. plant in San Jose, California, I felt we could work out the mechanical bugs once we got the machine on location here at the mine. I had some reservations about being able to control the oil temperature in the system and voiced my opinion at the time. My feelings were based on historical experience with the types of motors and pumps that were being used on the machine.

As it turned out the oil temperatures appeared to be directly related to the performance of the system. As the oil temperature raised, the efficiency of the machine was reduced. The time it took to auger each hole was increased proportionately to the raise in the temperature of the oil.

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An attempt to introduce an additional heat exchanger did not prove to be too fruitful in that it did little to help reduce or limit the heat build-up in the hydraulic oil. A brief synopsis for 90% of the failure of the machine was the inability to control the oil temperature, which again pointed out, was directly related to the overall performance of the augers.

Be that as it may, the basic design of the machine was fairly good. The crab steering was very practical and made it very easy to maneuver into position for each hole.

The remote control made was a high plus in allowing the operator to position himself in the safest work area at all times and still have a good view of his work site.

The safety roof jacks did not prove to be too effective because the changing elevations in the roof exceeded the limit of reach of the jacks at times. There was a lot of question as to whether the jacks were ever necessary to begin with, and my feelings were against them.

The rigidity of the total frame of the machine, plus the long wheel base presented an occasional problem when tramming over uneven roadways. Fortunately, we have a dry coal mine, so we really can't give any information about tramability in wet, muddy, conditions that exist in other fields. The tram motor system appeared to have sufficient power to each wheel, but problems occurred when any individual wheel was not in full contact with floor surface.

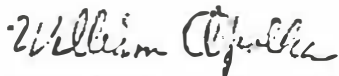
The sumping mechanism, being dependent on chains and sprocket system, caused some problems in clogging with coal and coal dust, and might have been better served with a threaded or worm gear thrust system.

The rotation power was the hardest to maintain efficiently. A little more horsepower to that area plus a flywheel to give continuous inertia would probably have been a worthwhile consideration. This should be considered if another machine similar to this would be designed in the future.

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I would like to express my feelings to this concept of mining. We are overdue in the industry for a machine such as this. It would not only produce a high tons per manshift, but also allow us to recover additional coal in a safe manner, that has forever in the past been left behind for posterity. The feasibility of one or two percent more coal being mined by this method surely has to be attractive to mining company officials. There is very little to be expensed to this operation compared to the return. I would hope some manufacturer would copy this program and design a working machine based on what we have learned here. I would like to express my disappointment in not being able to get this particular machine up to our anticipated tonnages, but the required changes were more than we could design into the machine on location at the mine.

Cordially,



William R. Opolka
Superintendent
Marissa Mine

WRO:vm

cc: W. Ewing
J. Bennett
R. Gothard
C. Bollier
L. Jack