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**The Development of a
Miner/Bolter System
USBM Contract HO242057
Modification No. Three**



Automated Continuous Miner Preliminary Design

by
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A. N. Baldwin

**United States
Department of the Interior
Bureau of Mines
USBM Contract Report HO242057**

June 1975



FMC Corporation
Advanced Products Division
Mining Equipment Operations
San Jose, California 95108

AUTOMATED
CONTINUOUS MINER
PRELIMINARY DESIGN
Final Report

Prepared for
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by
K. C. McMahon
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In Response to
Contract No. H0242057
Modification No. Three

June 1975

Prepared by
FMC Corporation
Advanced Products Division
Mining Equipment Operations
San Jose, California

FOREWORD

This report was prepared by FMC Corporation, Advanced Products Division, Mining Equipment Operations, San Jose, California under USBM Contract Number H0242057, Modification Number Three. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PMSRC, with Mr. Mike Mahaffey acting as the Technical Project Officer. Mr. George Honold was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period February 1975 to June 1975. This report was submitted by the authors on 27 June 1975.

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During the course of this preliminary design phase, FMC has received much valuable assistance from several individuals and organizations. We would like to extend our thanks and appreciation to Mr. Webster Anderson, Bureau of Mines Spokane Mining Research Center, Technical Project Officer for the Miner/Bolter program; Mr. Mike Mahaffey, Bureau of Mines Pittsburgh Mining Research Center, the Technical Project Officer for the Automated Continuous Miner portion of the Miner/Bolter program; and Messrs. Tedd Bodimer, Ed Warner and Ray Lehner of Joy Manufacturing Co.

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SECTION I

INTRODUCTION

This report is the result of the engineering efforts performed by the Mining Equipment Operations of FMC to develop methods of automating a continuous miner. This work was done as part of modification number three of the contract for the development of a miner/bolter system.

As the demand for energy places an ever-increasing pressure on the coal mining industry to produce more coal, methods for underground mining which will increase productivity with a concurrent increase in safety are being actively sought. Removing the machine operator from his station on the continuous miner and placing him at a safer location behind the machine while retaining his control functions via an umbilical cable or a radio link was an important first step. However, the problems of poor visibility, no control "feel", and the judgmental problems of controlling the sump distance and the shear limits have not been conducive to the productivity increase that is desired.

A necessary step in the evaluation of a safe and high productive continuous miner is the addition of a programmed cutting cycle coupled with an effective guidance system which will control the mining cycle while maintaining the proper heading. The purpose of this contract was to provide the first step to total automation of the entire mining cycle and provide hands-off control of the mining machine for a specific number of sump shear cycles. The controls shall continually maintain the sump depth and the shear limits as well as activating certain ancillary functions such as water spray, gathering head, conveyor, and loading boom in their proper sequence.

The summary section that follows will give the reader a preview or insight into the remainder of the report. A recommendation and conclusion section contains information about two recommended miner guidance systems, the continuous miner selected for FMC's automation efforts, and interim test programs that should be run prior to commitment to a complete automated miner program. The two guidance systems include a laser light beam guidance system and an inertial guidance system. A detailed technical discussion of the laser system is found in section IV, System Selected, and section 5.1 contains technical data on an inertial guidance system. The balance of section V reviews all of the concepts considered for use on an automated continuous miner. Productivity, cost estimates, and future program plans complete the report. An appendix for miscellaneous calculations and other technical information has been included.

SECTION II

SUMMARY

2.1 PROGRAM OBJECTIVES

The objective of this program was to determine the feasibility and the modifications required to a continuous miner in order to accomplish the following:

- To automate a programmed face cutting cycle
- To develop an entry alignment control system
- To develop a cycle status monitoring system

These objectives have been met. A microprocessor can be effectively used to process various electronic sensor inputs, operator inputs and preprogrammed inputs to efficiently control the continuous mining machine's entry alignment, all cutting cycle functions, and to notify the remote operator of real time status. A laser beam is used to establish a reference plane for the heading alignment sensors and machine yaw and height sensors. An IR distance measuring unit provides for sump travel control and total distance mined information. An electronic microprocessor provides for all memory and program commands.

2.2 MINING MACHINE SELECTION

For the purpose of this study, a remote umbilical controlled Joy 12CM continuous miner was selected as the machine for converting to automation. This machine was chosen after discussions with Bureau personnel and Joy engineering personnel. The basis for this decision was:

- FMC Mining Equipment Operations is familiar with the remote controlled 12CM miner, and extensively modified a 12CM as part of the ISMS program.
- The umbilical remote control system could be converted virtually as is to an automatic system.
- The automatic system could be installed in a kit form with very little physical modification of the miners.
- Joy miners are widely used and accepted in underground mining.

2.3 SYSTEM DEFINITION

The design goals and system control requirements were established to meet the performance requirements stated in the contract. A functional flow chart, Figure 4-5, was developed which describes all functions and their sequence of operation. This defines the baseline from which the microprocessor programs required to automate and control the machine functions can be developed. Once this baseline was defined, guidance and control systems were generated which would meet the established requirements.

2.4 SYSTEM SELECTION

2.4.1 System Studies

An indepth study on various guidance systems and control methods was conducted to obtain as many alternative systems as possible. The ideas considered ranged from: (a) implanting sound or radiation sources within the coal bed to permit onboard electronic equipment to triangulate their location from those sources; to (b) cutting a slot in the floor behind the cutter head and using a "keel" on the miner to guide in the slot. Ideas of electronic guidance, mechanical guidance, acoustical guidance, light source guidance, were all discussed for their good merits and possible combination with other systems. From these studies, two systems emerged as possible candidates as meeting the program goals and requirements: A Laser System and an Inertial Guidance System.

2.4.2 Laser System

The advantages of using a laser system include its current usage and acceptance underground for aligning haulage conveyors and for mine surveying, its continued effective use for manual guidance if the electronic processor fails, its ideal application for controlling a miner in shortwall mining systems, and its relatively inexpensive initial cost and potentially high rate of return (section 7.0). A laser system does have certain drawbacks. These include: marginal use in seams of 5 to 6 feet and questionable use in seams lower than 5 feet; the laser beam may be dispersed by face dust and water spray, and may be distorted by heat raising from the miner. Any of these conditions may give erroneous signals to the processor.

2.4.3 Inertial System

The advantages of using inertial guidance systems include: it is not affected by seam height or equipment outby the miner; it can be effectively used in low coal applications; all required electronic equipment is located on the miner, and it can provide

inputs to surface facilities for total mine planning and control. The inertial system disadvantages include: this system has not yet been applied to underground operations, it is relatively expensive (\$300,000 initial cost), it takes a relatively long time for initial system start up, and may be very difficult to maintain underground.

2.4.4 Selection

Weighing the advantages and problems of each system led to the conclusions and recommendation that laser development is feasible for today's application in certain seam heights and should be carried on through a component test phase to evaluate its application to face equipment. Inertial guidance systems show real promise for future use and further studies on underground applications should also be conducted.

2.5 MODIFICATIONS TO THE MINER

Adapting either systems to the remote-controlled Joy 12CM would not involve major modifications. Both systems involve new electronic enclosures which would be mounted on the miner and the replacement of the remote control box with the automatic control/status box. A hydraulic valve will be added to the shear boom cylinder circuits to reduce the mass effects of the cutter head when raised or lowered. Additional sensors and their mounting brackets and protective armor would be required for the laser system.

2.6 PRODUCTION AND ECONOMICS

Adding programmed automation to a remote controlled miner does not drastically affect its direct productivity capabilities. The calculations and assumptions used in this report indicate a productivity increase of 6.6 percent and an economic payback in 35 weeks of initial cost (including lost coal due to miner being down during modification).

Indirect effect of automation includes hands-off operation, thus permitting the operator to be more aware of roof and rib conditions, haulage systems and general face operations. It may also free the operator to assist in ventilation and trailing cable handling. The programmed sequence can be adjusted to match the shuttle car haulage capacities thus more efficient utilization of the face equipment.

In a shortwall application, the laser system can be processed to continue to the end of the panel and then back tram using the beam as reference. The operator, while monitoring the progress

of the miner, can be used to advance the extensions on the roof supports thereby possibly reducing the face personnel requirement by one.

These indirect effects of automation further indicate this technology should be advanced to underground demonstrations.

2.7 PROGRAM CONTINUATION

Since programmed automated systems will be new to the underground coal mining environment, section III of this report recommends a series of tests and engineering investigative steps to be followed before a large commitment to any complete automatic control system is considered. This will insure that subsystems, such as laser light sensors, microprocessors, and electronic distance measuring equipment will perform reliably in an underground environment. As outlined in section VIII, these component tests would be planned and costed during Phase II and then conducted during a Phase III program. The following is a brief summary of some of these anticipated interim test and study programs:

- An underground test of the proposed laser light beam system to determine the feasibility of having a light sensing target mounted on the miner near the cutter boom pivot point (to check effects of dust, heat, and water spray), to develop a quick-mount/disconnect bracket for attaching the laser light source to the roof of the mine outby the miner and methods and techniques for rapidly moving the laser light source and setting it up in a new location.
- An onboard test of a microprocessor and distance measuring device to determine their reliability in the underground environment.
- A study and test of some new innovative methods of determining the coal to roof interface.
- A productivity study of a "face-to-tipple" mining system that would justify the use of the more sophisticated inertial guidance system.
- A scale model of a continuous miner to test and evaluate on-board guidance systems for controllability and response.

SECTION III

RECOMMENDATIONS AND CONCLUSIONS

FMC recommends two courses of action for the Bureau to follow for the automated/remote controlled continuous miner program: a short range plan with a laser guided miner that has the immediate potential to increase productivity, and a long range plan utilizing an inertial guidance system for a machine that would be developed to match new innovative support equipment in future mine plans.

3.1 LASER GUIDED MINER (SHORT RANGE PLAN)

The development of a laser-guided miner is recommended as a near term goal for a rapid impact on the mining industry because it has the potential of immediate increases in productivity, it can be used to match existing support equipment such as haulage, roof bolters, ventilation, and rock dusting equipment and its cost/benefit ratio is very attractive to the mine operator.

This program would use a laser beam generator supported from the mine roof as the reference for machine guidance. Quick-mount or dismount brackets would be designed so that the laser unit could rapidly be advanced in the entry with minimum time and effort. This mount would be bolted or pinned to the mine roof and have provisions for adjusting or aiming the laser light beam down the entry. In addition, a 90° rotational adjustment should be provided to assure right angle and parallel entries and cross cuts are developed. Prior to moving the operating laser source, a new mounting bracket would be bolted to the roof well ahead in the entry. Two cross hair reference targets would be temporarily attached to the new bracket so the cross hairs could be lined up with the red laser reference beam. After adjustment, the reference cross hair assembly is replaced with the laser light source unit that was used to adjust the cross hairs. This leap-frog advancement of the laser will eliminate the need for many survey crew set ups and will make it possible for the section foreman or other qualified section personnel to perform most of the laser source moves. The adjustable portion of the mounting bracket would be reuseable and detachable from a base plate that is permanently bolted or pinned to the roof.

A sensor array or target, located on the miner, would pick up the laser beam and a microprocessor or minicomputer would read the target information and determine the necessary corrections to the miner heading or cutter boom elevation. The microprocessor could also be adjusted to approximately follow a coal seam with slight undulations. The miner operator would visually

determine the changing slope of the seam and, by hand control at his remote station, set the microprocessor to either lower or raise the cutter from the level of the preceding sump. If larger seam undulations occurred, the laser source would have to be moved forward and readjusted to follow the new slope.

The laser system will function with, and show some productivity increase when used with shuttle car haulage, but is best suited for continuous haulage provided good roof is present and lifts of 30 or 40 feet can be made without installing temporary or permanent roof support. However, this is not practical in many mines. In these poorer roof situations various alternatives would have to be considered: shorter lifts and more place changes; the automated miner would have to be equipped with on-board roof bolters that could bolt the roof as coal cutting was taking place (a miner/bolter); or, a new automatic remotely controlled, compact bolter would have to be developed. This bolter would be smaller than present day bolters and would bolt the roof around the miner while the bolter and miner operators stood back under permanently supported roof. The mine plan would be developed to allow the bolter to install bolts beside and around the working miner.

The laser-guided automatic system would provide the research and development data that could quickly be adopted by the mining industry for increases in productivity and efficient mine planning. Since there is a Bureau of Mines approved laser immediately available, this system could be designed for continuous miner installation and be working underground with very short lead times. The laser system can be manufactured in retrofit kit form and installed on a remote controlled Joy 12CM during a rebuild period, or if required, installed underground.

The laser-guided automation system is recommended for use in high coal seams, 6 feet or greater and for shortwall operations. Low coal seams do not provide enough clearance between the top of the miner and the roof for mounting the 14-inch high laser sensor target. Shuttle cars and personnel working in low coal seams would be continually obstructing laser light transmission.

The application of a laser automation system would be an excellent choice for the control of a continuous miner being utilized for shortwall mining. A shortwall mining system will allow the laser and sensor target to be mounted off to the side of the miner closest to the roof support chocks. In this position there would be little or no shuttle car or personnel interference problems. The laser source could be permanently mounted on the end roof support chock and provide excellent miner guidance for panels as long as 150 to 200 feet. The operator could

remotely monitor and control the miner from under the roof support chocks, position himself for an improved view of the drum cutter, and advance the chocks during periods when the miner was in the complete automatic mode. This operation could possibly reduce the section crew by one man. Upon completion of a panel the miner would be automatically laser guided back along the face into position to start another cut. An automatic miner power cable handling device would be used to payout and retract the trailing cable.

As an ideal test for a laser-guided system, a shortwall operation should be utilized, thus effectively comparing the programmable and automatic features of this system without the delaying effects of roof bolting and ventilation changes.

3.2 INERTIAL GUIDANCE SYSTEM (LONG RANGE PLAN)

The second guidance plan would be a longer range program with longer engineering design and development lead times. It would be directed toward the eventual complete automation of all the mine equipment from the "face to the tipple", and be combined with innovative or new mining plans. The miner designed for this effort would have an onboard inertial guidance system utilizing gyros and acceleration sensors to effectively guide the miner and report to the remote operator the status of the mining operation. The estimated cost of this inertial guidance system would be approximately as much as or greater than the cost of the basic miner itself but may be offset by reduced mine section labor and increased total system productivity of the "face to the tipple" mine plan.

An inertial system could be designed for a miner as the first step to complete mine automation, but there would be no immediate increase in production beyond the yield of a laser-guided system. However this inertial system design does have promise in low coal operations and a parallel effort with the laser system should be undertaken to further establish criteria for underground inertial systems.

3.3 INTERIM TEST PROGRAMS

Since both the laser beam and the inertial guidance systems will introduce new electronic equipment to the harsh environment of underground coal mining, FMC recommends some interim engineering design and test programs be conducted before a full commitment to automated systems is established. These preliminary programs would insure that proven components and spares would be available for production, and that they would reliably function when a continuous miner is modified for demonstration. These test efforts would include the following:

- A. A laser study and underground test program would develop data on the use of a laser at the coal face to control face equipment. Measurements of light intensity in relation to dust conditions would be made. A roof quick-mounting plate would be developed to allow fast accurate relocation of the laser beam source and power supply. The results of this test would determine the effects and the practicality of a laser sensing target located on the miner near the cutter boom pivot point. A procedure would also be developed for the section foreman to set up and rapidly relocate the laser source and power supply during place changes.
- B. A second underground test should be run with a microprocessor and the distance measuring system mounted on a working continuous miner. The microprocessor would be programmed to simulate various functions and to read the output of the distance measuring system. The simulated performance data could be recorded with remote recording equipment located beyond the last open crosscut. The results of this test would determine the reliability and feasibility of this electronic equipment surviving in the harsh underground environment. It would also check the measuring accuracy of the distance sensing equipment.
- C. A study of innovative methods of sensing coal to roof or coal to floor interfaces, is a project that is absolutely essential for "face-to-tipple" automated mining. One system that may prove successful would be to send probes into the interface, just exposed by mining, and check the electrical conductivity of the material between the probes with a low power, permissible, electrical source, or drill short core samples from interface and analyse the conductivity of the core after it is retracted from the roof or floor hole. Since carbon content of coal is a better conductor of electricity than shale, sandstone, or clay, it may be possible to determine the coal interface with the roof or floor by this method.

Other things that could be tried are:

- Measure the forces and penetration rate of a drill as it is forced into the roof or floor. Soft coal layers versus harder shale strata could be checked using this method. Using a flexible drill assembly, this testing could be combined with roof supports checks and a total picture of roof coal interface and supporting roof strata would be available for the mine industrial engineer. The timing of these checks could correspond with the shuttle car change-out time.

- The depth and rate of penetration of a hydraulically driven, constant force, piston/probe into the exposed interface may determine different layers by their relative hardness and resistance.

D. FMC has submitted a proposal to build a scale model of a continuous miner, see figure 3-1. After this model is completed it would be used to conduct laboratory tests of many different programmed continuous miner control systems (figure 3-2).

By using this test model, many tests and adjustments can be made in a controlled laboratory environment. This test bed would allow the development of automatic control systems in stages, checking and proving out one item before proceeding to the next, thus isolating potential problems and identifying engineering solutions. Finalizing development decisions above ground will save many times over the cost of the test bed and also accelerate the various systems being developed.

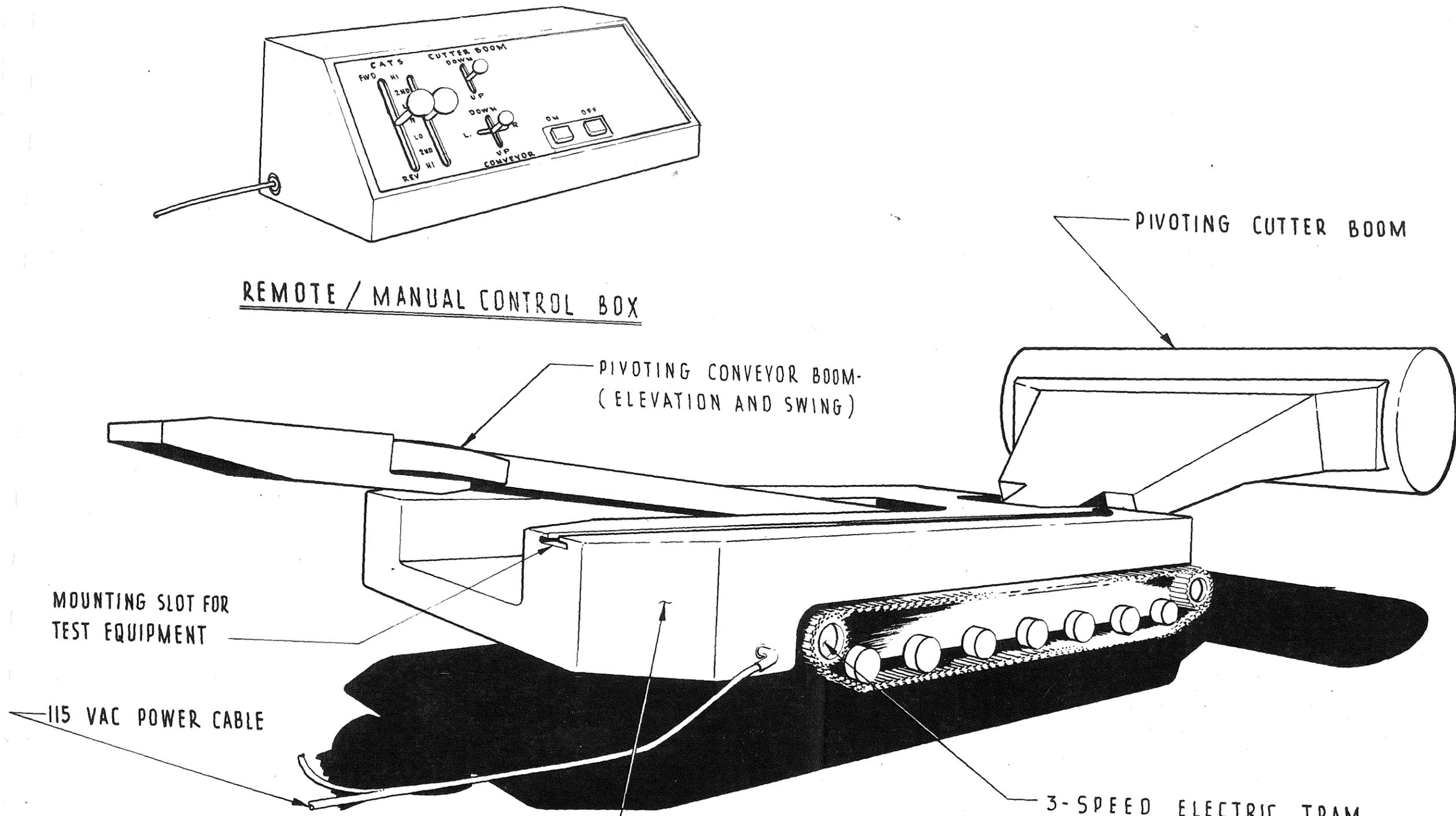
An additional benefit of the test bed is its ability to demonstrate concepts conveniently to visitors and vendors and to provide visibility at all levels of management, both within FMC and the Bureau.

As methods of controls and inter-relations between controls develop, complex systems can be reduced to a group of elements which can then be evaluated individually. Decisions whether or not to proceed with a particular configuration are fortified with visible, demonstrable data.

3-4. THE RELIABILITY OF AN AUTOMATED CONTINUOUS MINER

Since electronic equipment such as microprocessors and infrared distance detectors have not been used before on underground face equipment, there is no data available on their life expectancy in this environment. This electronic equipment would have to be installed on a continuous miner and tried underground before any conclusions could be made. The retrofit laser guidance system described in this report could be rapidly installed on any existing remote/manual controlled miner and be ready quickly for actual automation system testing.

Automating a continuous miner should not appreciably affect the built in reliability of the basic machine systems because our add-on automation kit will not alter the already proven systems of the Joy 12CM remote controlled miner. Reliability may be improved somewhat due to the fact that the cutting cycle will no longer be subjected to possible operator error or improper judgment.



REMOTE / MANUAL CONTROL BOX

PIVOTING CUTTER BOOM

PIVOTING CONVEYOR BOOM-
(ELEVATION AND SWING)

MOUNTING SLOT FOR
TEST EQUIPMENT

115 VAC POWER CABLE

3-SPEED ELECTRIC TRAM

SPACE ALLOCATED FOR FUTURE AUTOMATIC
PROGRAMMABLE MACHINE CONTROLS:

- ALIGNMENT CONTROLS
- CUTTING HEIGHT CONTROLS
- SUMPING DISTANCE CONTROLS

Figure 3-1. Quarter Scale Powered Test Bed
(Continuous Miner)

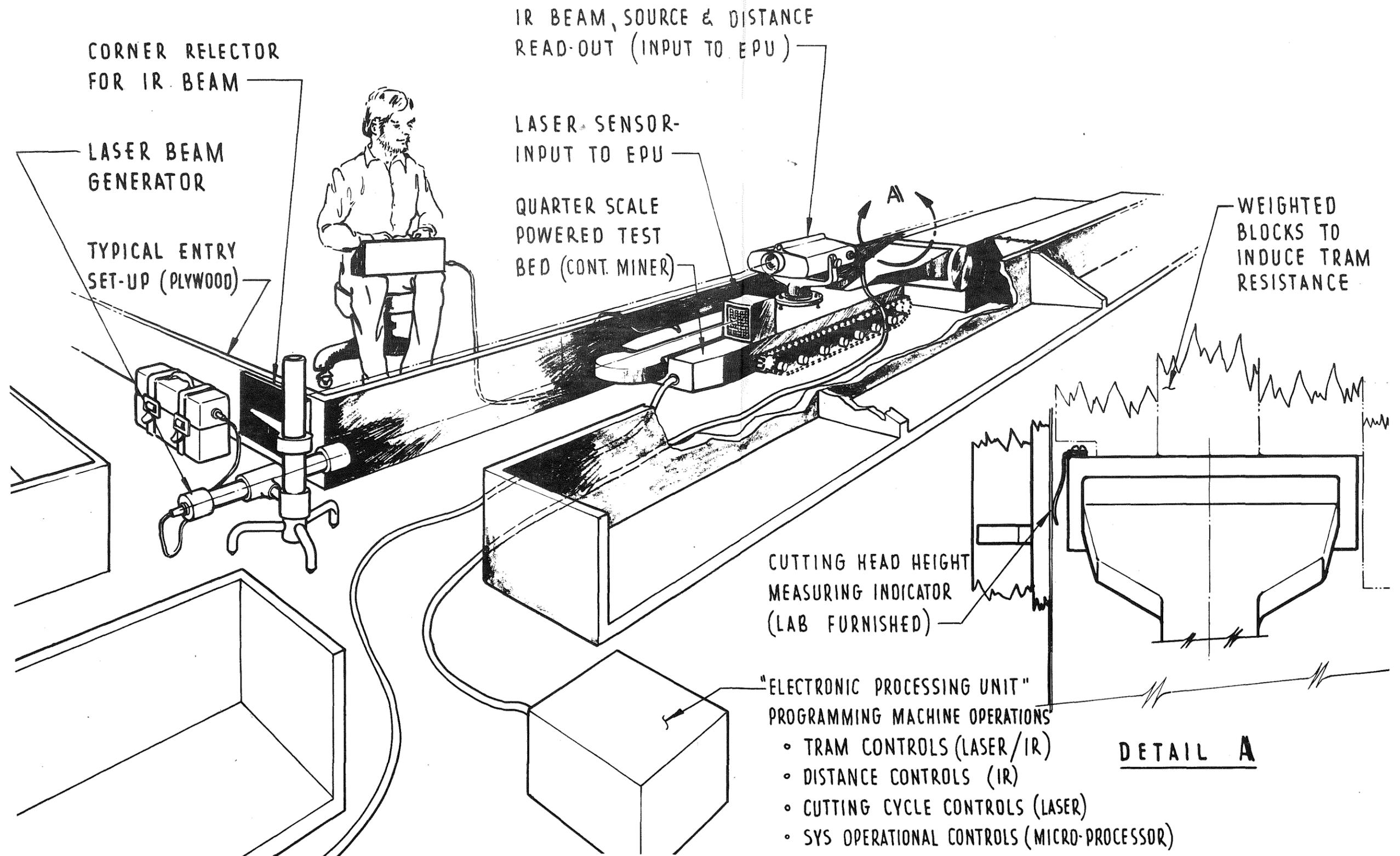


Figure 3-2. Typical Test Bed Arrangement

SECTION IV

SYSTEM SELECTED

4.1 CONTINUOUS MINER

The primary task in FMC's approach to automating a continuous miner was to choose a miner being presently produced that would best meet the contract objectives without extensive physical modification and replacement of parts. A miner that could be quickly connected to a "black-box" control circuit would be the ideal choice. Continuous miners that are remotely controlled through an umbilical cable come close to meeting the above criteria. Since FMC Mining Equipment Operations personnel are familiar with the Joy 12CM remote controlled miner used in the Inherently Safe Mining System (ISMS) program, and Joy miners are in wide use in the coal industry, FMC selected a remotely controlled Joy 12CM to convert to an automatically controlled miner. Joy Manufacturing Company confirmed that this was the best Joy miner to automate and agreed to supply FMC with a list of mines that have purchased 12CM's and any engineering information needed.

The hardware to convert the 12CM to automatic control would be in a kit form designed for installation underground. This would make it possible to convert any available remote controlled 12CM to a new automated unit.

4.2 GUIDANCE SYSTEM

The guidance system selected uses a laser beam and is depicted on the continuous miner in figures 4-1 and 4-2. The major items of the automated miner guidance system are the laser source, the laser sensor target, the infrared (electronic) distance meter, the infrared retro-reflector target, the electronic processor, and the remote control panel.

The selected guidance system utilizes a laser source located behind the continuous miner, to provide an accurate and visible reference. The red pencil beam of light is aligned parallel to the desired roof and floor planes and in the desired lateral direction to provide both lateral and roof and floor reference. The laser can operate either horizontally or at a desired slope, up or down, as normally found in mining.

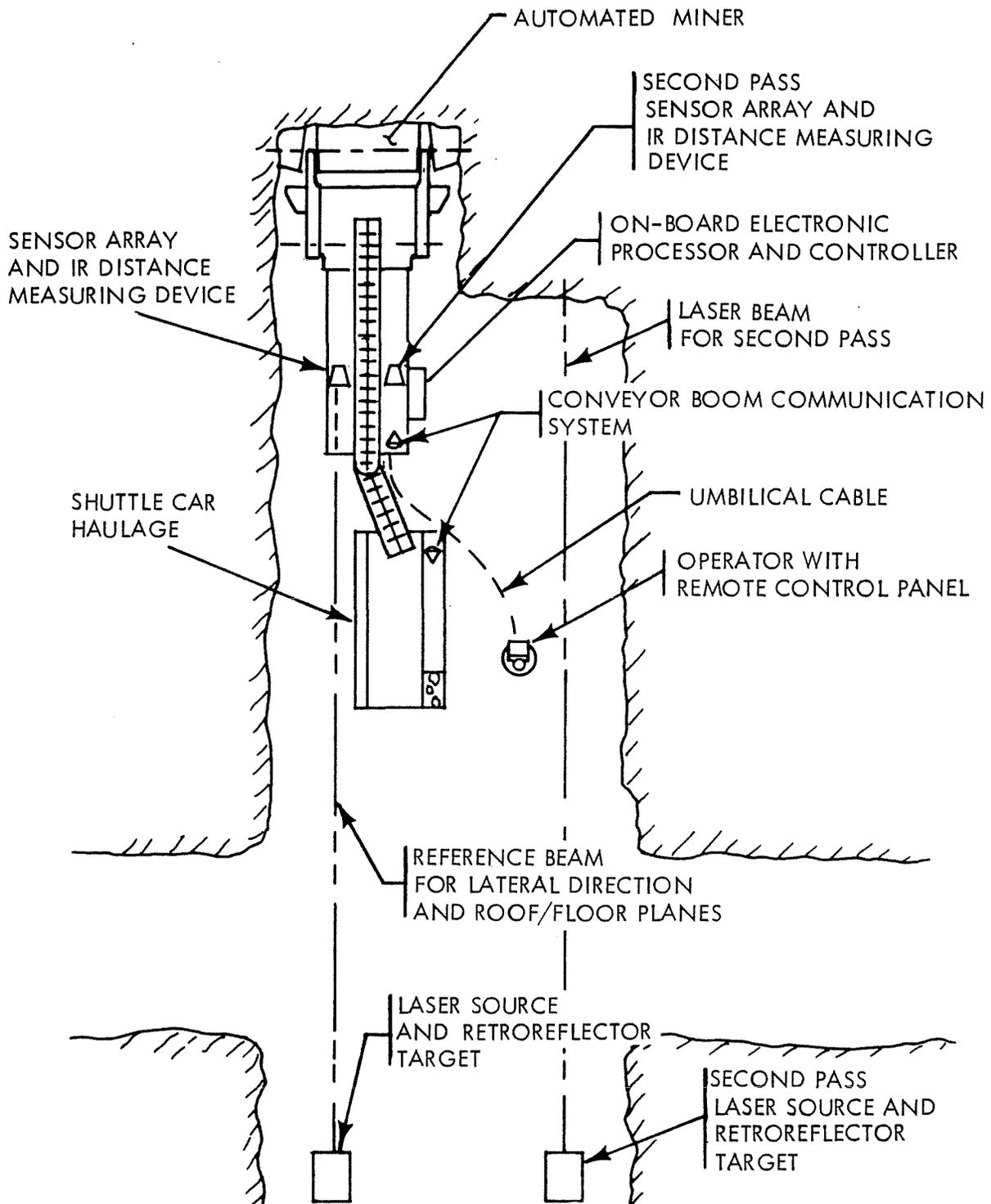


Figure 4-1. Automated Miner Guidance System, General Arrangement

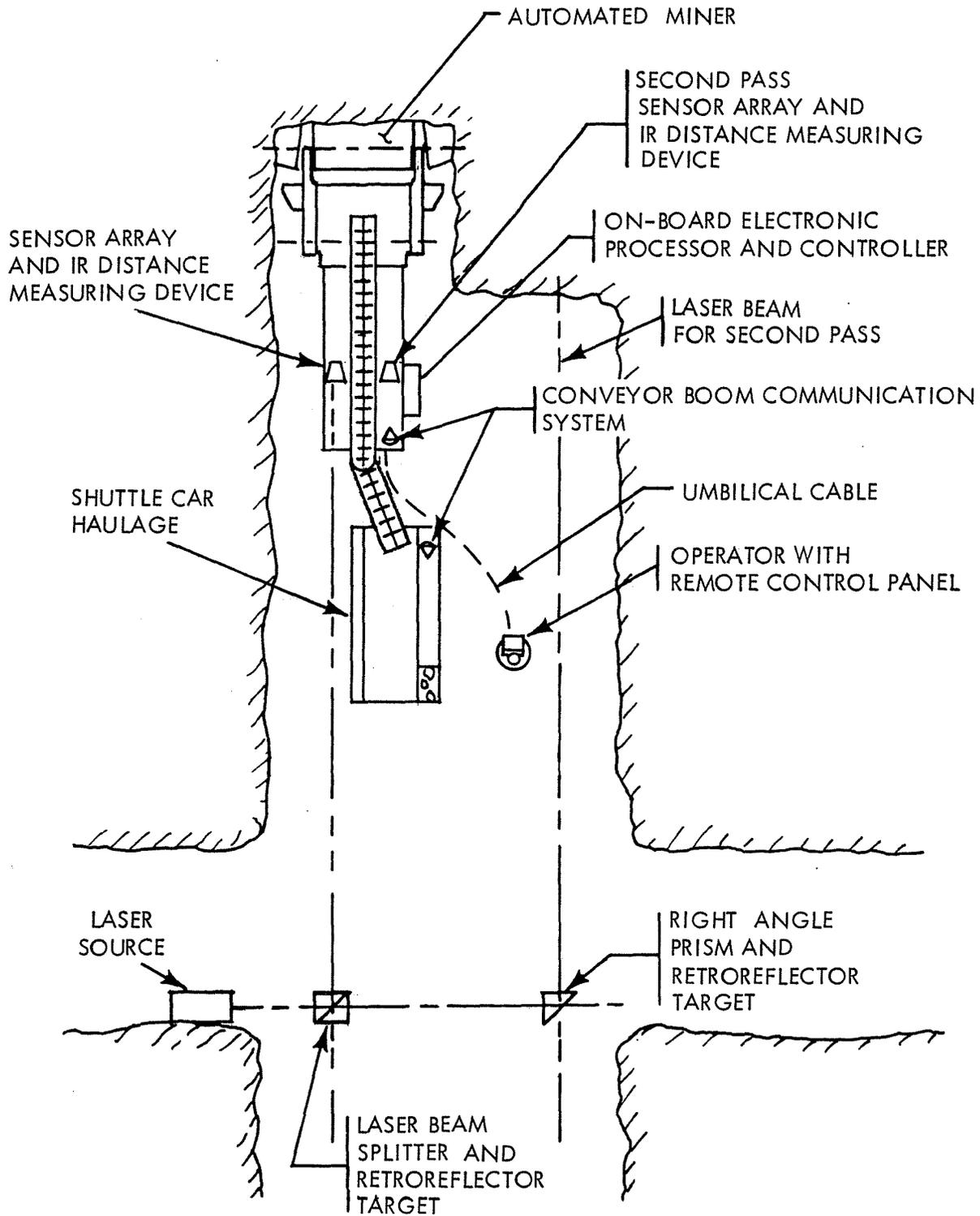


Figure 4-2. Automated Miner Guidance System, Alternate Laser Arrangement

Using a Joy 12CM-10B continuous miner in a 6-foot seam, the beam is located approximately 26 inches from the left rib and 54 inches above the floor. This location was determined with consideration to the miner configuration and the sensor array (figure 4-3). In single-pass mining, one laser beam will suffice, but for two-pass mining, two beams would be used to facilitate repositioning of the miner. The two beams can be supplied from one laser using two beam splitters or from two separate laser sources.

When interruption of the laser occurs, the electronic processor will retain the last signal in memory and continue operation on that basis for a fixed time delay. This delay time would be a function of where in the mining cycle the interruption occurred. The back-tramming function would be immediately disabled whenever the beam is lost. If the beam is still being interrupted after the time delay, the miner operators control panel informs him that the beam has been lost. Anytime the beam is interrupted, a flashing light on the miner indicates the interruption. The light will be of sufficient intensity to inform the section crew within the vicinity so the cause of the interruption can be corrected quickly. For personnel safety, when the beam is restored to the sensors, the miner will not continue on the automatic cycle. The miner operator must initiate the continuation of the automatic mining cycle by pressing the continue switch.

With the laser providing the reference, a laser sensor array, 12 inches by 12 inches, mounted on the miner detects the lateral deviation, lateral heading, and vertical displacement. The laser sensor array provides the lateral position and heading information to the electronic processor which initiates the necessary commands to the tram motors for the proper corrections. This will maintain the machine on the desired lateral direction. For safety of personnel and equipment during the automatic cycle, the miner is restricted in its turning capability and not allowed to accomplish pivot turns (i.e. one track forward, other track reverse). Turns can only be done with one track held, and the other at low speed only. A proportional tram sensing and control system is also incorporated into the design, that is, as the detection of the laser beam strays further from the desired lateral displacement and heading, the greater the correction commands to the tram circuits.

The vertical displacement signal from the sensor array, combined with the miner pitch orientation, the shear boom angle sensor, and the miner geometric configuration, determines the exact

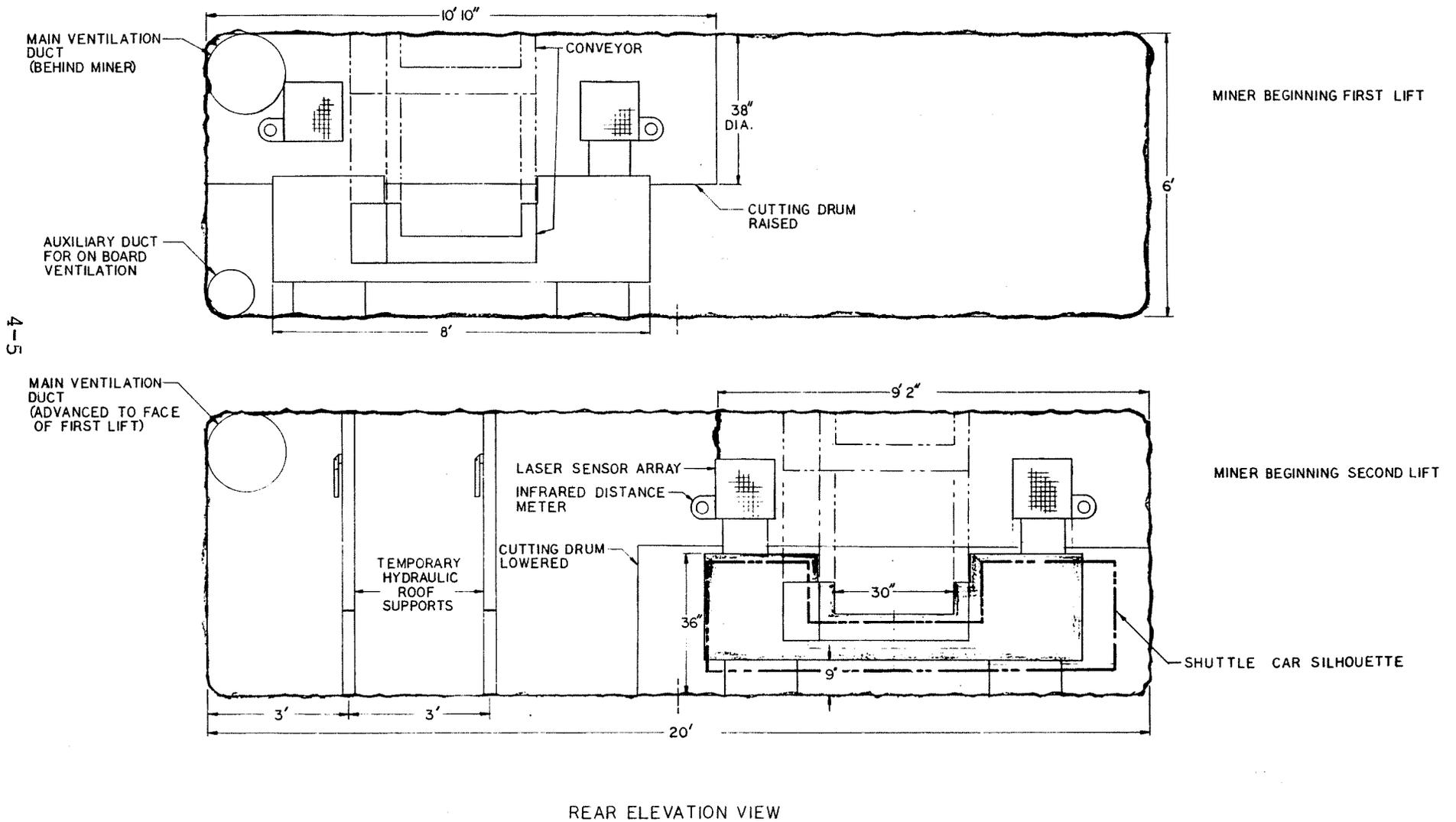


Figure 4-3. Automated Miner in Two-Pass Entry (1 of 2)

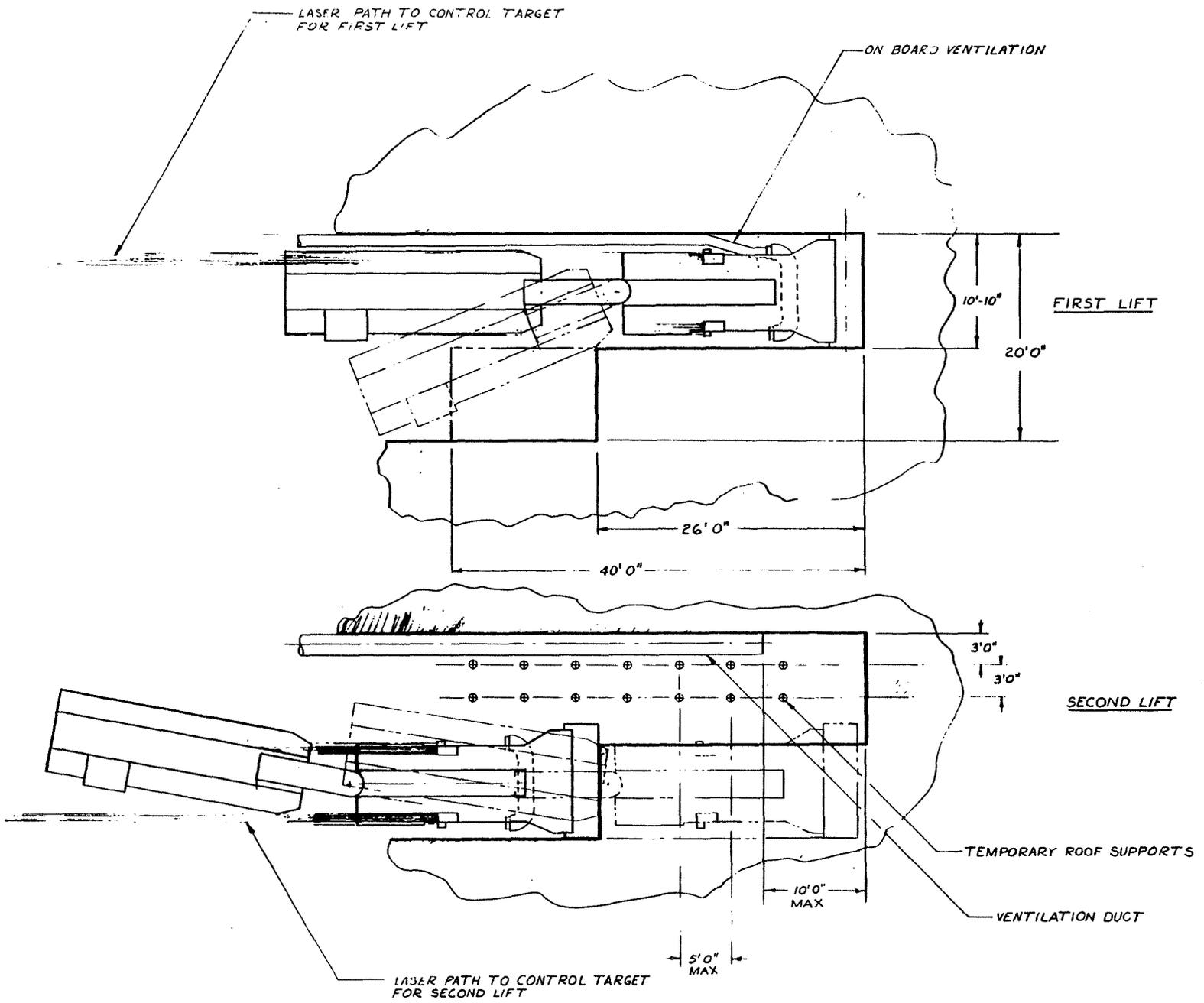


Figure 4-3. Automated Miner in Two-Pass Entry (2 of 2)

position of the cutter above and below the reference laser beam. These positions, above and below the beam, corresponds to the roof and floor planes, respectively. The seam height and floor limits are selected by the miner operator at the remote control panel and dialed into the "brain". At the remote control panel, the operator is provided with the actual seam height and floor limits of the previous cycle and the real time position of the shear boom indicated by lights (figure 4-4).

To control tramming during sump-in, cusp removal, and clean-up during alternate cycles, machine advancement distance must be known. A modified electronic distance meter mounted on the miner is pointed outby towards a retro-reflector target located at the same location as the laser reference source. The distance meter is capable of reading to within 0.1 of a foot. Although the tracks can provide distance travelled information, the measurement of the tracks is not utilized due to potential excessive track slippage. Use of the electronic distance meter will provide the necessary accuracy for monitoring and controlling the sump depth and total distance travelled by the miner.

4.3 AUTOMATED MINING SEQUENCE

The laser light source is set up by bringing the miner up to the face just as it would be to start the first pass. The cutter boom would be near the floor and as close to the face as possible. The visible laser reference beam must be set-up behind the miner in the desired heading called for by the mining plan. The beam must be properly located with respect to the rib and roof (or floor) to illuminate the laser sensor array as near as possible to its center. The laser source should be set up away from the face at a convenient area where the possibility of disturbance and interference with haulage equipment is minimal. The beam must be within the 12-inch square sensor array for the automatic cycle to begin. For this application, the range of the reference was limited to 400 feet but the laser can be operated to much greater distances.

The miner is started on its automated cycle when the operator switches to AUTO mode and pushes the START button on the remote control panel. The automatic control system, including the guidance system and the electronic processor, will proceed through its programmed ten cycles. The sequence of this operation is shown in figure 4-5 and is further explained in the following paragraphs.

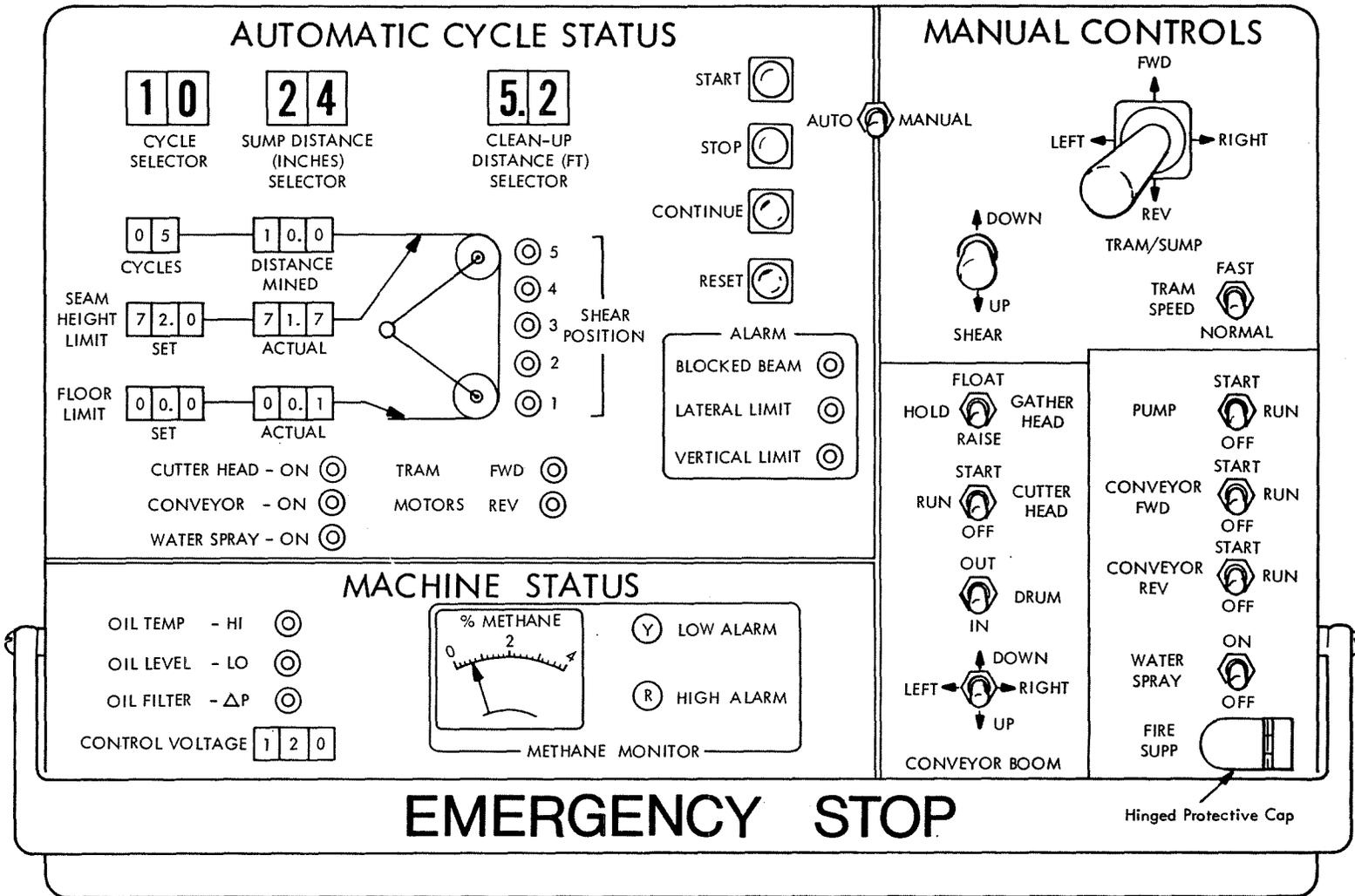


Figure 4-4. Remote Automated Control Panel

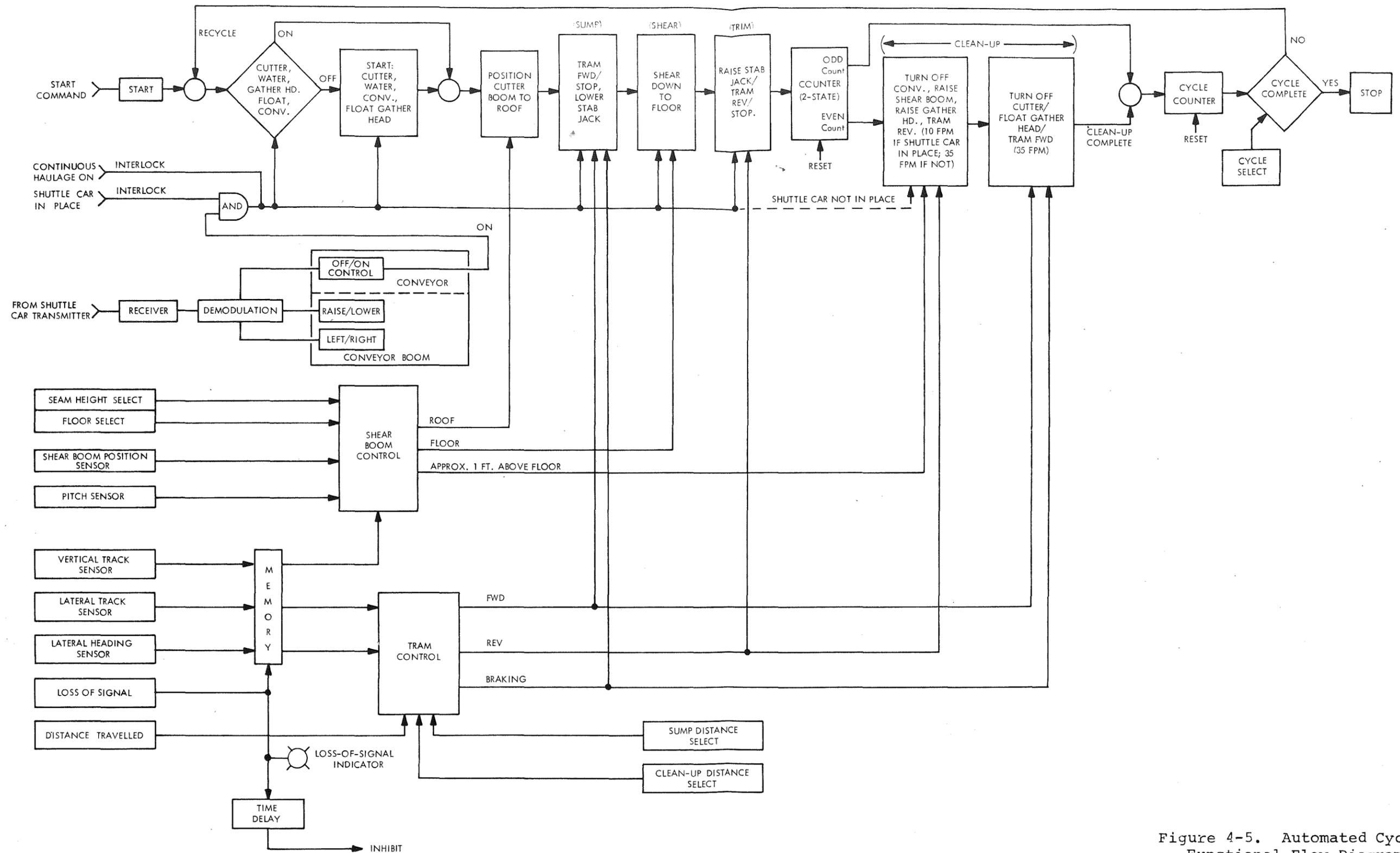


Figure 4-5. Automated Cycle Functional Flow Diagram

- The total cycle count is compared to that selected. If less than selected, the miner continues onto another cycle. When the count equals the selected number, the miner will come to a stop and the operation is complete. The number of cycles is selectable by the miner operator at the remote control panel and ranges from 1 to 99.

The remaining blocks shown in figure 4-5 depict the shear boom control processor, the tram control processor, and inputs from the guidance system, the remote control panel, the conveyor interlock, and the conveyor boom control.

In continuing program design work, each of these control sequences will be evaluated to determine the need for redundant or safety control system designs. If it is determined that a malfunction of any individual sequence could cause personnel injury to the face crew or damage part of the continuous miner, this function will be provided with a redundant control safety circuit. These additional safety systems will be in one or more of the following forms.

- A timer device that checks a sequence time. For instance if the back tramming functions exceeds a preset maximum limit the machine tram power will be cut off and the operator informed.
- Redundant input signals to the system might be provided. For example, if two shear boom angle detectors were designed into the shear control and one of them failed, the shear boom power would immediately be cut off.
- A second redundant program could be written into the microprocessor. The sole function of the redundant program would be to make confirming checks on the main program. This would insure important time and space targets were met.

4.4 LASER AND SENSOR ASSEMBLY

The laser source is mounted on the mine roof and provides a narrow high intensity light beam. The sensor assembly is located on the miner and senses the lateral position, vertical position, and lateral heading of the continuous miner with respect to this beam. This information is transmitted to the microprocessor in digital form for processing.

4.4.1 Laser

The laser was selected for this application because of its unique ability to provide a narrow, highly collimated beam of light. This permits the sensor assembly to locate the center of the beam accurately.

The laser has the additional advantage of being monochromatic, or radiating at a single precise wavelength. A narrow band-pass filter in the sensor assembly masks out all other extraneous light sources of other wavelengths. This results in a high signal to background noise (radiation) ratio.

The helium neon (HeNe) laser was selected for this application primarily because of availability. A variety of different types of lasers are currently available, but the HeNe laser is by far the most highly developed and commercially available laser.

One HeNe laser (LOADSTARTM) has been approved by the Bureau of Mines and is permissible for use underground. At least one other unit (Spectra Physics mining laser) will be submitted for approval in the near future. Specifications for these lasers are given below.

| | Loadstar TM (Laser alignment) | Spectra Physics (Mining lasers) |
|---------------|---|---|
| Wavelength | 6328 A ^o (red) | 6328 A ^o (red) |
| Beam power | 2.0 mw | 2.0 mw |
| Beam diameter | 7/16 in. (at laser) 3/4 in. (at 500 ft) | 1-1/4 in. (approx. constant to 1000 ft) |
| Power source | 12 watts (battery) | Nicad battery gives 8-10 hrs operation |
| Weight | | |
| Laser | 12 lbs | |
| Battery | 18 lbs | |
| Total Weight | 30 lbs | 25 lbs (including battery) |

4.4.1.1 Requirement

The laser beam should be slightly over .707 inch diameter (between 50 and 400 ft), and should not diverge excessively. The beam must be larger than 0.707 inch diameter so that it will always be incident on at least one positional sensor (the positional sensors are located on ½" centers). The beam should not be made excessively large, because the power per unit area in the beam (mw/cm²) is inversely related to the square of the beam radius. Ideally, the beam should converge slightly from the laser. This would result in an increase (with increasing range) in power per unit area due to convergence, thus offsetting losses resulting from attenuation and scattering.

4.4.1.2 Modification

Both of the laser systems described above would require modification to get the proper beam characteristics for automatic guidance of a continuous miner. The modification would be to the optics in front of the laser and should have no impact on Bureau of Mines approval.

Typically, HeNe lasers radiate a beam one millimeter (mm) in diameter with a divergence of one milliradian (mr). Without optics this mm beam would grow to 4.8 inches at 400 ft. For a 2.0 mw laser the power density would vary from 254 mc/cm² at the laser to 0.017 mw/cm².

Adding a telescope in front of the laser results in increasing the beam diameter and decreasing the divergency. If properly selected, this results in a beam that is larger at the laser but smaller at 400 ft. For example, if an 18-power telescope is added to the typical HeNe laser, the beam would be 18.83 mm at 50 ft, and 24.6 mm at 400 ft. That is,

$$\begin{aligned}\text{Beam divergency} &= 1.0 \text{ mr} \div 18 \\ &= 5.55 \times 10^{-5} \text{ radians}\end{aligned}$$

$$\begin{aligned}\text{Beam dia at laser} &= 1 \text{ mm} \times 18 \\ &= 18 \text{ mm}\end{aligned}$$

$$\begin{aligned}\text{Beam dia at 50 ft} &= 18 \text{ mm} + 2 \times \tan \left\{ (5.55 \times 10^{-5}) \div 2 \right\} \times 50 \text{ ft} \times \frac{300 \text{ mm}}{1 \text{ ft}} \\ &= 18 \text{ mm} + .83 \text{ mm} \\ &= 18.83 \text{ mm} (0.75")\end{aligned}$$

$$\begin{aligned}\text{Beam dia at 400 ft} &= 18 \text{ mm} + 2 \times \tan \left\{ (5.55 \times 10^{-5}) \div 2 \right\} \times 400 \text{ ft} \times \frac{300 \text{ mm}}{1 \text{ ft}} \\ &= 18 \text{ mm} + 6.6 \text{ mm} \\ &= 24.6 \text{ mm} (0.98 \text{ inch})\end{aligned}$$

The resulting power densities will be 0.70 mw/cm² at 50 ft, and 0.42 mw/cm² at 400 ft.

$$\begin{aligned} \text{i.e. Power at 50 ft} &= 2.0 \text{ mw} \div \{(1.9 \div 2)^2 \times \pi\} \text{ cm}^2 \\ &= 0.70 \text{ mw/cm}^2 \end{aligned}$$

$$\begin{aligned} \text{Power at 400 ft} &= 2.0 \text{ mw} \div \{(2.5 \div 2)^2 \times \pi\} \text{ cm}^2 \\ &= 0.41 \text{ mw/cm}^2 \end{aligned}$$

A converging beam can be attained by adding a positive lens to the magnified beam. The beam, by geometrical optics, will converge to a point in the focal plane of the lens. After passing through the point of convergence it will diverge. If the lens is added at the laser, and if it has a focal length greater than 400 ft, then the beam should converge throughout the operational range of the automated continuous miner.

Careful analyses are required, however, since diffraction effects enter the picture. The beam is focused into an airy disc rather than a point. The airy disc can be calculated from the following equation:

$$\text{Airy disc (AD)} = 0.4632 \times (\text{FD/BD}),$$

Where = FD = Distance from laser to focal point (in feet)

BD = Beam diameter (in mm)

and AD is in mm

If the system discussed above (18-power telescope) is focused at 400 feet, the diameter of the disc will be 10.3 mm and the beam will converge; that is,

$$\begin{aligned} \text{AD} &= 0.4632 \times (400/18) \\ &= 10.3 \text{ mm} \end{aligned}$$

The airy disc however, will contain only 84% of the energy in the beam. The remaining energy will be in concentric fringes around the disc. Detailed information on the laser and some experimentation will be required to get the optimum beam characteristics.

4.4.2 Sensor Assembly

The sensor assembly measures the position (lateral and vertical) and heading of the automated continuous miner with respect to the laser beam. The information is transmitted in digital form to the microprocessor.

When the laser beam is incident on the sensor assembly window (figure 4-6), it travels through the window, through the matrix plate, and is focused to a point by the lens.

The position at which the beam strikes the matrix plate is sensed by a series of row and column sensor modules. These modules are connected to apertures on the matrix plate by fiber optic light guides. Each aperture is connected to one row and one column sensor module.

The position (X) of the focused point is directly proportional to the tangent of the angle (θ) between the lens axis (normal) and the beam (figure 4-7). Note that the focus point is not related to the position of the beam. The position of the focused point will be detected by photosensors.

The front window will be fabricated from thick glass plate because only glass has the scratch resistance necessary for this application. It will be tilted out slightly at the top to aid in self cleaning and protection. An air stream may be required to assist cleaning.

The inner surface of the glass window and both surfaces of the matrix plate and lens will have a thin film antireflection coatings peaked for 6328\AA . Antireflection coatings maximize transmission by reducing the 4% reflection normally occurring at air-glass and glass-air interfaces to less than 1/2%. This will maximize transmission of the laser beam. The coating will not be added to the outer surface of the glass window since these coatings are not scratch resistant enough to endure normal cleaning.

The entire assembly will be sealed and pressurized with 5 psi of dry nitrogen. This is normal procedure in optical assemblies and will prevent the condensation of moisture on the optical surfaces and dust from entering the assembly. Narrow (200\AA) band pass filters peaked for 6328\AA radiation will be placed in front of both the position and heading sensors. A typical filter of this type is Oriol Corporation P/N G-522-6328. This filter will transmit 60% of the laser radiation while attenuating more than 99% of the radiation from broad band radiators such as shuttle car lights and miner's cap lights. This results in a high signal to background noise (radiation) ratio.

4.4.2.1 Position

The function of the matrix plate is to position and support the two fiber optic probes making up each aperture. The plate will be fabricated from acrylic because acrylic has good transmission

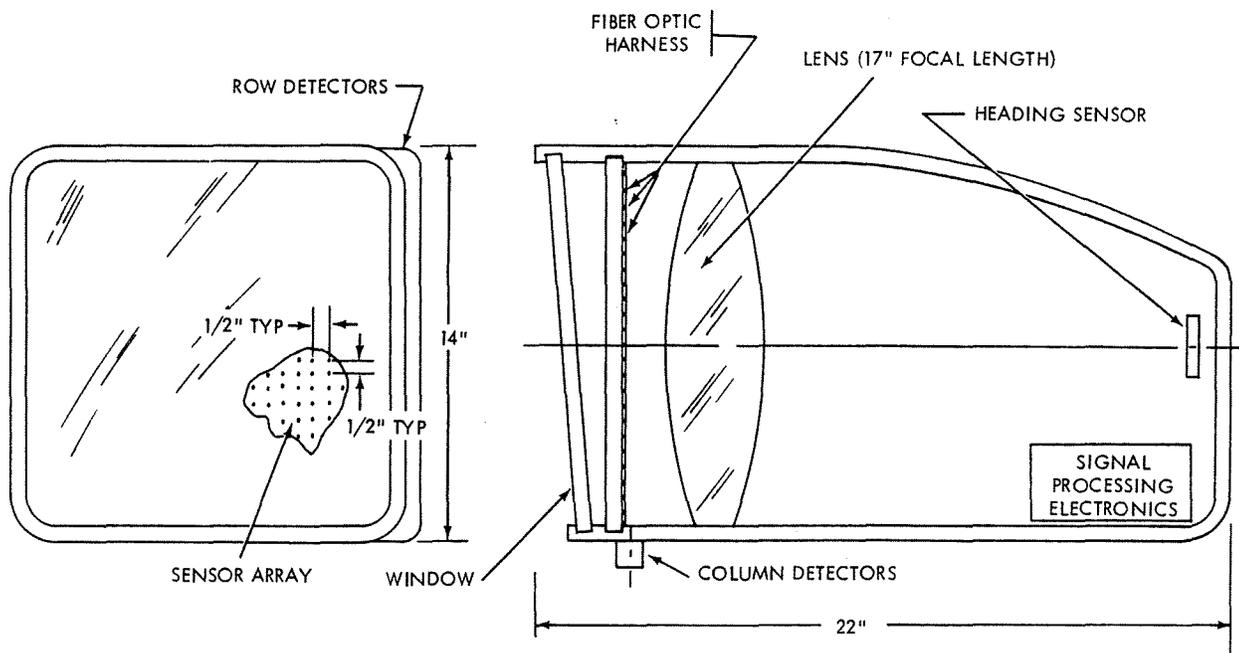


Figure 4-6. Sensor Assembly

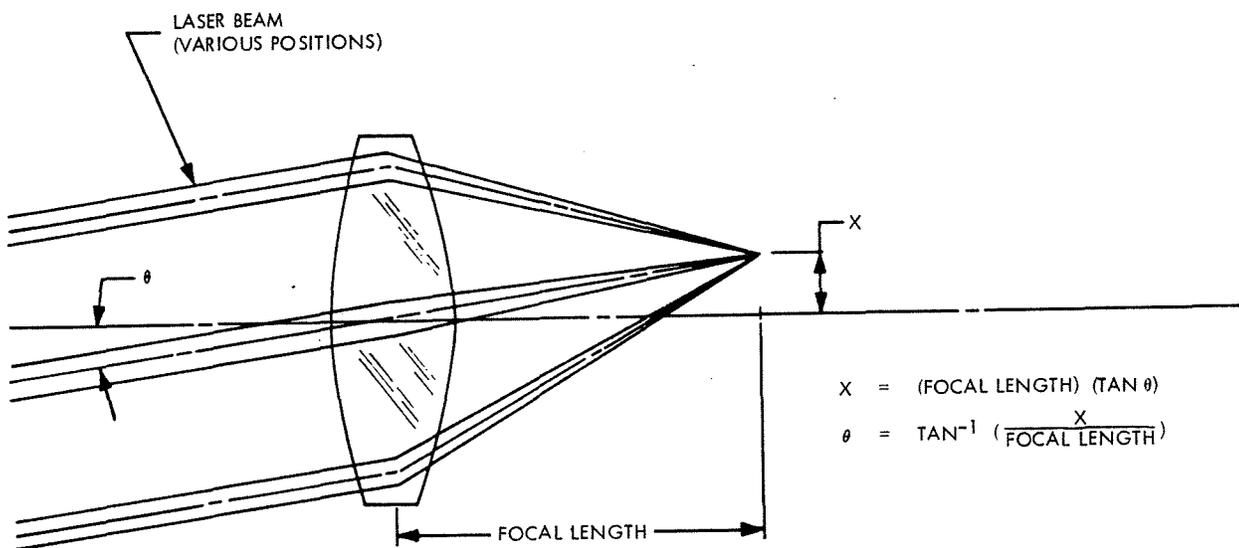


Figure 4-7. Laser Beam Focus Point
Plan View of Lens shown
in figure 4-6

characteristics (about 90%, 1/2 thick) and is lighter and less expensive than glass. There will be 25 rows and 25 columns of apertures (625 total).

The fiber optic probe from each aperture in a column and each aperture in a row will be molded into a harness. There will be 25 identical row harnesses and 25 identical column harnesses. The harnesses will be fabricated from 25 fiber optic light guides. Each guide will have an active cross section of 0.0005 in² and will extend from the aperture to the sensor module. The maximum diameter of the harness will be about 0.125 in. This is dependent on the packing ratio (i.e., space between fibers).

The 25 row and 25 column sensor modules will form identical potted assemblies. The modules will contain the following components.

- Narrow band pass filter (discussed above)
- Silicon photodiode with preamplifier. This will be an integrated unit. A typical device of this type is the Bell & Howell type 509 optical detector.
- The output of the detector/preamplifier will be fed into a digitalizing device (Schmidt trigger).

The silicone photodiode was selected because of its ability to detect radiation at very low light levels and because of its large active area. The ability to detect radiation at low light levels is necessary because of the small diameter of the fiber optic probes, the beam characteristics, and the transmission of the laser radiation through the various optical components.

For example, assume the laser radiates 2.0 mw of energy into a 18 mm beam.

$$\begin{aligned} \text{Beam power density (BPD)} &= \frac{2 \times 10^{-3} \text{ watts}}{\frac{(18 \text{ mm})^2}{2} \times \pi} \\ &= 7.86 \times 10^{-6} \text{ watts/mm}^2 \end{aligned}$$

4% reflection at glass surface (window)

$$\begin{aligned} \text{BPD} &= 7.86 \times 10^{-6} \text{ watt/mm}^2 \times (1-0.04) \\ &= 7.55 \times 10^{-6} \text{ watt/mm}^2 \end{aligned}$$

90% transmission (matrix plate)

$$\begin{aligned} \text{BPD} &= 7.55 \times 10^{-6} \text{ watts/mm} \times (.9) \\ &= 6.79 \times 10^{-6} \text{ watt/mm}^2 \end{aligned}$$

4% reflection (1st surface of fiber optic probe)

$$\begin{aligned} \text{BPD} &= 6.79 \times 10^{-6} \text{ watt/mm} (1-0.04) \\ \text{BPD} &= 6.52 \times 10^{-6} \text{ watt/mm} \end{aligned}$$

Power = BPD x fiber optic active area

$$\begin{aligned} &= 6.52 \times 10^{-6} \text{ watt/mm} \times 0.0005 \text{ in}^2 \times 625 \text{ mm/l in}^2 \\ &= 2.04 \times 10^{-6} \text{ watts} \end{aligned}$$

Transmission through fiber optics is 80% (assuming 1-1/2 ft length, DuPont CrofonTM Fibers)

$$\begin{aligned} \text{Power} &= 0.80 \times 2.04 \times 10^{-6} \text{ watts} \\ &= 1.63 \times 10^{-6} \text{ watts} \end{aligned}$$

4% reflection (2nd surface of fiber optics)

$$\begin{aligned} \text{Power} &= 1.63 \times 10^{-6} \text{ watts} \times (1-0.04) \\ &= 1.56 \times 10^{-6} \text{ watts} \end{aligned}$$

50% coupling efficiency (fiber optics to detector)

$$\begin{aligned} \text{Power} &= 1.56 \times 10^{-6} \text{ watts} \times 0.50 \\ &= 7.82 \times 10^{-7} \text{ watts} \end{aligned}$$

The Bell & Howell Type 509 optical detector can operate at input power levels down to 1×10^{-10} watts (assuming a signal to noise ratio of 10 and 6328 Å⁰ radiation). The large area of the photodiode is required to get a good coupling coefficient between the fiber optic harness and the photodetector.

4.4.2.2 Heading

A small amount of the laser beam will be attenuated by the fiber optic harness. The remainder will be incident on the lens and will be focused on the focal plane detector. This subsystem will measure the heading angle (θ) of the miner with respect to the laser beam.

The lens will have a focal length of 17 inches and an F-number of 1. The edges of the lens will be trimmed so that a 1-foot square aperture remains.

A high quality lens (photographic) with this focal length and F-number would be extremely expensive to design and fabricate. Preliminary analysis, however, indicates a high quality lens is not required for this application. A single aspherical component, fabricated from acrylic will suffice.

A position sensitive detector in the focal plane of the lens will determine the position of the focused spot. The signal from the detector will be processed and digitalized for transmittal to the microprocessor. A 4 x 5 inch detector would have the required position sensitivity for this application. The 5 inches length of this detector would permit heading readings out to $\pm 8.5^\circ$. This exceeds the limit requirements required for guidance, that is,

$$\frac{\theta}{2} = \tan^{-1} \left(\frac{\text{Detector length} \div 2}{\text{Focal length}} \right)$$

Where θ = horizontal limit of lens/detector system

$$\frac{\theta}{2} = \tan^{-1} \left(\frac{5/2}{17} \right)$$

$$\frac{\theta}{2} = \pm 8.5^\circ$$

The 4 inch height of the detector will allow the automatic continuous miner to pitch $\pm 6.7^\circ$ about the axis of the sensor assembly with respect to the laser beam without losing heading information.

$$\frac{\theta}{2} = \tan^{-1} \left(\frac{4 \div 2}{17} \right)$$

$$\frac{\theta}{2} = \pm 6.7^\circ$$

4.5 DISTANCE METER

A system is required to accurately measure the advance of the miner in the entry. This system must be accurate enough to measure and control proper sumping of the cutter head and must operate in real time. The following specification was developed for evaluation of available and proposed systems.

| | |
|--------------------|------------------|
| Operational range: | 50 - 400 ft |
| Accuracy: | ± 1.0 inches |
| Time to operate: | 0.1 seconds |
| Output: | Digital |

Two basic system concepts were evaluated and one selected for further development. The first system operated on a triangulation principle, the second system is called Electronic Distance measurement.

4.5.1 Triangulation

This system (figure 4-8) utilizes a point light source and objective lenses with focal plane detector arrays. The lenses focus the point source on the detector array. The position of the focused point on the detector array is a measure of the angle between the optical axis and the point source. Two lens/detector systems are required so that ambiguities between changes in heading and changes in range can be resolved. The triangulation system was eliminated for two reasons:

- Clear lines of sight are required down one side and also across the entry. This was considered impractical because of the presence of shuttle cars and other obstacles in the entry.
- The optical system (lenses) required would become excessively complicated and cumbersome. A long focal length lens (1000 mm) would be required to measure the angles at 400 feet with sufficient precision. Because of field of view limitations on long focal length lenses, the lens could not keep the point source in view throughout the range from 50 to 400 feet. The lens would therefore have to be servo controlled or another shorter focal length lens/detector system added for ranging at shorter ranges.

4.5.2 Electronic Distance Measurement (EDM)

The EDM system selected for further development consists of an amplitude modulated light beam which is transmitted toward a retro-reflector outby the miner and then reflected back towards the device. The device measures the phase shift between the transmitted and reflected beam. The phase shift is directly related to the range as shown in figure 4-9. For this application the EDM would be mounted on the miner and the retroreflector would be mounted behind the entry.

This type equipment has been developed into surveying instruments. The following devices were evaluated for conformance to the specification.

- Model 76 (AGA)
- DM 500 (Kern)

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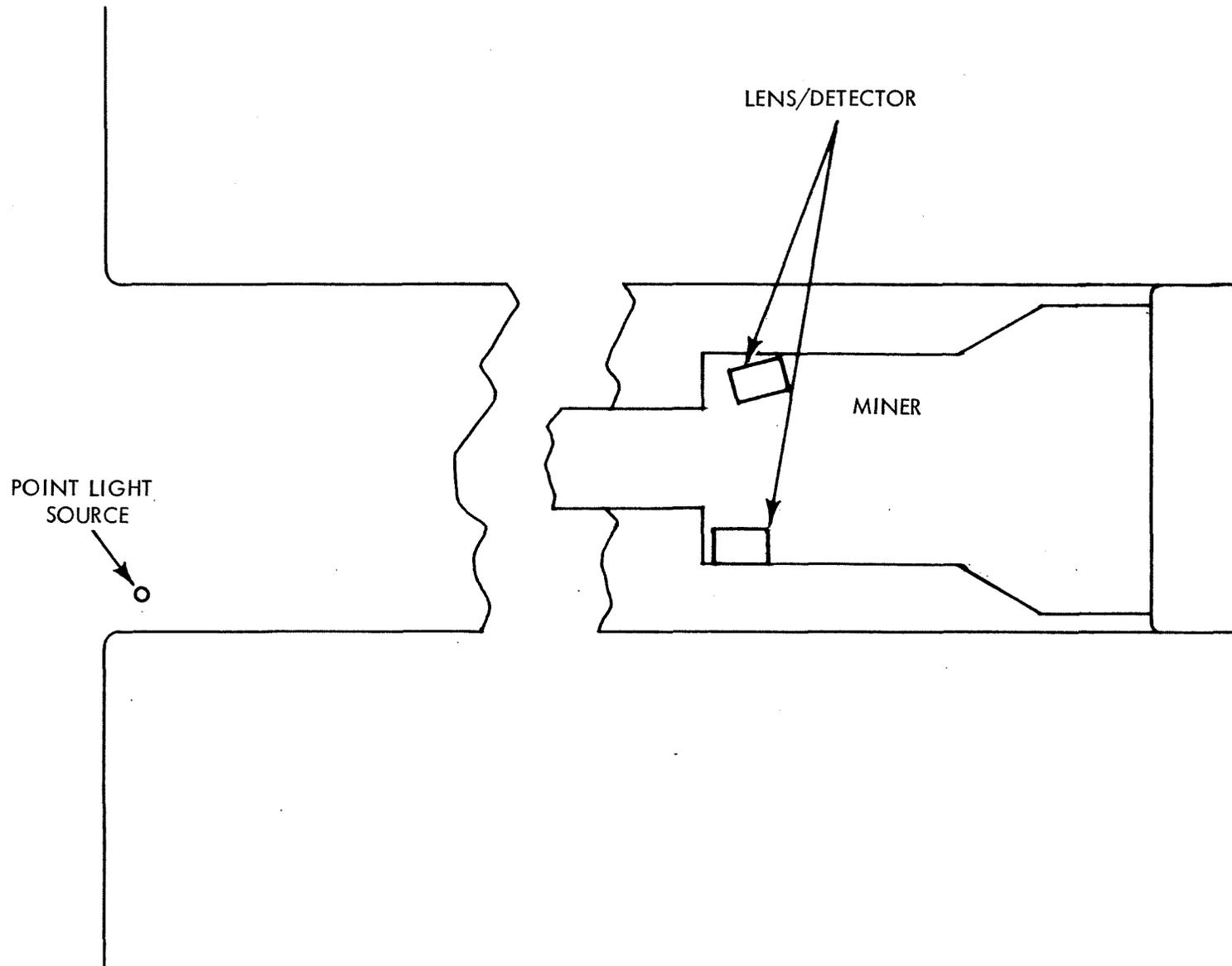


Figure 4-8. Triangulation

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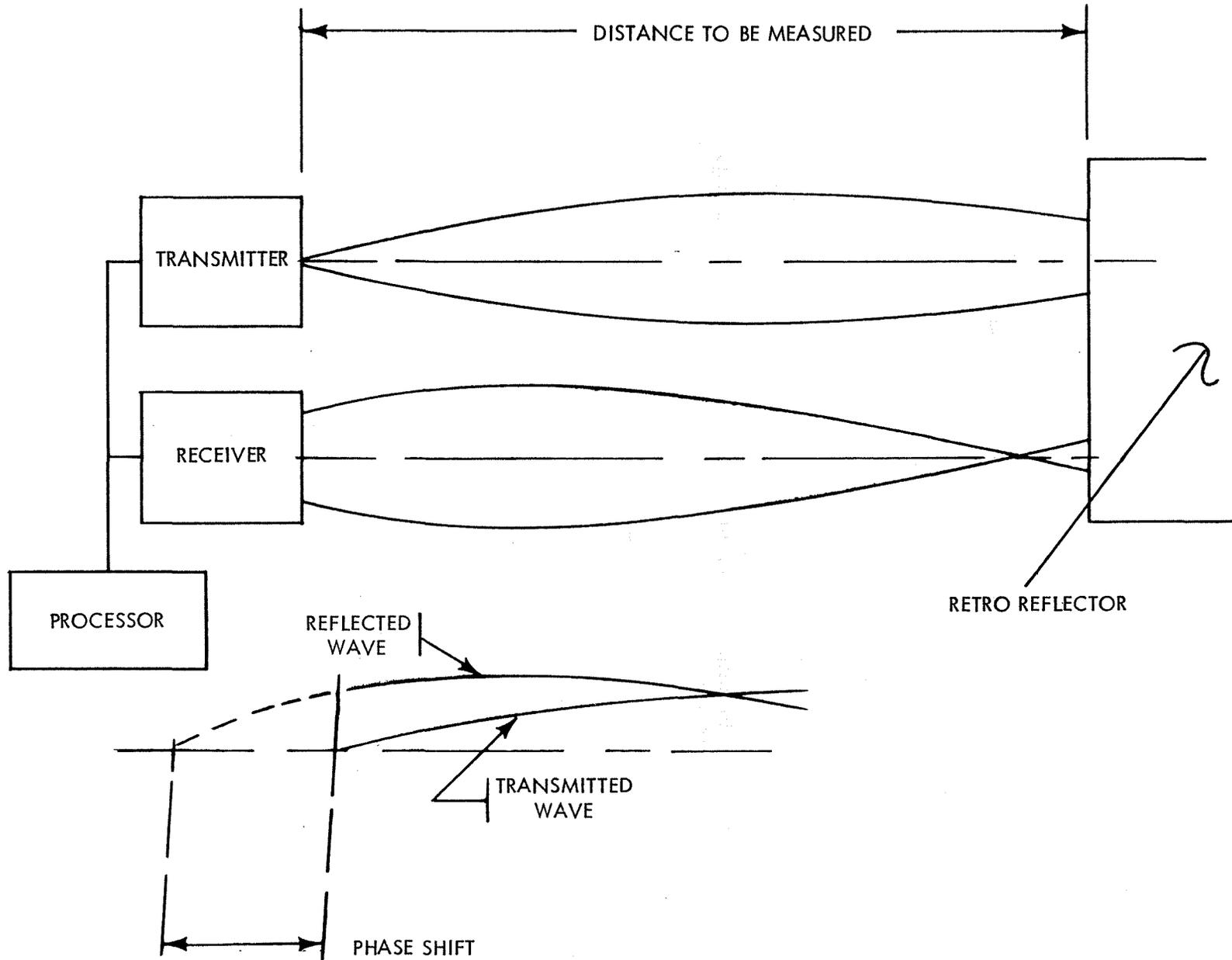


Figure 4-9. Electronic Distance Measurement

- Cubitape (Cubic Industrial Corporation)
- MicroRanger (Laser Systems)
- Wild D13 (Distomat)
- CA 1000 (Tellurometer)
- Model 3805A (Hewlett-Packard)

These devices all required excessive time to range (i.e., 6 to 15 seconds). The time is required because measurements are made at four different modulation frequencies and a large number of measurements are taken at each frequency. In addition, the modulation frequency is converted to a lower frequency for ease of processing. The phase measurement is made at this lower frequency and the time required must be multiplied by the conversion factor.

The large number of measurements are required because of low signal to noise ratios resulting from limited transmitting power. The measurements at different modulation frequencies are required to resolve ambiguities because a phase measurement is not unique to a range. The same measurement can be obtained from a multiple of the range.

Discussion was held with the following vendors:

- Hewlett-Packard
- Cubic Industrial
- Laser Systems

Laser Systems, Tullahoma, Tennessee, expressed interest in development of a system to meet the specification and indicated a unit similar to their MicroRanger could meet the requirement. A single modulation frequency (1.2 MHz) would provide unique ranges between 50 to 400 ft. One hundred measurements would be adequate for ± 1 in. accuracy. If the modulation frequency is converted to 1.2 KHz for the phase measurement then the conversion factor would be 1000. This would result in a maximum operating time of 0.08 seconds.

Time for one measurement at modulation frequency (MFM)

$$\begin{aligned}
 \text{MFM} &= (400 \text{ ft} \times 2) \div C \text{ (speed of light)} \\
 &= 800 \text{ ft} \div 9.75 \times 10^8 \text{ ft/sec} \\
 &= 8.2 \times 10^{-7} \text{ sec}
 \end{aligned}$$

Time to make phase measurement (PM):

$$\begin{aligned} \text{PM} &= \text{MFM} \times \text{conversion factor} \\ &= 8.2 \times 10^{-7} \text{ sec} \times 1000 \\ &= 8.2 \times 10^{-4} \text{ sec} \end{aligned}$$

$$\begin{aligned} \text{Total Time} &= \text{PM} \times \text{number of measurements} \\ &= 8.2 \times 10^{-4} \times 100 \text{ sec} \\ &= 0.082 \text{ sec} \end{aligned}$$

The output would be in BCD form for interfacing with the guidance unit.

4.6 ENTRY ALIGNMENT CONTROLS

The contract states for entry control:

"The lateral displacement of the entry from the planned center line shall not exceed one foot in 100 feet."

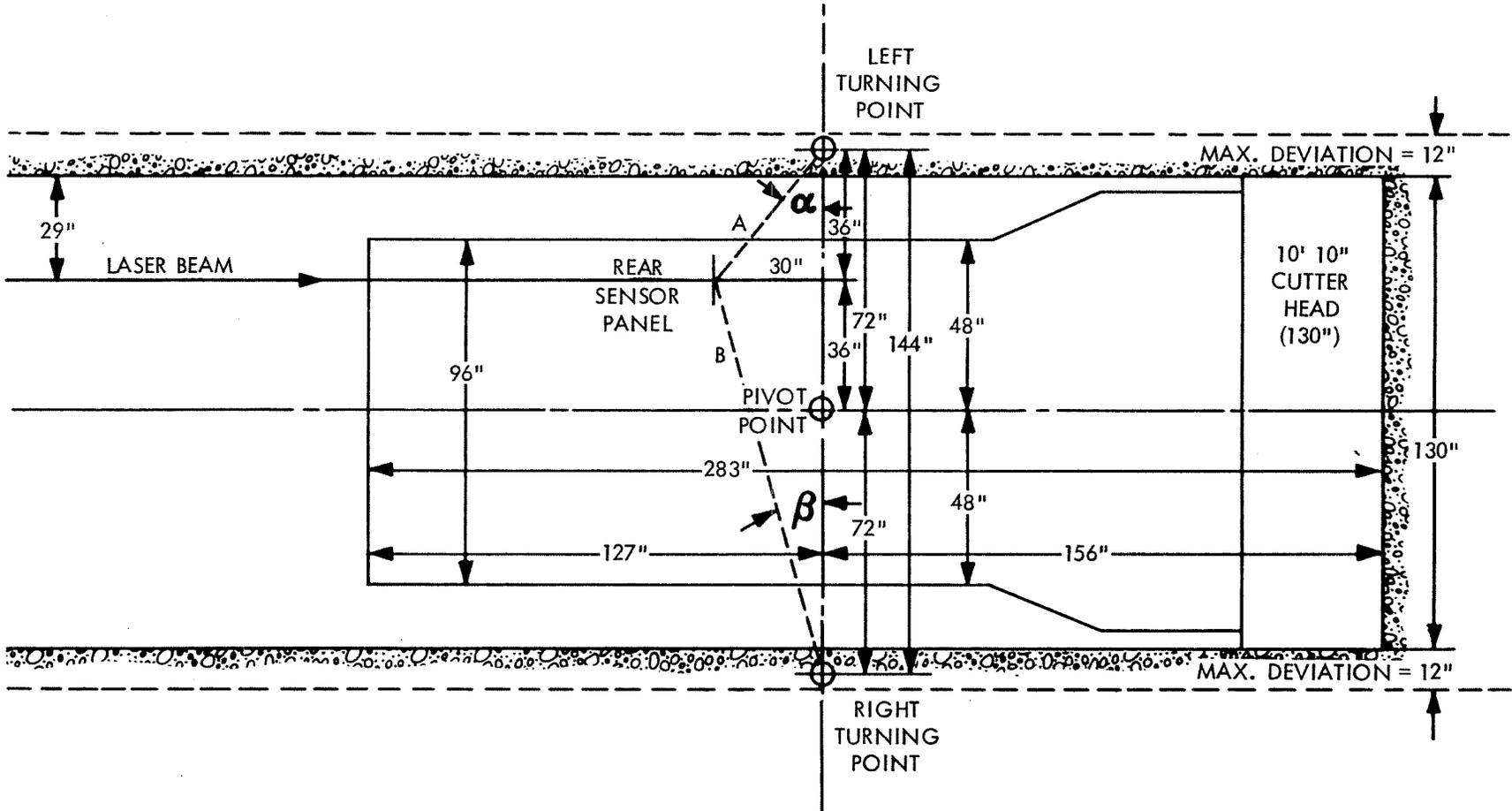
For the purpose of design, this was interpreted as a parallel displacement and not as an angular error. We shall control the miner in such a way, that the cumulative displacement error will not exceed ± 1 foot, regardless of distance traveled (figure 4-10). Automation of the entry alignment control of a continuous miner can be achieved by guiding the machine along a laser beam with better accuracy than prescribed in the contract. Operations will be controlled by a microprocessor with associated input/output, memory, and storage circuits.

Various methods were reviewed as possible solutions.

4.6.1 Deviation Sensing

Deviation from the desired heading or tracking is sensed by a laser beam impinging on a dual sensor array. This is described in section 4.2. Physical size of the miner limits control actions to a maximum practical range of ± 3 degrees heading deviation. The dual sensor array has been designed to give control signals with $\pm \frac{1}{2}$ degree heading resolution and $\pm \frac{1}{2}$ inch position accuracy.

Because of the limited heading range, it is deemed best not to pivot-steer the miner, but to control its heading and position by stopping one or the other track while the machine is moving in the forward or reverse direction.



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Figure 4-10. Outline of Continuous Miner Making the First of Two Passes (Zero Heading Error, Perfect Tracking)

The size of the sensor array is 1 foot square, whereby the outermost rows and columns are limit sensors. As soon as laser light falls onto them, power to the tram motors is cut off, thus stopping the machine. Precautions are taken to make the control system insensitive to changes in background illumination and spurious light beams caused by men or equipment moving nearby by using narrow band pass filters in the sensor assembly (section 4.2.1).

4.6.2 Control Actions

The tram control actions will initially be limited to the lowest speed of 10 feet per minute, or 2 inches per second. We feel that the tram speed may be stepped up for manual control by the operator, but in automatic mode the lowest speed is required at least until the control system has been adjusted to the machine dynamics. The speed may be stepped up later.

The following commands are possible:

| | |
|--------------------|--------------------|
| Left tram forward | Left tram reverse |
| Right tram forward | Right tram reverse |
| Both trams forward | Both trams reverse |
| Both trams stop | |

The information obtained from the sensor array is buffered and fed into a microprocessor with its associated circuitry. The program for the automatic operational control of the miner is stored in peripheral circuits.

Any deviation from the program, which includes heading and tracking control, is sensed and converted to control commands. Even under manual control, the heading of the miner probably changes, due to differences in face condition, friction under the tracks, uneven floor, etc. In automatic mode, such errors will be compensated for by the control system. The microprocessor can easily be programmed to put different "weights" to different magnitudes of error (figure 4-11).

If, for instance, a right turn is required, the right track is stopped, while the left track continues to move. In this case, the machine would turn at about 1 degree per second around the right turning point. Corresponding action takes place for left turn. It is expected that the machine will "feel" its way along the laser beam with left and right corrections while tram forward or reverse action is in progress. See figure 4-12 for some typical control sequences. A brief mathematical analysis of various control aspects is given in the appendix.

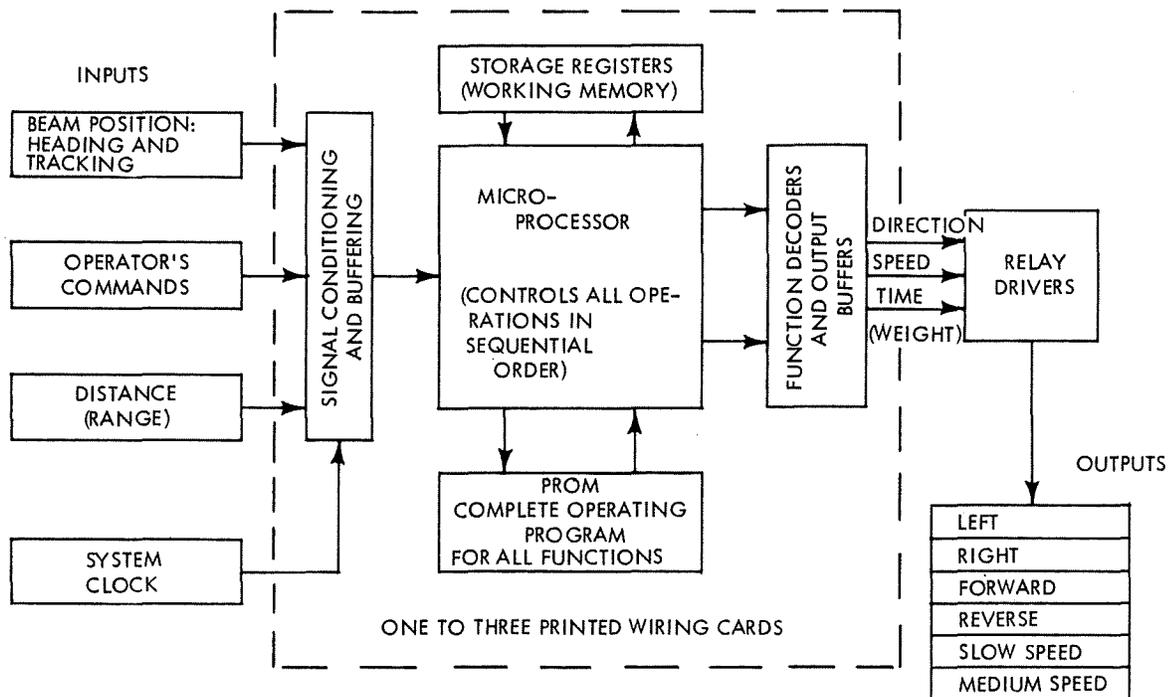


Figure 4-11, Block Diagram for Tram and Lateral Control Using Laser Guidance

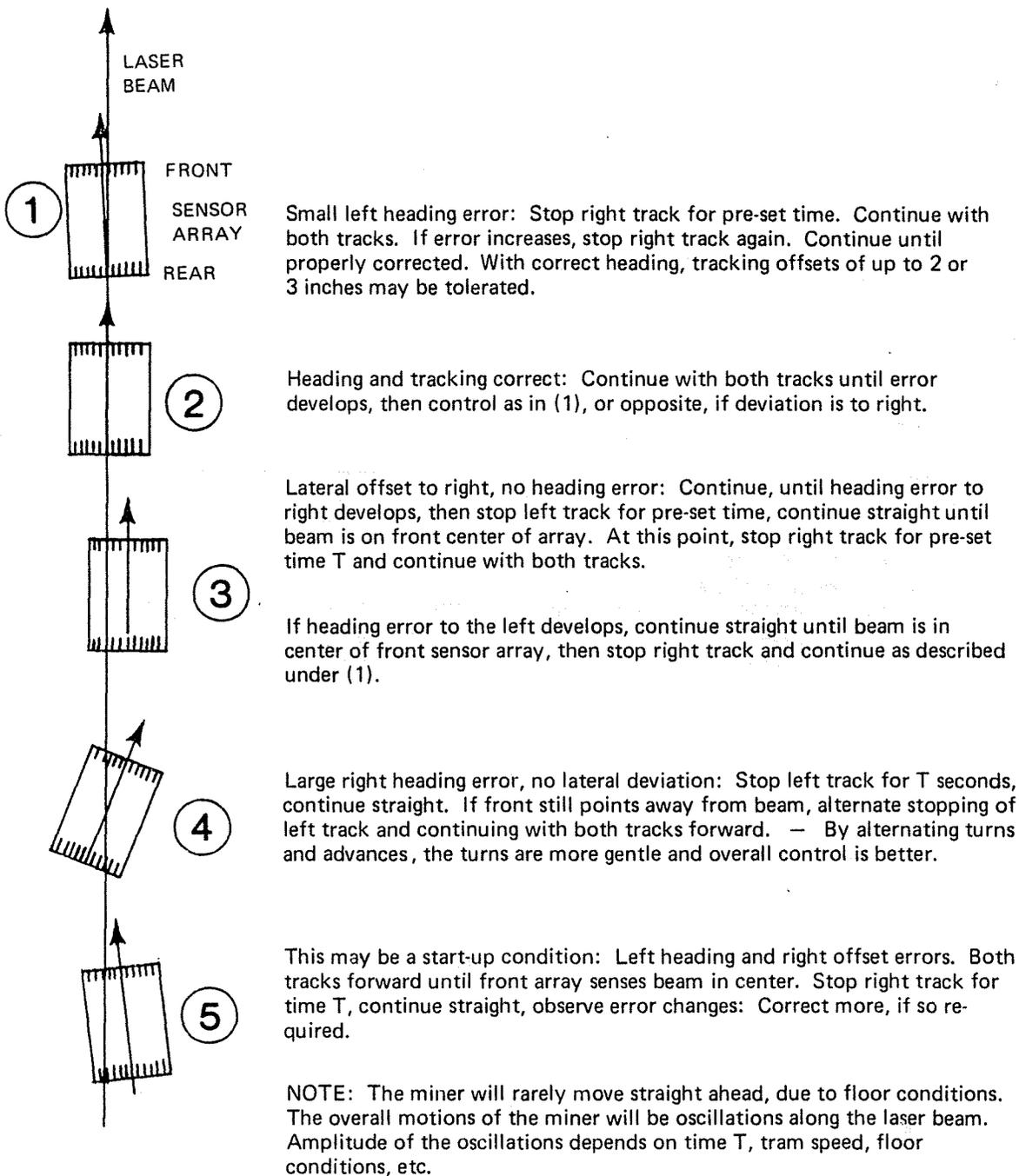


Figure 4-12. Control Sequences for Various Heading and Tracking Error Conditions

4.6.3 Limits

The limits for automatic control of the lateral alignment of the miner will be:

| | |
|---|----------------------------------|
| Angular deviation | = ± 3 degrees max. |
| Lateral position | = $\pm 5\frac{1}{2}$ inches max. |
| Maximum cutter penetration into wall at 3° error | = 8 inches |
| The resolution is as follows: | |
| Angular deviation | = $\pm \frac{1}{2}$ degree |
| Lateral position | = $\pm \frac{1}{2}$ inch |

4.6.4 Suggestions for Future Improvements

Future continuous miners could be improved by changing the relay control to solid state control of the tram motors, thus achieving closer control of tracking and heading. The greatest advantage would be the elimination of relays, which would be replaced by silicon-controlled-rectifiers (SCR's) on the high-voltage side of the 3-phase transformers. The SCR's would also adjust the tram speed of the miner, thereby eliminating more relays, however, relays would remain for forward/reverse control.

4.7 VERTICAL DISPLACEMENT OF ENTRY

The contractual vertical displacement requirement is as follows, "Variation in machine control of vertical displacement of the driven entry from the initial bottom or top planes shall not exceed one inch during 10 foot of advance in the programmed mode."

Using the laser guidance system, the vertical alignment is maintained using the beam as a reference. A geometric model is shown in figure 4-13. For control purposes, the roof and floor planes are considered to be parallel. The symbols shown in the figure represent the following:

- "a" is the horizontal distance between vertical plane of the sensor array and the boom pivot point.
- "b" is the vertical distance between the center line of the sensor array to the boom pivot point.
- "c" is the vertical distance between the centerline of the sensor array and the bottom of the tracks.

- "l" is the length of the boom between its pivot and the cutter drum center.
- "r" is the effective radius of the cutter drum.
- "S" is the operator selected seam height limit distance between the desired roof and floor.
- "F" is the operator selected floor limit distance between the actual and desired floor.
- "α" is the angular pitch sustained by the miner due to floor changes. Forward down is defined as positive. 0° is horizontal.
- "ε" is the linear error from the center where the reference beam hits on the sensor array. Error is positive above center.
- "θ" is the angular displacement of the shear boom from level. 0° is horizontal with positive angles above the horizontal.

The dimensions a, b, c, l, and r are fixed dimensional characteristics of the specified automated miner. F and S are operator selected quantities. The quantities α, ε, and θ are the variables which are related to the position of the miner and must be measured. Pitch angle, α, is measured by a pitch transducer mounted on the miner; vertical error, ε, is measured by the laser beam sensor array; and shear boom angle, θ, is measured by a rotary absolute shaft angle transducer. These three quantities are listed below with their range and accuracy necessary to meet the requirement.

| <u>Quantity</u> | <u>Range</u> | <u>Precision</u> |
|-----------------|-----------------|------------------|
| α | + 10 degrees | 0.1 degree |
| ε | + 6 inches | 0.5 inch |
| θ | +55, -5 degrees | 0.1 degree |

Referring to figure 4-13, the roof and floor angular commands are:

$$\theta_{\text{roof}} = \alpha + \sin^{-1} \frac{S - C + F - r + (\epsilon + b \cos \alpha + a \sin \alpha)}{l}$$

$$\theta_{\text{floor}} = \alpha + \sin^{-1} \frac{(\epsilon + b \cos \alpha + a \sin \alpha) + r - c}{l}$$

These commands are derived by the electronic processor using a microprocessor with a trigonometric (sine, arc sine) memory chip or a calculator chip. The computation block diagram, figure 4-14, shows the necessary computation to derive the seam height and floor angular commands and the actual seam height and floor limits for display to the miner operator. The relative boom position display output is also shown. The relative cutter boom position indicator on the remote control panel is provided for monitoring by the operator.

The shear boom control diagram for the seam height and floor limits is shown in figure 4-15. The microprocessor located within the electronic processor is used as a five-limit comparator (A is much greater than B through A is much less than B) which can be shortened to ($A \gg B$ through $A \ll B$). Either the seam height or floor command is allowed to be compared, but never both simultaneously. The commands are derived as shown in figure 4-14. The seam height or floor command is compared to B, the encoded shear boom angle. If the comparator output is either $A \gg B$ or $A \ll B$, the rapid raise or lower is activated which in turn actuates the proper solenoid valve. The solenoid valve allows oil to enter the shear cylinder at a fast flow and raises or lowers the shear boom quickly. As the command, A, and the boom angle, B, approached equality, the comparator output changes to $A > B$ or $A < B$. When this occurs, the slow raise or lower solenoid valve is actuated allowing slower movement of the shear boom to minimize the possibility of overshoot and unstable operation (i.e., oscillation due to excessive pitching of the miner).

Because the microprocessor is relatively easy to change, the comparator limit points can be selected during hardware development. Also during the development phase, orifice, V, in figure 4-15 may be of the variable type to determine the optimum size. It is recommended that the rapid/slow "bang-bang" type control be used due to lower cost, fewer retrofit parts, less maintenance due to increased tolerance to contamination, and less installation time.

The alternative approach is to use the microprocessor as a subtractor and a digital-to-analog converter with a servovalve and amplifier as shown in figure 4-16. This method minimizes the possibility of unstable operation by using the analog error command method. The cost is high since the hydraulic system presently on the Joy 12CM-10B must be changed from the constant volume, variable pressure type to the more expensive variable volume, constant pressure type. Also the present Joy remote control scheme (bang-bang) must be discarded and proportional control installed for the shear boom control.

4-35

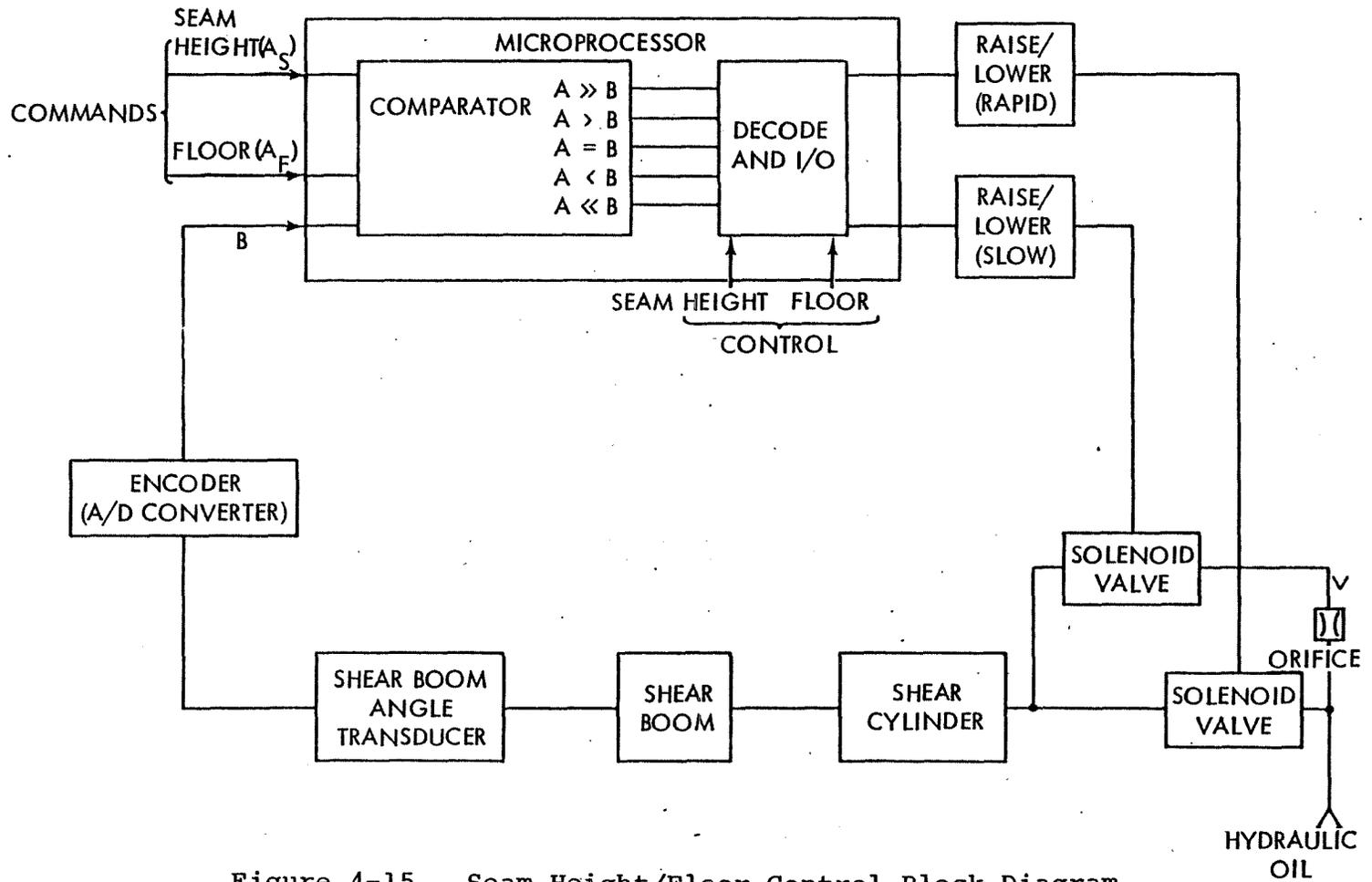


Figure 4-15. Seam Height/Floor Control Block Diagram

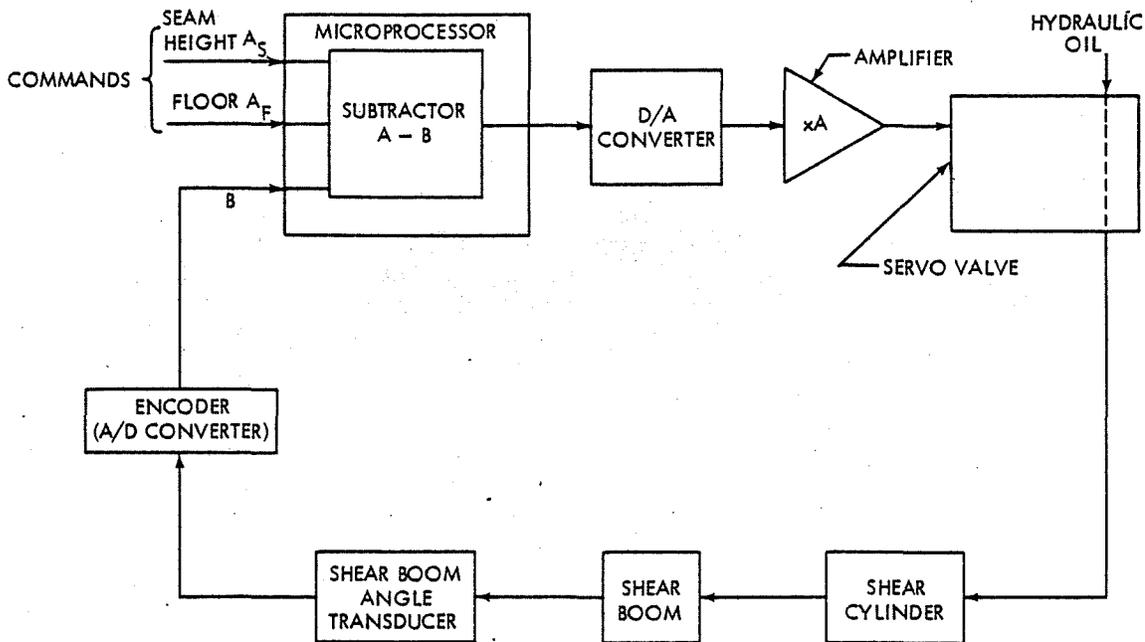


Figure 4-16. Seam Height/Floor Control Block Diagram
(Alternative Approach)

4.8 ELECTRONIC MICROPROCESSOR

4.8.1 System Description

The electronic microprocessor located on the continuous miner will be required to do all computation, issue control commands to the tram and shear boom actuators, do self-checks, and display important information on the operator's control panel.

These operations will be done sequentially in an order fixed by the program. The continuous miners mechanical responses will come in rapid but smooth order.

The system will consist of the Pro-Log Corporation PLS-400 or a similar system. It will be installed in a sealed box, which also contains the required power supplies, and is mounted on the continuous miner after permissibility approval has been obtained from USBM. Total power requirements should be less than 100 watts at available single phase ac voltage.

Following are excerpts from Pro-Log Corporation's "Designer's Guide to Programmed Logic for PLS 400 Systems".

Explanation of terms used in the excerpts:

CPU = Central Processing Unit
RAM = Random Access Memory
ROM = Read-Only Memory
TTL = Transistor-Transistor Logic, one of the many but probably the most used type of logic.
BIT = BInary DigiT, the smallest unit handled in digital systems. Has two possible states: 0 and 1.
WORD = A fixed number of bits; 4, 8, or 12 is used here.

SUMMARY

PLS 400 systems are micro-programmable processing systems suitable for implementing random logic, and numeric and small alpha numeric data handling applications. As shown in Figure 1-1, the PLS-400 system consists of a CPU, RAM register storage, ROM program memory, and input/output ports. The CPU is an Intel 4004 CPU chip, RAM registers are the Intel 4002 circuits, ROM program memory is implemented using Intel 1702 or NSC 5202 erasable reprogrammable ROM's or equivalents, and I/O ports are TTL latches and selectors.

CPU CAPABILITIES

- Twelve bit program address
- Three level address stack for subroutines
- Sixteen, four bit index registers
- A four bit accumulator plus carry
- One, eight bit instruction word per cycle
- Forty one single word instructions
- Five double word instructions
- Arithmetic and accumulator instructions

Add and subtract with carry

Complement, rotate, increment, decrement, clear,
and load the accumulator

Complement, clear, and set carry

- Decimal arithmetic instructions
- Decision making (address control instructions)
- Test accumulator for zero or nonzero
- Test carry for logic one or zero
- Test external input for high or low
- Increment any index register and test for zero

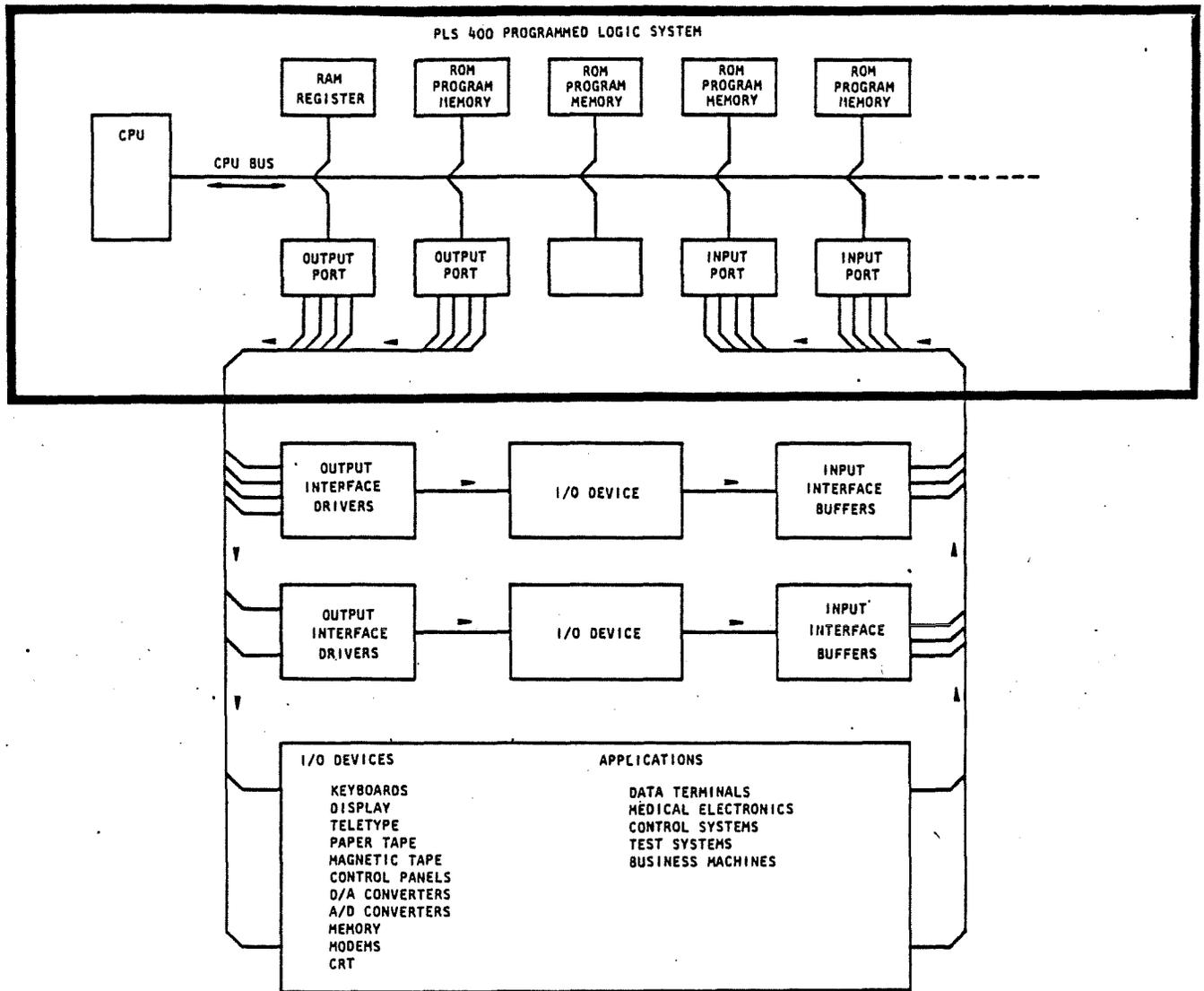


FIGURE 1-1

PLS-400 Programmed Logic System Application

- Input/output instructions
- RAM register instructions
- Register instructions

ROM PROGRAM MEMORY

- Programmable erasable ROM's MSC 5202, Intel 1702
- 256 eight bit instructions words per page
- Sixteen pages maximum (ROM's) 4096 words of instruction

RAM REGISTER STORAGE

- Intel 4002 RAM
- Organized as four registers of 16 four bit words plus four status words for each register
- Requires CPU instruction addressing
- Includes four output lines used with CPU output instruction

INPUT/OUTPUT

- TTL output latches and input selectors
- Requires CPU selection by instruction
- 128 lines directly selectable
- Input instruction, gates data into the CPU accumulator
- Output instruction, latches accumulator data at output

PLS 400 HARDWARE

The PLS 400 series provides a choice of micro-processor card sets with varying expandability. Each set provides the CPU, ROM program memory, RAM register storage and I/O. All sets are implemented with CPU clock and external reset and power-on reset circuits. ROM program memory on each card set is implemented with programmable erasable ROM. The use of erasable, re-programmable ROMs provides a speedy tool for implementing programmed logic. The PLS 401 one card set is complete on a single

card providing the lowest cost for limited system size. The system expansion is limited to 1024 words of ROM program memory, 320 characters of RAM register storage, four output ports, four input ports, and one RAM output port.

The PLS 402 two card set provides for reasonable program memory and extensive I/O. The system expansion is limited to 1536 words of program memory, 320 characters of RAM register storage, 4 RAM output ports, and up to 128 I/O lines.

The PLS 403 three card set provides maximum expansion capability on ROM, RAM and I/O. The system expansion is unlimited to the full CPU capability of 4096 words of program memory, 1280 characters of RAM register storage, 48 lines of RAM output, and 128 lines of I/O. The PLS 403 CPU Card 4111 will accept either eight 4002 RAM register devices or eight 4001 masked ROM devices. This card in itself can become a one card system with masked ROMs.

4.8.2 Programs

Programs must be developed for the applications in the miner. The manufacturers of Programmed Logic Systems supply programming aids and FMC's Data Processing Center has knowledgeable people to help in the design of the programs. The programs would be designed by the control system manufacturer and the miner operator would not be required to do any programming.

Depending on complexity, more than one processing unit may be employed, which would shorten the program sequences for each unit and give faster updating. Both microprocessors would be installed in the same box on the continuous miner.

The program for tram control would be required to:

1. Read heading and tracking information into register.
2. Compare two sets of information to determine change.
3. Consults pre-programmed memory for action to take.
4. Execute required action.

4.8.3 Summary

The use of a programmed logic system is the best way to control the automatic continuous miner.

Status information can be obtained in many cases directly in digital form or easily converted to it from analog data. Digital processing is fast, accurate and inexpensive. The digital system can be contained on a few printed wiring cards and needs only a comparatively small power supply system, which is easily matched to the available power on the miner.

4.9 REMOTE MACHINE CONTROLS

The required remote machine controls and displays are those listed in figure 4-17. A machine control block diagram is shown on figure 4-18 and shows that all operator controls originating at the control panel are processed by the system electronics. The electronic processor then commands the existing Joy remote controller to control all the machine functions. The electronic processor also interfaces with the input transducers (e.g. boom angle, pitch angle, etc.) monitoring machine action, the laser sensor array, and the electronic distance meter for guidance information. The control panel also displays the machine status and the automatic cycle status to inform the operator of machine performance and cycle program. In the unlikely event that the automatic controls fail, the manual override controls will take over and maintain control. The electronic processor can be pulled out for repair while the miner continues to operate on manual control. The remote control panel is shown in figure 4-19.

The automatic cycle controls are:

- Auto/manual selector switch for selection of automatic or manual controls.
- START, STOP, CONTINUE and RESET switches to control the program of the automatic cycle.
 - START - starts automatic cycle at beginning of program.
 - STOP - stops automatic cycle at any point in the program.
 - CONTINUE - re-starts automatic cycle at point where program was previously stopped.
 - RESET - when actuated, resets automatic cycle program to the beginning.
- Sump distance selector switch is a thumbwheel type with decimal number positions and binary output which is directly compatible with the digital electronic processor. Range is 0 to 30 inches.

| AUTOMATIC CYCLE | | MACHINE STATUS | MANUAL OVERRIDES |
|---|---|---|--|
| CONTROLS | DISPLAYS | | |
| <ul style="list-style-type: none"> • AUTO/MANUAL • START • STOP • CONTINUE • RESET • SUMP DISTANCE • CLEAN-UP DISTANCE • CYCLE SELECT • SEAM HEIGHT LIMIT • FLOOR LIMIT | <ul style="list-style-type: none"> • CYCLES • DISTANCE MINED • ACTUAL FLOOR LIMIT • ACTUAL SEAM HEIGHT LIMIT • RELATIVE SHEAR BOOM POSITION • CUTTER ON • CONVEYOR/GATHERING ARMS ON • WATER SPRAY ON • TRAM MOTOR(S) FWD - ON • TRAM MOTOR(S) REV - ON | <ul style="list-style-type: none"> • METHANE LEVEL METER • METHANE LEVEL, LOW ALARM • METHANE LEVEL, HIGH ALARM • CONTROL SYSTEM VOLTAGE • HIGH OIL TEMPERATURE • LOW OIL LEVEL • HIGH ΔP ACROSS OIL FILTER | <ul style="list-style-type: none"> • TRAM: LEFT/RIGHT AND FWD/REV • TRAM SPEED: NORMAL/FAST • SHEAR BOOM: RAISE/LOWER • GATHERING HEAD: RAISE/FLOAT • CONVEYOR BOOM: RAISE/LOWER AND LEFT/RIGHT • DRUM: IN/OUT • WATER SPRAY: OFF/ON • FIRE SUPPRESSION: OFF/ON • CUTTER MTR: OFF/RUN/START • PUMP AND TRACT: OFF/RUN/START • CONVEYOR FWD: OFF/RUN/START • CONVEYOR REV: OFF/RUN/START • CIRCUIT BREAKER: OFF/ON • EMERGENCY STOP |

Figure 4-17. Remote Machine Controls and Displays

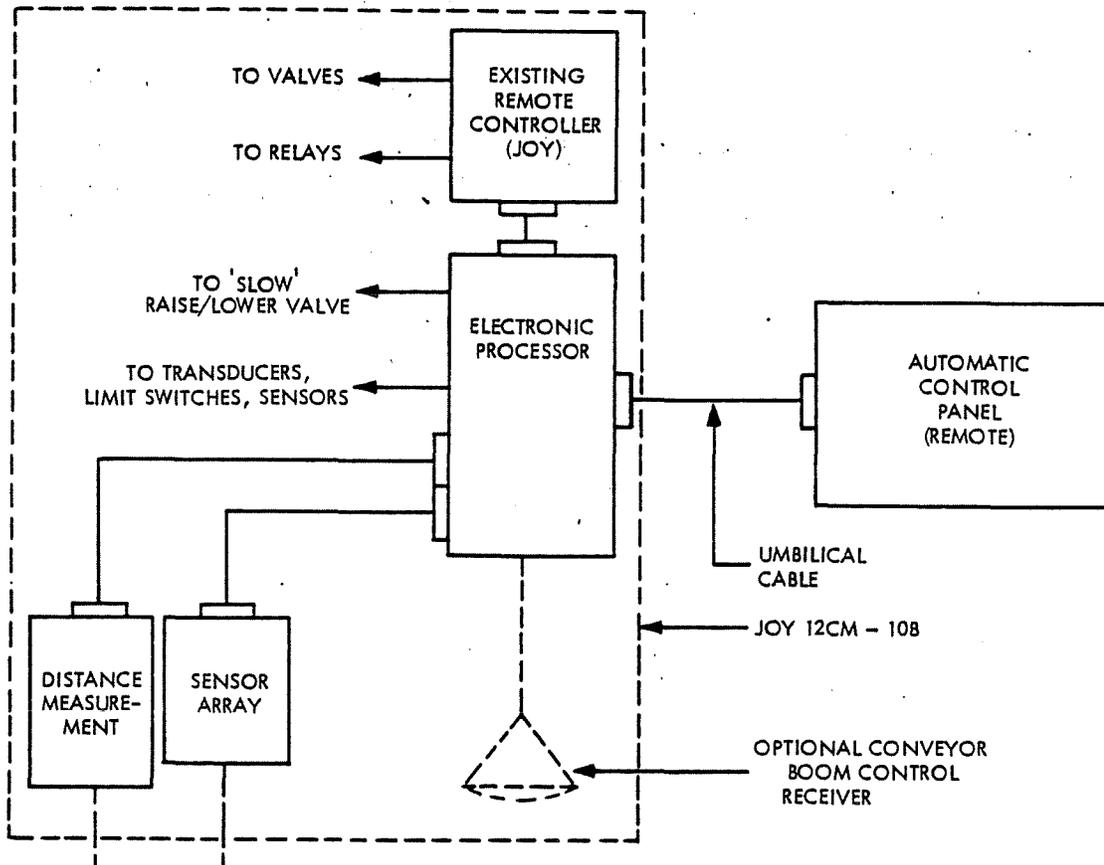


Figure 4-18. Machine Control Block Diagram

4-44

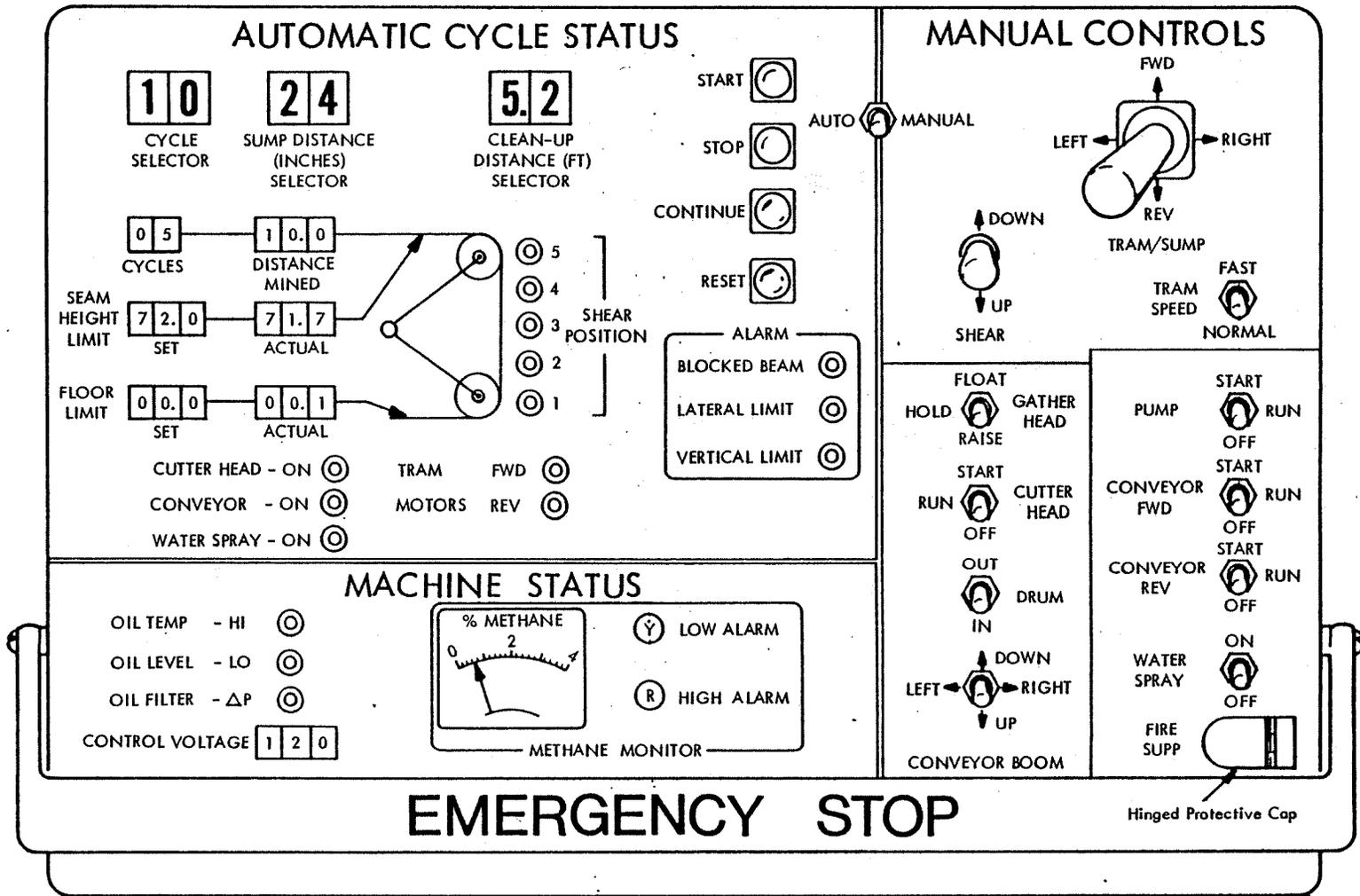


Figure 4-19. Remote Automated Control Panel

- Clean up distance selector switch is a thumbwheel type with numbers similar to the one above (sump distance). Range is 0 to 10 feet.
- The cycle selector switch is also a thumbwheel and is used to select the number of cycles to be completed. The cycle can be selected from 0 to 99.
- Seam height and floor limit selectors are also thumbwheel switches to select the desired floor and seam height.

The automatic cycle status which will include displays are:

- Cycles since start
- Distance mined since start
- Actual seam height and floor limits
- Relative position of shear boom depicted by five discrete lamps in a line; the one which is lit will indicate the position.
- Indicator lights to indicate:
 - Cutter motors on
 - Conveyor/gathering arms motor on
 - Water spray on
 - Tram motors on FWD or Reverse

The machine status displays will show:

- Methane level of 0 to 4 percent concentration.
 - Low alarm point reached indicated by a yellow light at 1% concentration.
 - High alarm point at 2% concentration indicated by a red light with shutdown of the miner.
- Electrical control system voltage (120 volts ac)
- High hydraulic oil temperature
- Low hydraulic oil level
- High differential pressure across the oil filter

The manual controls will include:

- Tram controls - Left/Right and Forward/Reverse
- Shear boom position - Raise/Lower
- Gathering head position - Raise/Hold/Float
- Conveyor boom position - Raise/Lower and Left/Right
- Cutter drum extension - In/Out
- Water spray - Off/On
- Fire Suppression - Off/On
- Motor Controllers
 - Cutter - Off/Start/Run
 - Pump and Track - Off/Start/Run
 - Conveyor FWD-OFF/Start/Run
 - Conveyor REV-OFF/Start/Run
- Circuit breaker - Off/On
- Tram speed - Fast/Normal
- All Stop (Emergency)

4.10 CONVEYOR BOOM CONTROL

The automated laser-guided continuous miner will work with either a continuous haulage or shuttle car haulage systems.

Using the miner with a continuous haulage system, the need for automatic control of the conveyor boom position is not necessary. The continuous haulage vehicle behind the miner is mechanically linked to the miner and continuous automatic control is not required. Any change in conveyor boom position can be accomplished by the miner operator because misalignment and, therefore, correction does not occur frequently. With use of a continuous haulage system, an interlock signal from the haulage system must be supplied whenever the haulage is stopped. The miner control system will then disable the conveyor/gathering arm motor to prevent spillage of the coal.

When using the shuttle car haulage system, the control of the conveyor and conveyor boom may be in the hands of the shuttle car operator. To prevent spillage of coal, shuttle car detection is necessary on the miner to disable the conveyor/gathering arm motor when a shuttle car is not present.

The conveyor and conveyor boom control could be located on the shuttle car and thereby requiring a method of communication between the shuttle car and the continuous miner. The communication system recommended is the low power, frequency modulated infrared carrier system. The system uses frequency modulation of the carrier by five discrete frequency signals generated for each of the five functions; (1) conveyor-OFF/ON, (2) raise, (3) lower, (4) left and (5) right positions of the conveyor boom. The five control functions individually modulate the carrier independent of the other four. The communication link between the shuttle car and the miner is an infrared beam generated by light emitting diodes (LED). The number of diodes is to be determined by the radiation pattern required. The LED's are low voltage, low power devices and can be designed intrinsically safe.

The receiver located on the miner has an array of photo detectors to receive the infrared carrier beam. The carrier is demodulated and the signals (up to five) are detected and amplified. The signals to be detected are the five discrete frequencies. When the signals are present, the output will command the movement of the conveyor boom and control of the conveyor.

Loss of signal will be fail-safe, and the conveyor boom will not move. The range of this infrared carrier system is very short and line-of-sight and will be quite suitable for this application. With the limited range, only commands from the shuttle car in range will be received. A distant shuttle car will be unable to activate the boom.

There is a potential visibility problem when the shuttle car operator is controlling the conveyor boom by remote control. If the operators control station is located at one of the rear corners of the car he may not be able to see across the load of coal to guide the conveyor boom as the continuous miner is turning a cross cut toward the opposite side. If the shuttle car control station is located on the side and between the front and rear wheels visibility should be good and conveyor boom control can be handled satisfactorily by the shuttle car operator.

In the event that the operator is not able to see and thus control the conveyor boom while negotiating a turn then the continuous miner operator will have to take over until the turn is completed. This should not pose a problem because the miner operator is required to have all controls on manual mode during turns.

The exact conveyor boom control sequence and methods will have to be studied further after a test mine site is selected, the mine plan being used, and the shuttle car type known.

An alternate communication system is to communicate through the conductors of the power cable. Similarly, a transmitter is located on the shuttle car. This transmitter will send the radio frequency (rf) carrier with the five possible signals onto the conductors back to the power center. At the power center, couplers are used to effect a link between the shuttle car and the miner. The carrier is then received by the miner receiver. After demodulation, the five outputs will command the movement of the conveyor boom and control of the conveyor. Hauling with more than one shuttle car will necessitate special sensing and discriminating circuitry to prohibit the distant shuttle car from controlling the conveyor boom.

4.11 EMERGENCY SHUT OFF CONTROLS

Besides the panic bar located on the operators hand held remote control unit, other emergency shut off switches will be designed into the automated system. These switches will be strategically placed on the sides and rear of the continuous miner so they may be quickly activated by face personnel near the machine. The area just to the rear of the miner and around the conveyor boom is a very hazardous location particularly on an automated miner that will be back tramming on a programmed cycle. The microprocessor that programs the miner is not capable of checking the area before action is initiated so safety engineering effort must be devoted to protecting any personnel that may accidentally get too close to the working machine.

It would be ideal to have a panic bar on the conveyor boom sides so the boom would be shut off before it could accidentally trap and crush some one between the boom and rib. However, the same emergency panic bar may be continually shutting down the machine as the boom is swung into the loaded coal on the shuttle car or into the rib as the miner negotiates a turn.

Further study must be made of these potentially dangerous areas in the continuing phase of this program. Panic shut off devices must be designed and located in areas that are within reach of personnel but are not exposed for unintentional shut down of the continuous miner.

The automated miner will also be provided with an emergency shut down circuit override device. If actuated, this override device will allow restarting of the machine to free a man who may be pinned between the rib and one of the power shut off switches. A situation could occur where a trapped man's body would actuate the panic switch thus shutting off power to the machine. In this trapped situation, he would have to be dug out by cutting the coal away from behind his body. This lost time could cause the miner the loss of his life. The override device would allow emergency restarting of the continuous miner so the machine could be moved away from the trapped man.

SECTION V

REVIEW OF CONCEPTS CONSIDERED

During the course of this program FMC engineers examined available reference material on automation and guidance systems, visited users and developers of automated remote controlled equipment, and held discussion periods and brainstorming sessions to determine the best means of achieving the goal of realistic preliminary designs and specifications for an automated/remote-operated continuous miner. The most promising of these concepts were selected and developed and are presented in Section IV, Guidance System Selected. The other concepts considered are presented here.

The inertial guidance system, which has promise as part of a long range development program, is presented separately in section 5.1 and in greater detail than the other concepts. All the concepts examined are displayed in chart form in section 5.2 under the categories of light sensing, mechanical, electrical, sound sensing and miscellaneous or combinations of the other categories. These systems are presented to show the wide variety of ideas considered and their relative advantages and disadvantages.

5.1 CONTROL OF MINER BY INERTIAL GUIDANCE

A future possibility for control of the miner would be the use of an Inertial Guidance System. This system, adapted to the special requirements of coal mining, would be:

- Completely independent from any external beam (laser, light, radar, etc.).
- Very stable and accurate. Azimuth stability is in the order of 0.01 to 0.02 degrees per hour. Position accuracy (range) is approximately one-tenth foot in every direction.
- A must for long range "face-to-tipple" automated mining systems and innovative mine plans.

Following are excerpts from a Litton brochure on Automatic Surveying:

"At the heart of the Auto-Surveyor System are gyroscopes and accelerometers. By a computer-controlled process known as 'Gyrocompassing' two gyros sense the earth's rotation and orient themselves, one facing North/South and the other East/West. Switching the system to 'Operate' causes these instruments to remain in this orientation while their electronics box (Inertial Measuring Unit) is capable of being moved without disturbing this orientation. This is accomplished by mounting the gyros on a set of moveable elements, gimbals, which are turned in a direction exactly opposite to box movement. The gyros never physically change their North and East orientation. Vertical orientation is also maintained by the same gyros.

'Mounted on the Gyro-Stabilized Platform are three accelerometers mechanically aligned to each gyro axis. When the system has completed gyrocompassing, the accelerometers are all oriented North/South, East/West and vertical.'

'When the System is moved, accelerations or movements as small as 1 part in 10^6 are measured and the system's electronics computes instantly the distance travelled. Since each accelerometer is designed to provide measurements in only one direction, the movements in each cardinal direction are computed separately and displayed as present latitude/longitude or elevation.'

The latitude/longitude and elevation information can be automatically converted to give heading, pitch and range of the miner and can be used directly for guidance by the microprocessor.

The control system will be very similar to the one proposed for laser guidance. Heading and pitch angles will be set with thumb-wheel switches as well as other program information, number of cutting cycles, roof height, etc. See figure 5-1 for tram and lateral control using inertial guidance.

Any deviation from present values and/or programs produces immediately an error signal which is used to correct the condition.

The major reasons that this system has not been selected are:

- Its present high basic hardware cost (\$100,000 to \$300,000). (The cost is expected to come down in the future).
- Long development time to design a unit that will function reliably underground.

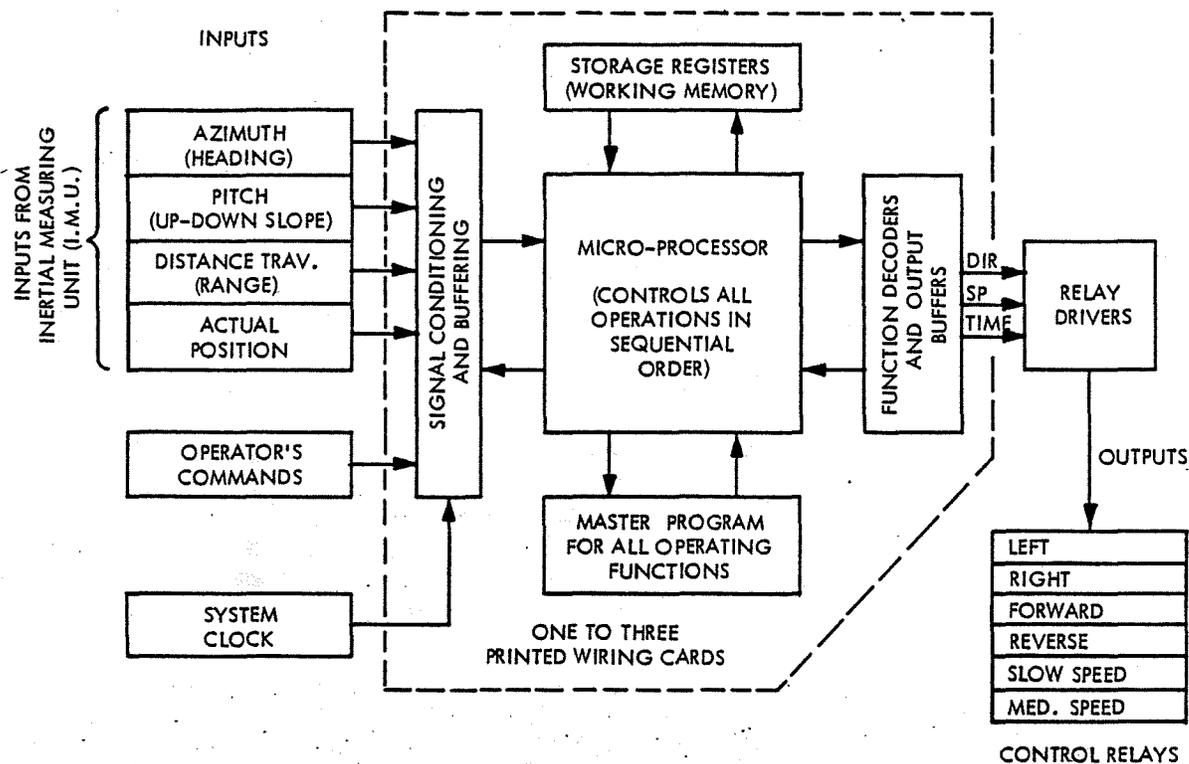


Figure 5-1. Block Diagram and Lateral Control Using Inertial Guidance.

The Guidance and Control Division of Litton, Inc., in Woodland Hills, CA, has offered demonstrations of their present "PADS" (Position and Azimuth Determining System) and the LN-33 Navigation System at their plant. They have further indicated their willingness to work with FMC to design a system tailored for coal mining use.

Copies of brochures describing the Litton "PADS" or LN-33 Systems are to be found in the appendix of this report.

5.2 CONCEPTS CONSIDERED

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|---|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Light Sensing | | | | General: Light sensing systems are not subject to cumulative error. |
| 1. Laser source outby the miner with receiver (target) mounted on the miner, and vice versa. | X | X | | <ul style="list-style-type: none"> +1. Reference light beam cannot be knocked down. +2. Light beam will still guide the operator even if the on-board automated controls fail. +3. In level seams the laser beam may eliminate some surveying requirements. +4. No moving parts to wear. -1. Of limited value in undulating seams. -2. Of limited value in low seam heights. -3. Beam can be blocked by moving objects such as shuttle cars and people. -4. Two sensors or two beams required in a two pass system. |
| 2. Geodimeter (Laser based distance measuring device). | | | X | <ul style="list-style-type: none"> +1. Very accurate +2. May eliminate much surveying +3. Measuring device (modulated light beam) cannot be knocked down. +4. Inexpensive (commercial units about \$2,000) -1, -2, -3, Same as for item 1. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|---|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Light Sensing (Continued) | | | | |
| 3. Triangulation on a point light source. A light bulb (small, intense source) is mounted outby the miner. Rotating mirrors reflect light onto a photodetector. Angle of mirror displacement and photodetectors will determine relationship to point source. An alternative is to put the point source on the miner and mirrors and photodetector outby miner. | X | X | X | <ul style="list-style-type: none"> +1. Very accurate +2. Straight forward triangulation techniques could be used. +3. Beam cannot be knocked down. -1, -2, -3 Same as for item 1. -4. Two sets of mirrors would be required to accomplish all three functions. -5. Dust on mirrors could be a problem. -6. If light source fails there is no guide for the operator. -7. Machine vibration would require mirrors to constantly be re-orienting which could shorten useful bearing life. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|---|
| Light Sensing (Continued) | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| 3. (Continued) Data could be transmitted to miner by tie-in to control pendant, multiplexing over trailing cable, or radio. | | | | |
| 4. Laser beam with a 90° constant deviation prism on the miner. The prism splits the beam into two beams at right angles to each other. This allows the sensing of both lateral displacement and yaw or vertical | X | X | | <p>+1. No moving parts to wear.</p> <p>+2. Reference beam cannot be knocked down.</p> <p>+3. Could be relatively insensitive or very sensitive by varying the distance between mirrors and prism.</p> <p>-1, -2, -3 same as for item 1.</p> |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|----------------------------|--|--------------------|--|
| Light Sensing (Continued) | Lateral Entry Alignment | Vertical Dis- placement of Entry | Machine Advance | |
| <p>4. (Continued) displacement and pitch. Two laser beams and two sets of prisms and sensors required to fill both applications. Vice versa should also work.</p> | | | | |
| <p>5. Horizontally fanned laser beam with target on shear boom for vertical control, with a vertically fanned laser beam with target on miner for lateral control.</p> | X | X | | <p>+1. The vertically fanned beam is more useable in undulating seams for lateral control than is a single pencil-sized beam.</p> <p>+2. The horizontally fanned beam would be useful for vertical control in a two-pass mining system.</p> <p>-1, -2, -3, same as item 1.</p> <p>-4. Twice as many beams and sensors required as in item 1 to do the same task.</p> |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|---|----------------------------|--|--------------------|---|
| Light Sensing (Continued) | Lateral Entry Alignment | Vertical Dis- placement of Entry | Machine Advance | |
| 6. Pulsed lamp somewhat to geodimeter except would use an incandescent or mercury vapor source. Lamp would be outby the miner and receiver on the miner, or vice versa. | | | X | <p>-1, -2, -3 same as item 1.</p> <p>-4. Could be subject to extraneous signals from cap lamps or machine lighting.</p> <p>-5. Possible permissibility problems with high intensity lamp.</p> <p>-6. Bright flashing lamp could be very distracting.</p> <p>-7. Would require more development than geodimeter.</p> |

5.2 CONCEPTS CONSIDERED

| Concept | Application | | | Advantages and Disadvantages |
|---|-------------------------|--------------------------------|-----------------|---|
| Mechanical | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | <p>General: (+) These devices are often self-contained on the miner, requiring no external beams or references.</p> <p>(-) Mechanical devices are usually subject to cumulative error.</p> |
| | | | | 1. Inertial Guidance (gyroscope) |
| 2. Whisker or ski against rib, roof and/or floor would locate the machine with respect to the entry just cut. | X | X | | <p>+1. Would work in undulating seams.</p> <p>+2. Skis are presently used to control fine grade construction equipment.</p> <p>+3. Practical</p> <p>+4. Mine could cut seam height based on a roof reference instead of a floor reference, so that the effect of poor bottom conditions would be minimized.</p> <p>-1. Machine would block off entire entry and make maintenance more difficult.</p> <p>-2. Rib rolls and roof falls would introduce large errors.</p> <p>-3. Sudden moves of the machine, such as tramping over a roll in the floor, which causes the machine to pitch forward, could damage the skis or whiskers by forcing them against the roof or twisting them against the rib.</p> |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|---|-------------------------|--------------------------------|-----------------|--|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Mechanical (Continued) | | | | |
| 2. (Continued) | | | | <ul style="list-style-type: none"> -4. Skis would ride over high spots and thus indicate only minimum seam heights and entry widths. -5. No lateral control when starting a new cut from an intersection. |
| 3. Keel riding in floor groove. A device at the front of the miner would cut a slot in the floor in which a keel or sensor assembly would ride. | X | | | <ul style="list-style-type: none"> -1. Requires a firm, strong floor. -2. Sensor or keel subject to error due to mechanical wear from abrasion by floor material. -3. Subject to error due to accumulations of mud on keel or possible distortion of keel. -4. Destroys ground clearance when tramping in non-keel-guided areas. |
| 4. Taut cable from miner to roof or floor with cable location sensors on roof or floor. Taut cable creates a | X | | X | <ul style="list-style-type: none"> +1. Could double as a distance measurement device. -1. Doesn't indicate yaw of machine. -2. Vibration wire may cause erroneous signals. These could be eliminated by time averaging or time delay devices. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|--|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Mechanical (Continued) | | | | |
| 4. (Continued) straight line from miner to distant reference point. The line indicates the miner's direction of travel. Sensors detect cable movements or deviations from true course. | | | | -3. Cable can be knocked down, people and machines will run into it, especially in low seams. |
| 5. Air jets to locate ribs and roof. Similar to item 2. | X | X | | +1. All components readily available. +2. Simple, easy to use. -1. Would give erroneous readings due to mud accumulations and debris on floor. |
| 6. Fifth wheel. Commonly used on test tracks and roadways | | | X | +1. All components readily available. +2. Simple, easy to use. -1. Would give erroneous readings due to mud accumulations and debris on floor. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|--|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Mechanical (Continued) | | | | |
| 6. (Continued) as a distance measuring device. | | | | |
| 7. Cogged track. A track with large teeth capable of preventing track slippage so that track sprocket revolutions could be counted to measure distance traveled. | | | X | -1. Turning the machine would be either impossible or would tear up the floor very badly. |
| 8. A pilot hole would be drilled in the face ahead of the miner. A probe would periodically check the location | X | X | | -1. Would interrupt the sump shear cycle and lessen productivity. -2. Probe would be exposed to a large risk by being so close to the face. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|---|-------------------------|--------------------------------|-----------------|---|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Mechanical (Continued) | | | | |
| 8. (Continued) of the hole. Similar techniques are used with rotary tunneling machines. | | | | |
| 9. Manometer with floats to measure boom angle, roll; and pitch, would probably be used in conjunction with other systems | X | X | | +1. Has been tested. +2. Would give a continuous reading of angular displacement. -1. Not commercially available. |
| 10. Push rod against face floor, roof or rib. | | | X | +1. Push rod could actuate linear and rotary transformers or potentiometers to indicate length and angle or rod, from which miner displacement could be calculated. Would be good for measuring sumping depths. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|--|
| Mechanical (Continued) | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| 10. (Continued) | | | | <ul style="list-style-type: none"> -1. Would not work well against face, too many hazards. -2. Would not indicate large distances, such as 30 to 40 foot lifts. |
| 11. Positive stops on shear boom would be hydraulically moved by remote operator to control boom travel. | | X | | <ul style="list-style-type: none"> +1. Simple and reliable. +2. This device could be used in conjunction with a laser or other reference to precisely control the shear boom. -1. Stops would have to be self-cleaning. -2. Operator must be able to observe cutting drum well enough to adjust its location to nearest 3/8 inch of correct location. -3. Requires consistent clean floor. Debris under tracks would cause the roof and floor to be cut too high. |
| 12. The miner could be equipped to install magnetically permeable | X | | X | <ul style="list-style-type: none"> +1. This is a completely self-contained system with independent lights, light beams, hanging cables, rib and floor variations. Variations in seam height might cause some problems. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|--|
| Mechanical (Continued) | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| 12. (Continued) or electrically conductive spads or pins in the roof entry every four feet. Sensors would detect the position of two markers to determine where to place a third marker. | | | | <p>+2. Markers could be used as a reference for spacing roof bolts.</p> <p>-1. If the location of the first two markers is sensed exactly, the third must be emplaced within $\pm .019$ inch.</p> <p>-2. If the device for emplacing markers fails, there is no guidance available.</p> |
| 13. Mark trailing cable or attach a tape or graduated rope to it. | | | X | <p>+1. Would indicate total distance traveled.</p> <p>-1. Trailing cable repairs could make it inaccurate.</p> <p>-2. Mud and abrasion would obliterate the markings.</p> |

.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|---|
| Electrical | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| <p>Two wire reels could be attached to the miner and the wires tied off at a point on the roof. The reels would turn rotary potentiometers which would generate electrical signals to indicate wire length paid out.</p> | X | X | X | <p>+1. This is a triangulation procedure and would be accurate.</p> <p>-1. Error due to friction in the reels.</p> <p>-2. Wires can be knocked down; people and machinery will run into them.</p> |
| <p>2. Multiplexing over trailing cable.</p> | | | | <p>Considered only as a means of transmitting data to perhaps eliminate the umbilical cord of the operator's pendant.</p> |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|---|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Sound Sensing | | | | |
| 1. Triangulation with ultrasonic sound source out-by miner, two receivers on miner, and vice versa. | X | X | X | <p>-1. Possible physiological problems.</p> <p>-2. Echoes from ribs, floor, and roof would create noise signals.</p> <p>Has most of the advantages and disadvantages of lasers.</p> |
| 2. Reference face, ribs, roof, and floor with ultrasonic sound waves. This is the ultrasonic equivalent of a mechanical whisker or ski or air jet. | X | | X | <p>+1. Indicates contour of surfaces, high and low points.</p> <p>-1. Possible physiological problems.</p> <p>-2. Echoes could be a problem.</p> |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|--|--------------------------------|-----------------|---|
| Miscellaneous or Combinations of Various Systems | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| | <p>1. A transmitter or source of sound, radio, microwave, or radio-active signals could be emplaced in the earth ahead of the miner and it could home in on these signals. Two signal sources would allow triangulation.</p> | X | X | X |
| <p>2. Microwave generator on miner with receiver on miner. The receiver would form an image of its surroundings from the reflected microwaves.</p> | X | X | X | <p>-1. Effect of objects moving through the receiver's field of view.</p> <p>-2. Echoes may create noise.</p> |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|--|-------------------------|--------------------------------|-----------------|--|
| | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| Miscellaneous or Combinations of Various Systems (Continued) | | | | |
| 3. Same as item (2) above except use Doppler radar. | X | X | X | -1. Effect of objects moving through the receiver's field of view. -2. Echoes may create noise. |
| 4. Guide on belt haulage system. A sufficiently long haulage system, rope or similar device could protrude from behind the miner and be instrumented, such as with strain measuring devices to tell the miner whether or not it was bending. This bending would indicate : | X | X | X | -1. Would require long lifts, probably several hundred feet, to make this system worthwhile. |

5.2 CONCEPTS CONSIDERED (Continued)

| Concept | Application | | | Advantages and Disadvantages |
|---|-------------------------|--------------------------------|-----------------|--|
| Miscellaneous or Combinations of Various Systems (Continued) | Lateral Entry Alignment | Vertical Displacement of Entry | Machine Advance | |
| | | | | 4. (Continued) the miner was going off course. |
| 5. Always return miner to same starting point during automatic cycle. | X | | X | +1. This would tend to cancel out errors due to track slippage. -1. This is time consuming and would reduce productivity. |

SECTION VI
PRODUCTIVITY

6.1 SUMMARY

Table 6-1 shows an idealized per shift production for three types of Joy 12CM-10 continuous miners. The miners are operating in a five-entry mine with entries and breaks on 80-foot centers, as shown in figure 6-1. Entry width is 20 feet, and seam height is 6 feet. The miner features a 10' 10" wide cutting head and is two-pass mining.

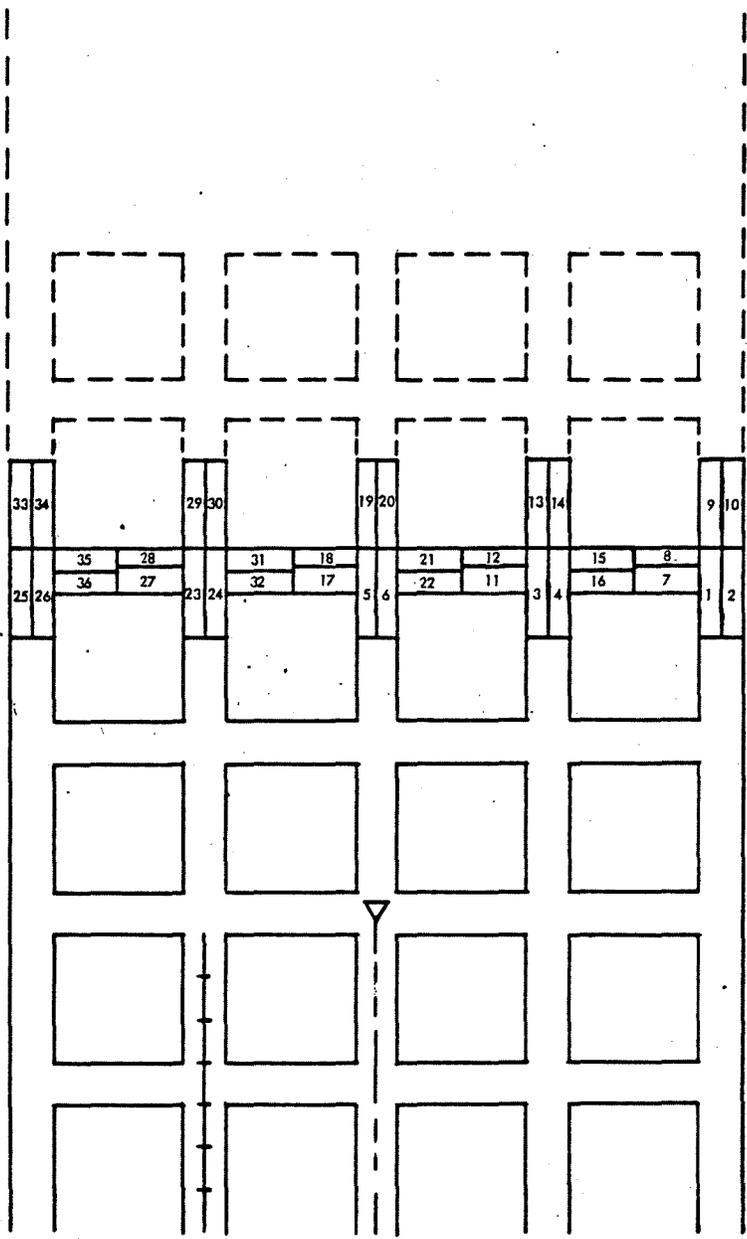
TABLE 6-1. MINER PRODUCTION COMPARISON

| Type of Miner Controls | Per Shift Production (tons of raw coal) | | Relative Increase over the On-board Operator with Manual Controls (%) |
|--|---|--------------------|---|
| | Shuttle Car Haulage | Continuous Haulage | |
| Automated with Remote Manual Override | 695 | 754 | 19.8 |
| Remote Manual | 652 | 707 | 12.5 |
| On-Board Operator with Manual Controls | 580 | 628 | - |

6.2 DISCUSSION

The productivity of the automated miner was determined by using an idealized mine plan which utilizes its automated features to greatest advantage; i.e., long uninterrupted cuts with a minimum of place changes. This can be accomplished if, in addition to the automated controls, an on-board exhaust ventilation system is provided which can maintain ventilation within 10 feet of the face. This system can be utilized in conjunction with a duct and auxiliary fan ventilation system. The on-board system would have to remove at least 3900 cfm (cubic feet per minute) of air from the face and perhaps as much as 6500 cfm, depending on local requirements. In certain mines, such a miner used in conjunction with two Joy 16SC shuttle cars or continuous haulage could advance up to 42 feet beyond the last full row of roof bolts. This presupposes that the roof is strong enough to remain intact when a 10-foot, 10-inch wide entry is driven this deep.

100 FEET



NOTES:

1. ENTRIES ON 80 FOOT CENTERS.
2. BREAKS ON 80 FOOT CENTERS.
3. ENTRIES AND CROSSCUTS ARE 20 FEET WIDE.
4. ▽ FEEDER BREAKER.
5. + + + RAIL
6. - - - CONVEYOR
7. RIGID AND FLEXIBLE DUCTING FOR VENTILATION
8. 10 FOOT, 10 INCH WIDE CUTTER HEAD.

Figure 6-1. Mine Plan and Cut Sequence

If roof conditions are such that 40-foot lifts can not be safely accomplished, then shorter lifts with more place changes would be required. This would result in a slightly less efficient use of the automated capabilities of this system.

The cutting cycle utilized is shown in table 6-2. Two planning features should be noted: (1) the shuttle car leaves as soon as the cusp is removed, and (2) cleanup is performed every second cutting cycle. This will keep the floor as clean as possible and minimize the loose material the crawler tracks have to travel over. The depth of sump is selected by the operator so that each cycle produces one shuttle car load of coal (5.34 tons).

On the basis of the mine plan, the modified continuous miner, the selected haulage system, and the cutting cycle discussed above, a Gantt chart was prepared and analyzed (section 6.3) to show that 695 and 754 tons of raw coal could be produced by shuttle car and continuous haulage systems respectively. However, an identical miner with only remote manual controls and operating in the same mine could produce almost as much coal. A careful comparison of the two machine loading and operating cycles reveals that the only measurable difference is the time required by the operator to actuate the remote manual controls. By adding time for actuating manual controls to the automated miner cycle times shown in table 6-3, cycle times for the remote manually operated miner can be developed. These two sets of cycle times can be compared to each other to determine the potential time savings and production increase. Figure 6-2 shows that the potential production increase is 6.6%. Using this value, production figures for a remote manually operated miner can be calculated to be 652 and 707 tons for shuttle car and continuous haulage, respectively.

As a basis of comparison, Joy Manufacturing reports that one coal operator has experienced productivity increases of 10 to 15% by using remotely controlled miners.¹ Using a nominal average of 12 1/2%, production figures for a miner with on board manual controls can be calculated as 580 and 628 raw tons for shuttle car and continuous haulage, respectively.

Comparing the automated miner to one with on board manual controls shows a relative increase in production of 19.8%. Time studies which show net changes of less than 15% are generally viewed with some skepticism as it is felt the inputs to the study are no more accurate than $\pm 15\%$. However, the combination of remote controls and automation should show a production

(1) Warner, E. M., "Cable and Wireless Remote Control of Continuous Miners", paper presented to American Mining Congress, Washington, D. C., Sept., 1973, pg. 7.

TABLE 6-2. CUTTING CYCLE

| Operation | Cutter Motors | Conveyor and Gathering Table Motors | Tram Motors | | Shear Cylinders | Gathering Table Cylinders |
|--|---------------|-------------------------------------|-------------|-----------|-----------------|---------------------------|
| | | | 10 f.p.m. | 35 f.p.m. | | |
| 1 Sump | x | x | forward | | | |
| 2 Shear | x | x | | | down | |
| 3 Remove Cusp | x | x | reverse | | | |
| 4 Shuttle car leaves | | | | | | |
| 5 Return to Face (Raising Shear Simultaneously) | x | | forward | | up | |
| 6 Wait for signal from shuttle car or remote operator. | | | | | | |
| 7 Sump | x | x | forward | | | |
| 8 Shear | x | x | | | down | |
| 9 Remove Cusp | x | x | reverse | | | |
| 10 Shuttle car leaves | | | | | | |
| 11 Cleanup (back tram, raise gathering table) | | | | reverse | up | up |
| 12 Cleanup (drop gathering table, tram forward) | | | | forward | up | down |
| 13 Return to face | | | forward | | up | |
| Wait for signal from shuttle car or remote operator. | | | | | | |

x = on or energized

TABLE 6-3. LOADING CYCLE TIMES FOR AUTOMATED MINER WITH REMOTE
MANUAL OVERRIDES

| Step | Description | 10'10" Wide Cut | | | 9'2" Wide Cut | | |
|------|---|----------------------|-------------------|--------------------|----------------------|-------------------|--------------------|
| | | Production (tons) | Time (sec) | Rate (tons/min) | Production (tons) | Time (sec) | Rate (tons/min) |
| 1. | Sump at 1.5 ips 23.2" in 10'10" cut | | 15.5 | 10.9 | | 18.3 | 9.2 |
| 2. | Shear down 34 in. at 1.5 ips (38' cutter O.D.) | | 22.7 | 6.4 | | 22.7 | 6.7 |
| 3. | Brush floor (remove cusp) at 2 ips 23.2" in 10'10" cut 27.4" in 9'2" cut | | 11.6 | | | 13.7 | |
| | SHUTTLE CAR DEPARTS | | | | | | |
| | SUBTOTAL | 5.34 | 49.8 (.8 min.) | | 5.34 | 54.7 (.9 min.) | |

6-5

ASSUMPTIONS: 10'10" wide cutting head; 20 ft. entry; two pass
6 ft. seam height
Delete all operator control time.

| | |
|---|--|
| Potential Increase in a 10'10" cut is 6.9% | $\frac{(.0204 \frac{\text{min}}{\text{step}}) (3 \text{ steps}) (\frac{60 \text{ sec}}{\text{min}}) (100)}{49.8 \text{ sec} + .0204 \frac{\text{min}}{\text{step}} (3 \text{ steps}) (\frac{60 \text{ sec}}{\text{min}})} = 6.9\%$ |
| Potential Increase in a 9'2" cut is 6.3% | $\frac{(.0204 \frac{\text{min}}{\text{step}}) (3 \text{ steps}) (\frac{60 \text{ sec}}{\text{min}}) 100}{54.7 \text{ sec} + .0204 \frac{\text{min}}{\text{step}} (3 \text{ steps}) (\frac{60 \text{ sec}}{\text{min}})} = 6.3\%$ |
| <p>A weighted average increase can be determined, as 54.17% of a 20-foot wide entry of given depth will be cut as a 10'10" face and 45.83% will be cut as a 9'2" face.</p> $\frac{(54.17 \times 6.9) + (45.83 \times 6.3)}{100} = 6.6\% \text{ weighted average percent of time saved}$ | |

9-9

- Notes:
1. The available potential increases in production are equal to the potential time saved.
 2. To allow for human actions and reactions in a nonautomated system, add .0204 minutes to each step in the loading cycle. (FMC Corp. Phase I Report, The Development of a Miner/Bolter System, December, 1974, Section VII, pg. A-0).

Fig. 6-2 Potential Production Increase of Automated Miner Over Remote Manually Operated Miner

increase. It should be kept in mind that the increase will probably not be 19.8% but could vary from about 5 to 35% depending on the specific operating conditions of a given mine and a given operator.

There are other qualitative benefits of the automated miner which will tend to increase production but to which specific values can not be assigned. These include less time recutting ribs in misdirected entries, aligning the miner, or waiting for dust to clear so that the operator can see where the face, roof, and floor are. General operator fatigue and job-related awareness as the day progresses also adversely effect productivity.

6.3 SUMMARY OF GANTT CHART ANALYSIS OF AUTOMATED MINER

6.3.1 Raw Data

The following data was compiled based on an available mining time of 395 minutes.

| Operation | Time (min.) | % of total |
|----------------------------------|--------------|--------------|
| Loading | 158.2 | 40.1 |
| Clean up | 26.4 | 6.7 |
| Return to face | 55.5 | 14.1 |
| Tramming (place to place) | 38.5 | 9.8 |
| Preparing to mine | 10.0 | 2.5 |
| Preparing to leave | 10.0 | 2.5 |
| Waiting (shuttle car change out) | 22.3 | 5.6 |
| Time lost | .1 | 0. |
| Installing Tubing and Jacks | 74.0 | 18.7 |
| TOTAL TIME | 395.0 | 100.0 |

Total Number of Shuttle Cars = 188
 Total Tonnage = 1004 (Raw Coal)

This data is based on the cut sequence 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15 and 16 (partially mined) as shown in figure 6-1 and the Gantt Chart Analysis shown in figure 6-3.

6.3.2 Corrections for Delay Times and Other Variables

The above analysis allows no delay time for maintenance or other causes, except the 0.1 minute of time lost at the end of the 395 minutes because of the mining plan. The following allowances will be made for delays:

- Referring to FMC's Phase I Report on the Preliminary Design of the Development of a Miner/Bolter System, page 8-60, it was found that one mine experienced an average of 70.2 minutes (14.6¢) of downtime per 480 minute shift. (This was the average for 260 shifts.)
- This analysis presumed that right angle turns could be made at the same rate as cutting a straight entry, which they cannot. To allow for the manual operations which must be performed in establishing set back and making partial cuts to develop a turn, 6 additional minutes will be allowed for each of the three right angle cuts.
- Shuttle car waiting time is a very low 22.3 minutes. There are two reasons for this. First, the feeder breaker is two breaks outby the miner. Secondly, the shuttle cars leave the miner as soon as the miner has finished removing the cusp; the shuttle car operator does not wait for the miner to return to the face.

To allow for the feeder breaker not being kept two breaks behind the miner, but not more than three breaks, the waiting time will be increased by 50%.

- Total Delays

| | |
|--------------------------|-------------------------------|
| Maintenance | 70.2 minutes |
| Cutting turns | 18.0 |
| Shuttle car waiting time | |
| 1.5 x 22.3 min. = | <u>33.5</u> |
| | 121.7 minutes |
| | <u>- 0.1</u> minute lost time |
| Total Delay Time | 121.6 |

The actual mining time then is $395 - 121.6 = 273.4$ minutes.
Taking a direct ratio to determine the corrected production:

$$\text{corrected production} = \frac{1004 \text{ raw tons}}{395 \text{ minutes}} \times 273.4 \text{ minutes} = 695 \text{ tons of raw coal}$$

6.3.3 The Effect of Continuous Haulage

Assuming the use of continuous haulage completely eliminates shuttle car waiting time (33.5 minutes) makes this time available to extract coal.

$$\left(\frac{273.4 \text{ minutes actually mining}}{395 \text{ minutes available}} \right) 33.5 \text{ minutes} = 23.2 \text{ more minutes actually spent mining coal}$$

$$23.2 \text{ minutes} \frac{1004 \text{ tons}}{395 \text{ minutes}} = 59.0 \text{ tons of raw coal increased production}$$

6.3.4 Gantt Chart Standard Data

Equipment:

A. Automated Miner

1. Load rate
10'10" wide sump 23.2" deep = 0.8 minute
9'2" wide sump 27 4" deep = 0.9 minute
2. Tramming rate: 35 fpm
3. Cleanup: at 35 fpm forward and reverse.

B. Two Joy 16SC Shuttle Cars

1. Travel rate (empty and loaded on level bottom) -
.0025 fpm (4.5 miles per hour)
2. Dump time: 0.6 minutes
3. Capacity per car: 5.34 tons of raw coal

C. Feeder: 3-way dump

Other Time Data:

- A. Travel time to section: 30 minutes
- B. Travel time from section: 30 minutes
- C. Travel from man station to face: 5 minutes
- D. Prepare to work time: 10 minutes

- E. Time preparing to leave section: 5 minutes
- F. Travel from face to man station: 5 minutes
- G. Total time available to mine: 395 minutes

Dimensional Data:

- A. 5-entry system on 80-foot centers with breaks on 80-foot centers
- B. Width of entries: 20 feet
- C. Mining height of coal: 6 feet
- D. Sump Widths: 10'10" and 9'2"
- E. Depth of sumps: 40 and 30 feet

6.3.5 Code for Gantt Chart

- L - Load time
- W - Wait time
- CU - Cleanup time (table 6-2)
- R - Return to face time (table 6-2)
- TI - Travel in time, from change-out point to miner.
- TO - Travel out time, from miner to change-out point.
- TL - Travel loaded time, from change-out point to feeder.
- TE - Travel empty time, from feeder to change-out point.
- D - Dump time
- PL - Time preparing to leave a place, includes cable and duct handling and setting some temporary safety jacks.
- PM - Time preparing to mine a place, includes cable handling and establishing proper face ventilation.
- ②6 - Number of shuttle car load.

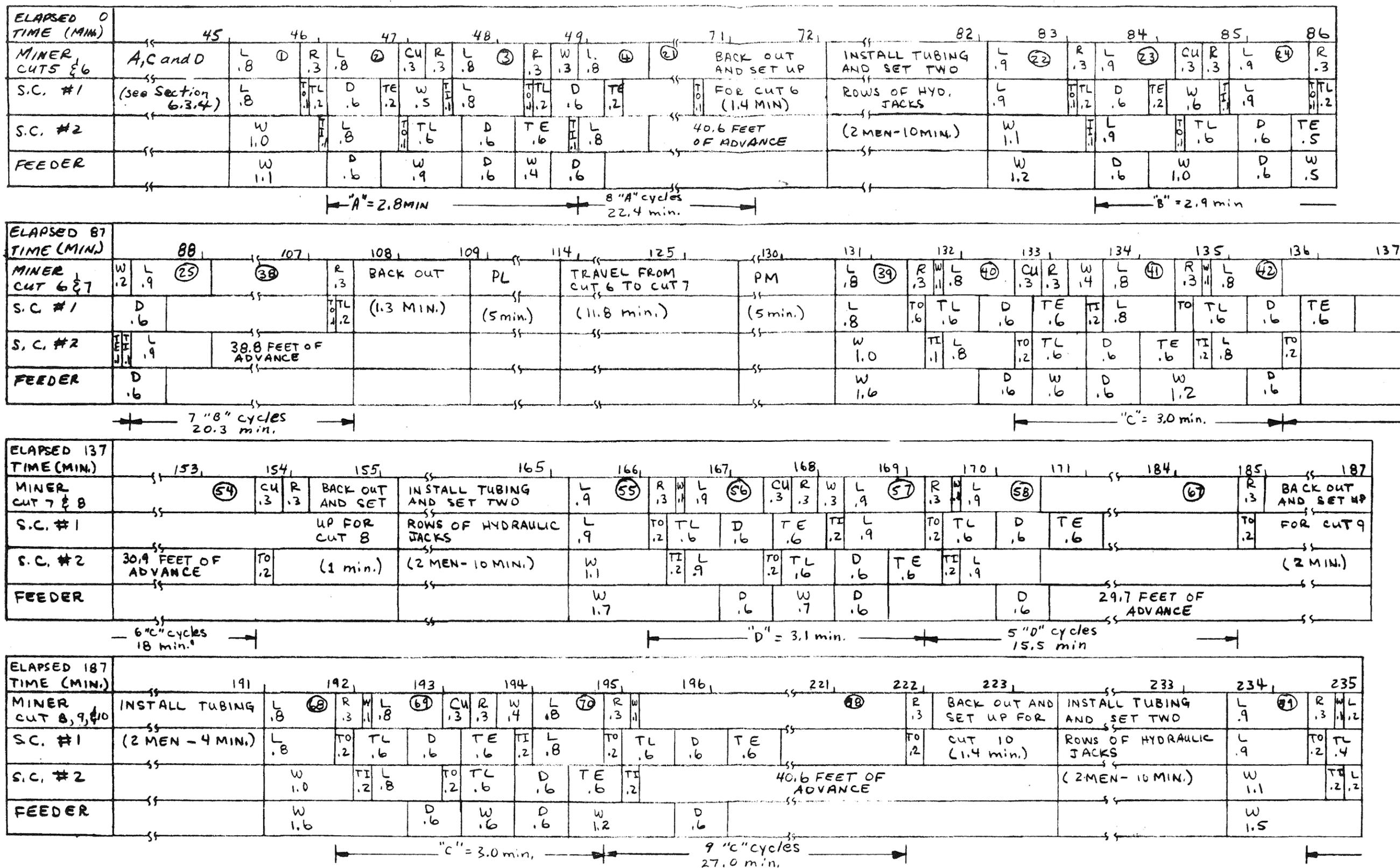


Figure 6-3. Gantt Chart Analysis (1 of 2)

| | | | | | | | | | | | | | | |
|---------------------|-----|----------------------|-----------|---------|----------------------------|---------|------------|----------------------|------------------------|------|------|----------------------------|------------|-------|
| ELAPSED TIME (MIN.) | 235 | 259 | 260 | 261 | 266 | 276 | 281 | 282 | 283 | 284 | 285 | 300 | 301 | 302 |
| MINER CUT 10 & 11 | | (103) R .3 | BACK OUT | PL | MOVE FROM CUT 10 TO CUT 11 | PM | L .8 (106) | R .3 W .1 L .8 (107) | CU R .3 L .8 (108) | | | (120) R .3 W .1 L .8 (121) | CU .2 | |
| S.C. #1 | | 38.8 FEET OF ADVANCE | (1.3 min) | (5 min) | | (5 min) | | | | | | | | |
| S.C. #2 | | | | | (10.9 min) | | | | | | | | | |
| FEEDER | | | | | | | W 1.0 | TI .2 L .8 | TO .2 TL .4 D .6 TE .4 | W .0 | D .6 | | TI .2 L .9 | TO .2 |



| | | | | | | | | | | | | | |
|------------------------|------|----------------------|----------------------------|------------|------------------------|------------------------|------------------------|------|------------|-------------------------|-----------------|------------|------------------|
| ELAPSED TIME (MIN.) | 302 | 303 | 313 | 314 | 315 | 316 | 317 | 318 | 331 | 333 | 337 | 338 | 339 |
| MINER CUT 11, 12, & 13 | R .3 | BACK OUT AND SET UP | INSTALL TUBING AND SET TWO | L .9 (122) | R .3 W .1 L .9 (123) | CU .3 R .3 L .9 (124) | R .3 W .1 | | (134) R .3 | BACK OUT AND SET UP FOR | INSTALL TUBING | L .8 (135) | R .3 W .1 L .4 |
| S.C. #1 | | FOR CUT 12 | ROWS OF HYD. JACKS | L .9 | TO .2 TL .4 D .6 TE .4 | TI .2 L .9 | TO .2 TL .4 D .6 TE .4 | | TO .2 | CUT 13 (2 MIN.) | (2 MEN - 4 MIN) | L .8 | TO .2 TL .4 D .2 |
| S.C. #2 | | (1 MIN.) | (2 MEN - 10 MIN.) | W 1.1 | TI .2 L .9 | TO .2 TL .4 D .6 TE .4 | TI .2 | | | 24.7 FEET OF ADVANCE | | W 1.0 | TI .2 L .4 |
| FEEDER | | 30.9 FEET OF ADVANCE | | W 1.5 | D .6 | W .7 D .6 | W .9 | D .6 | | | | W 1.4 | D .2 |



| | | | | | | | | | | | | |
|------------------------|-----|----------------------|----------------------|----------------------------|------------|-----|------------|-------------------------|------------------|------------|-----|-----|
| ELAPSED TIME (MIN.) | 339 | 364 | 365 | 366 | 376 | 377 | 399 | 401 | 405 | 406 | 407 | 408 |
| MINER CUT 13, 14, & 15 | | (155) R .3 | BACK OUT AND SET UP | INSTALL TUBING AND SET TWO | L .9 (156) | | (172) R .3 | BACK OUT AND SET UP FOR | INSTALL TUBING | L .8 (173) | | |
| S.C. #1 | | | FOR CUT 14 (1.4 min) | ROWS OF HYD. JACKS | L .9 | | TO .2 | CUT 15 (2 MIN.) | (2 MEN - 4 MIN.) | L .8 | | |
| S.C. #2 | | 40.6 FEET OF ADVANCE | | (2 MEN - 10 MIN.) | | | | 38.8 FEET OF ADVANCE | | | | |
| FEEDER | | | | | | | | | | | | |



*NO S.C. LOADED TO BE LOADED OUT AT END OF CUT 16. CONTROLLED MANUALLY.

| | | | | | | | | | | |
|---------------------|-----|-------------------|-----------------------|---|-----------------|-------------|-----|-----|----------------------|-----|
| ELAPSED TIME (MIN.) | 400 | 424 | 425 | 426 | 427 | 439 | 440 | 445 | 450 | 480 |
| MINER CUT 15 & 16 | | (187) R .3 L .8 * | BACK OUT AND SET | HANG BRATTICE WHERE CUTS MEET | L .9 (188) R .3 | | E | F | B | |
| S.C. #1 | | | UP FOR CUT 16 (1 min) | CUT 4 AND CUTS 7 & 8 MEET CUT 1 (2 MEN - 12 MIN.) | L .9 | TO .2 | | | (See section 6.3.4.) | |
| S.C. #2 | | TE .4 | | | | | | | | |
| FEEDER | | | 30.3 FT. OF ADVANCE | | | .1 min lost | | | | |

Figure 6-3. Gantt Chart Analysis (2 of 2)

SECTION VII

COST

This sections deals with the costs of the automated miner discussed in section VI; ie., the cost of taking an existing remote operated continuous miner with on-board ventilation and using shuttle car haulage, and adding automation and guidance systems in order to produce the 6.6% production increase shown in section VI, figure 6-2.

Analysis of the costs of a laser-guided automated miner reveals the following:

- Total cost for a retrofit kit is estimated at \$69,116.
- The kit will pay for itself in 35 weeks at a total cost of \$78,355 (including cost of capital and repair parts).
- The benefits-cost ratio is 3.27.
- The rate of return on the \$69,116 investment over an 18-month period will be 122%.

A general analysis of the economics of automating a miner show that:

- A 40 ton per shift increase in production will amortize a \$100,000 investment in 1 1/2 years plus show a 32% rate of return.
- Although an inertial guidance automated miner is not now economically feasible, it may soon be so.

7.1 LASER-GUIDED AUTOMATED MINER COSTS

The cost to convert an existing remote-operated miner (with existing on-board ventilation) to a laser-guided automated miner is estimated to be \$69,116. This is the cost for a factory produced retrofit kit which could be installed on the miner underground. It includes lost production during the installation period. The cost breakdown is as follows:

| | |
|---|-----------------|
| Miner electrical modifications | \$29,975 |
| Miner mechanical modifications | 2,002 |
| Labor and travel | 1,130 |
| Modifications to accommodate shuttle car haulage | 19,057 |
| Lost Production (652 tons per shift x 2 shifts x 65% ($\frac{\text{clean tons}}{\text{raw tons}}$) x \$20 per ton selling price) | 69,116 |
| | <u>\$69,116</u> |

A more detailed cost breakdown is shown in table 7-1.

The break-even point is at 35 weeks and \$78,355, and is shown in figure 7-1. The break-even point was determined based on the above cost of \$69,116 and the following assumptions:

- Two production shifts per day, 5 working days per week.
- Cost of capital is 10%.
- Increased production results in a weekly gross income increase. For the purpose of this estimate, a conservative 40% of increased income is directly applicable to amortizing the above investment and paying for repair parts.
- The annual repair parts cost can be estimated as 20% of the system hardware cost (this is a construction industry rule of thumb.)

$$40\% \times (695-652) \frac{\text{raw tons}^*}{\text{shift}} \times 65\% \left(\frac{\text{clean tons}}{\text{raw tons}} \right) \frac{x \$20}{\text{clean ton}} \times$$

$$\frac{10 \text{ shifts}}{\text{week}} = \frac{\$2236}{\text{week}} \text{ increased income}$$

A benefits-cost relation can be determined by assuming a 3-year life for the system and assuming an annual repair parts cost of 20% of the system price.

*See Section VI for production figures.

Benefits-Cost Ratio = $\frac{\text{Benefits to user}}{\text{Costs to user}}$

= \$2236 per week x 50 production weeks
per year x 3 years ÷ \$69,116 initial
investment + \$2208 cost of capital +
(\$52,164 initial system cost** x 20%
repairs per year x 3 years)

= $\frac{\$335,400.00}{\$102,622.40}$

= 3.27

**Initial investment less lost production.

TABLE 7-1 COST DETAILS
MINER ELECTRICAL

| Item | Description | Cost |
|------|---|-----------------|
| 1 | Microprocessor and access. | \$ 4,000 |
| 2 | Shear boom transducers and encoder | 950 |
| 3 | Output control devices | 700 |
| 4 | Pitch angle transducer and encoder | 700 |
| 5 | Laser source | 4,000 |
| 6 | Sensor assy. | 6,500 |
| 7 | Infrared Distance Meter (modified) | 6,000 |
| 8 | Reflectors | 500 |
| 9 | Remote Control Panel Assy. | 2,300 |
| 10 | Cables | 1,050 |
| 11 | Discrete Position Sensor, Stab Jack and Gathering Head | 250 |
| 12 | Machine Status Sensors | 300 |
| | | <hr/> |
| | | \$ 27,250 |
| | Contingency (10%) | <hr/> 2,725 |
| | | <hr/> \$ 29,975 |

MINER MECHANICAL

| | | |
|---|--|----------------|
| 1 | Processing Equipment Enclosure (assume explosion proof) | \$ 900 |
| 2 | Methane Monitor Junction Box | 160 |
| 3 | Mounting Brackets and Hardware | 325 |
| 4 | Armor for Sensor Array and Distance Meter | 260 |
| 5 | Hydraulic Valve | 175 |
| | | <hr/> |
| | | \$ 1,820 |
| | Contingency (10%) | <hr/> 182 |
| | | <hr/> \$ 2,002 |

TABLE 7-1 COST DETAILS (Cont.)

LABOR AND TRAVEL

| Item | Cost |
|---|----------|
| 1 Direct Mine Labor 3 men for 2 shifts at \$55 per shift | \$ 330 |
| 2 Factory Representatives 2 men for 2 days | 200 |
| 3 Travel for Factory Representatives | 600 |
| | <hr/> |
| | \$ 1,130 |

MODIFICATIONS TO ACCOMMODATE SHUTTLE CAR HAULAGE

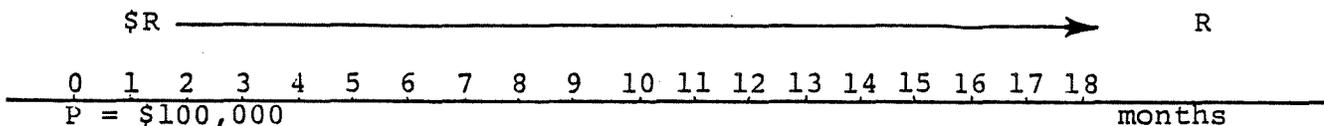
| | |
|--|-----------|
| 1 Infrared Shuttle Car Detectors | \$ 225 |
| 2 Conveyor Boom Communications System | 4,000 |
| 3 Laser Source (2nd) | 4,000 |
| 4 Sensor Array (2nd) | 6,500 |
| 5 Infrared Distance Meter (2nd, optics only) | 2,000 |
| 6 Retroreflector Assy. (2nd) | 500 |
| 7 Cables | 100 |
| | <hr/> |
| | \$ 17,325 |
| Contingency (10%) | 1,732 |
| | <hr/> |
| | \$ 19,057 |

7.2 ECONOMICS OF AUTOMATED MINERS

While gathering data for this report it was learned that one coal mining company typically required a 32% minimum rate of return on its investments with a payback period of 1 1/2 years. These figures actually apply to one or two section mines costing 1 1/2 - 2 million dollars to develop, but they can be used to obtain an indication of how many tons of increased raw coal production are required to offset an investment. This is done by using the following data and assuming that capital is internally generated:

| | |
|--|------------------------|
| Price of clean steam coal | \$20 per ton |
| Nominal initial investment | \$100,000 |
| Required rate of return | 32% |
| Payback period | 18 months |
| Before automation production | 652 raw tons per shift |
| Shifts per working day | 2 |
| Working days per month | 21 |
| Percent of increased production income applicable to amortizing investment and repair parts. Remainder goes into the cost of producing coal. | 40% (conservative) |

CAPITAL RECOVERY FLOW DIAGRAM



R = monthly payment to amortize principle P

$$R = P \left[\frac{i (1 + i)^n}{(1 + i)^n - 1} \right]$$

$$= \$100,000 = \frac{\frac{.32}{12} (1 + \frac{.32}{12})^{18}}{(1 + \frac{.32}{12})^{18} - 1}$$

R = \$7,068 monthly capital recovery

If repair parts cost 20% per annum of initial cost, add \$1,667 per month for repair parts to get a monthly cash flow requirement of \$8,735.

To relate this figure to an increase in shift production (Y):

$$Y = \text{Increase} = \left(\frac{\$8,735}{\text{month}} \right) \left(\frac{1}{40\%} \right) \left(\frac{1 \text{ clean ton}}{\$20} \right) \left(\frac{1 \text{ raw ton}}{.65 \text{ clean}} \right) \left(\frac{1 \text{ month}}{21 \text{ days}} \right) \left(\frac{1 \text{ day}}{2 \text{ shifts}} \right)$$

$$Y = \frac{(8,735)}{(.4) (20) (.65) (21) (2)}$$

$Y = \frac{40 \text{ raw tons}}{\text{shift}}$ increased production

This means that any improvement in the mining system which will increase shift production by 40 raw tons will amortize a \$100,000 investment in 18 months plus pay a rate of return of 32% on the investment. On this basis the \$69,116 for a laser guidance and automation retrofit kit is readily justified.

NOTE:

Based on a 652 tons/shift average, an increase of only 6.14% in raw ton production will pay back a \$100,000 investment in 18 months with a 32% return.

The use of the Litton "PADS" inertial guidance system, as discussed in section 5.1, is expected to add \$300,000 to the cost of a continuous miner. In order to justify this additional expenditure, a production increase of 120 raw tons per shift would be required. The present system of automated miner, shuttle car haulage, and mine plan shows a production increase of 43 tons. This makes an inertial guidance system economically unacceptable at this time.

Before discarding the inertial guidance continuous miner it would be interesting to reexamine the variables which resulted in the required 120 tons of increased production. One variable is the 40% ratio of investment amortization to increase in gross income. This is a conservative figure. If the entire increase in income is applied to investment amortization, only 16 tons increased production per shift is required to offset a \$100,000 expenditure; or 48 tons would offset a \$300,000 cost. In section VI it was determined that an automated miner in a continuous haulage section would boost production by 47 tons. This criteria may justify an inertial system.

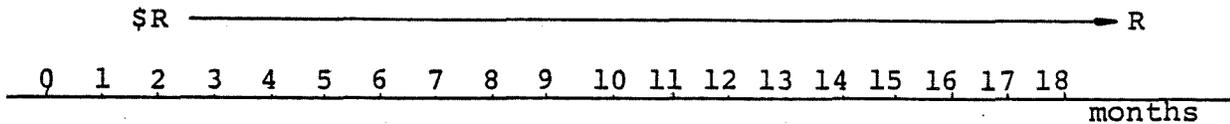
Another possibility would be for the price of coal to triple to \$60 per clean ton. A 13.33 raw tons production increase would offset a \$100,000 investment, and 40 tons would offset the \$300,000 inertial guidance system.

The last possibility is that the cost of the inertial guidance system could drop. Litton representatives have indicated that a substantial price decrease will occur next year.

The purpose of these arguments is to show that while an inertial guidance system may not be economically attractive at this time, it may become very feasible in the near future, especially as part of an overall improved mining system.

As a basis of comparison, the rate of return for the laser guided automated miner will be calculated for an 18 month period, assuming internally generated capital.

CAPITAL RECOVERY FLOW DIAGRAM



P = \$69,116

Monthly cash flow available to pay for repair parts and generate a rate of return:

$$40\% \times 43 \frac{\text{raw tons}}{\text{shift}} \times 65\% \left(\frac{\text{clean tons}}{\text{raw tons}} \right) \times \frac{\$20}{\text{clean ton}} \times \frac{2 \text{ shifts}}{\text{day}} \times \frac{21 \text{ working days}}{\text{month}} = \$9,291.20/\text{month}$$

Monthly repair parts cost is estimated at 20% per annum of initial system costs (total cost less lost production costs):
 $(\$69,116 - \$16,952) \times 20\% \times \frac{1 \text{ year}}{12 \text{ months}} = \$869.40/\text{month}$

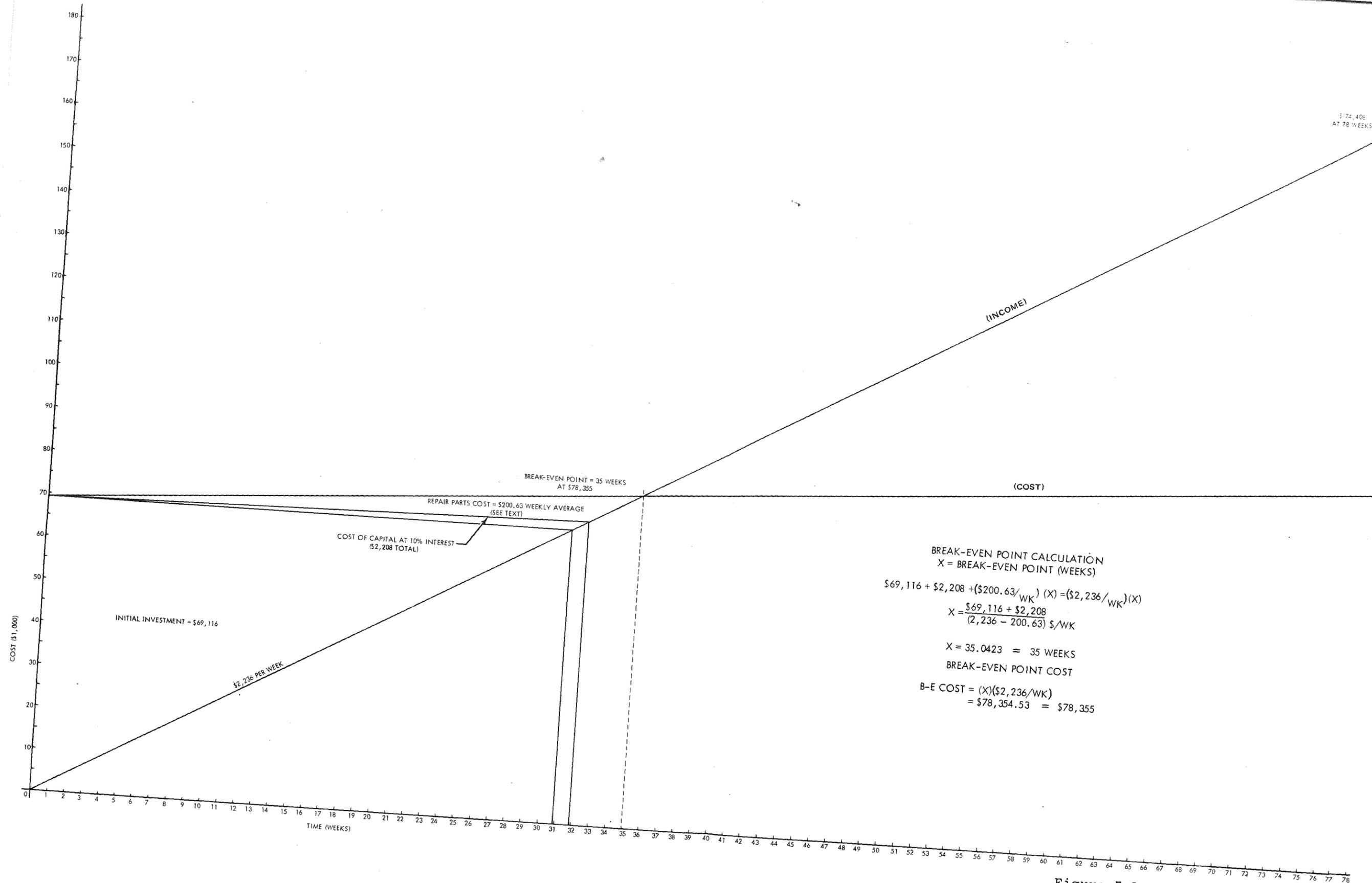
Therefore \$8,521.80 (R = \$8,521.80) is available each month to generate a rate of return on the initial investment.

$$R = P \left[\frac{i (1 + i)^n}{(1 + i)^n - 1} \right] = (P) i^{-n} \text{ crf}^*$$

$$i^{-18 \text{ crf}} = \frac{R}{P} = \frac{\$8,521.80}{\$69,116.00} = .1232971$$

By interpolation and successive iterations, the rate of return is determined to be 10.17% per month, or 122.04% per annum.

*Taylor, George A., Managerial and Engineering Economy, D. Van Nostrand Co., Inc., N. Y., 1966, pg 26. "crf" is defined as capital recovery factor.

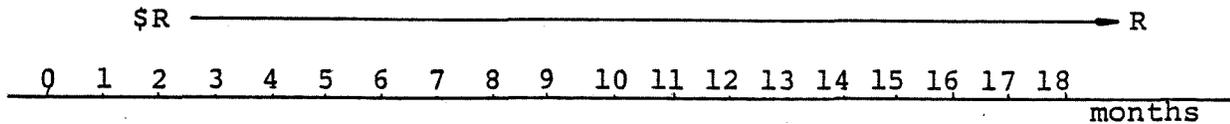


BREAK-EVEN POINT CALCULATION
 $X = \text{BREAK-EVEN POINT (WEEKS)}$
 $\$69,116 + \$2,208 + (\$200.63/\text{WK})(X) = (\$2,236/\text{WK})(X)$
 $X = \frac{\$69,116 + \$2,208}{(2,236 - 200.63) \$/\text{WK}}$
 $X = 35.0423 = 35 \text{ WEEKS}$
 BREAK-EVEN POINT COST
 $\text{B-E COST} = (X)(\$2,236/\text{WK})$
 $= \$78,354.53 = \$78,355$

Figure 7-1. Breakeven Analysis

As a basis of comparison, the rate of return for the laser guided automated miner will be calculated for an 18 month period, assuming internally generated capital.

CAPITAL RECOVERY FLOW DIAGRAM



P = \$69,116

Monthly cash flow available to pay for repair parts and generate a rate of return:

$$40\% \times 43 \frac{\text{raw tons}}{\text{shift}} \times 65\% \left(\frac{\text{clean tons}}{\text{raw tons}} \right) \times \frac{\$20}{\text{clean ton}} \times \frac{2 \text{ shifts}}{\text{day}} \times$$

$$\frac{21 \text{ working days}}{\text{month}} = \$9,291.20/\text{month}$$

Monthly repair parts cost is estimated at 20% per annum of initial system costs (total cost less lost production costs):
 $(\$69,116 - \$16,952) \times 20\% \times \frac{1 \text{ year}}{12 \text{ months}} = \$869.40/\text{month}$

Therefore \$8,521.80 (R = \$8,521.80) is available each month to generate a rate of return on the initial investment.

$$R = P \left[\frac{i (1 + i)^n}{(1 + i)^i - 1} \right] = (P) \quad i^{-n} \quad \text{crf}^*$$

$$i^{-18} \text{crf} = \frac{R}{P} = \frac{\$8,521.80}{\$69,116.00} = .1232971$$

By interpolation and successive iterations, the rate of return is determined to be 10.17% per month, or 122.04% per annum.

*Taylor, George A., Managerial and Engineering Economy, D. Van Nostrand Co., Inc., N. Y., 1966, pg 26. "crf" is defined as capital recovery factor.

SECTION VIII

CONTINUING PROGRAM DEFINITION

8.1 INTRODUCTION

The engineering efforts described in this report cover the first step in developing the techniques and hardware for automating and programming a continuous miner. This important first step determined the feasibility and possible solutions to meeting the overall goal of total hands-off face cutting operations. Since the results of this program indicate that a programmable automated continuous miner can increase section productivity, increase operator safety, and has direct applicability for efficient operation in shortwall mining, a total program to completion is outlined below. This outline will provide the Bureau, for planning purposes, the major tasks remaining, their proposed sequence of completion, and a logical sequenced plan of component development prior to a major commitment to total hardware demonstration.

8.2 PHASE II - COMPONENT SELECTION AND SYSTEM FINAL DESIGN

During this phase, the final system design, not to be confused with detail machine design, will be completed. On a system basis, all interconnected components will be evaluated and selected. The actual data sensors, data sources, and data evaluators will be defined by part number and, when necessary, test plans written to assure proper underground function. The results of this effort will be a data package describing each required component (excluding mounting equipment, cables, etc.), its function and specification, a list of those components which require further application evaluation, a test plan and cost for obtaining that evaluation, and a list of those components which are directly applicable to final underground demonstration. The details of the mounting method, the packaging into protective enclosures, and the final installation drawings will not be provided during this component evaluation effort. This will be accomplished after final TPO approval of evaluated components. This engineering effort will provide the Bureau with sufficient information, prior to committing major expenditures, to assess the probability of system success or failure and what would be required to overcome the potential problem areas.

An additional result from Phase II will be a list of mining machines which could be modified and the mining companies receptive to conducting the underground demonstration.

8.3 PHASE III - COMPONENT EVALUATION AND PACKAGING

As discussed in 8.2 it is anticipated that various components will require specific tests and evaluation to assure long-term underground operation. Those tests approved by the Bureau would then be conducted and decisions made as to the specific component acceptability. Test reports from each test would be submitted.

Concurrent with this evaluation effort would be the preliminary packaging design for the electronic equipment. This would include the remote miner operator's control/status enclosure, the on-board processor enclosure, and the shuttle car operator's enclosure from which he controls the continuous miner's conveyor boom.

An additional task to be accomplished during Phase III, is to establish which miner is to be modified and in what mine the demonstration will take place. A final cost estimate for the detailed design, the fabrication of all hardware components, the installation on a specific miner (including necessary modifications), the above-ground tests, and an underground demonstration of an automatic, programmable continuous miner would be submitted to the Bureau for evaluation and approval.

8.4 PHASE IV - FABRICATION AND DEMONSTRATION

The system developed through the sequenced programs outlined above would be detailed machine designed, fabricated, installed, tested, and demonstrated to the mining industry. The resultant effects on productivity and safety would be determined for an automated, programmable continuous miner.

SECTION IX

INVENTIONS

There are no patentable results or inventions from the work performed under this contract.

Motion of the cutter corner is then:

$$D = \frac{2 R \pi}{360} = \frac{R \pi}{180} = \frac{156 \pi}{180} = 2.72 \quad \underline{2.75 \text{ inches}}$$

If we divide the maximum deviation of one foot (12 inches) by the above angular motion, we get the maximum permissible heading error of the miner:

$$\text{MAX} = \frac{12 \text{ in.}}{3 \text{ in.}} = \underline{4 \text{ degrees}}$$

We are therefore limiting the miner to a PRACTICAL heading range of ± 3 degrees.

- B. Calculation of the lateral displacement of the laser beam on the rear sensor panel with respect to heading errors. The center of the rear sensor panel is located halfway between the pivot point and the left turning point of the miner, and 30 inches to the rear of a line connecting these points. The sensor panel turning radii are calculated then as follows:

$$A = \sqrt{36^2 + 30^2} = 46.86 \text{ inches}$$

$$B = \sqrt{108^2 + 30^2} = 112.1 \text{ inches}$$

The angles at the turning points are:

$$\tan \alpha = \frac{30}{36} = 0.83333, \quad \alpha = 39.8^\circ$$

$$\tan \beta = \frac{30}{108} = 0.27777, \quad \beta = 15.5^\circ$$

Turning around the left turning point, the lateral displacement is a cosine function of the angle α :

$$D_L = 36 - (A \cos \alpha), \text{ for } \alpha + 3, \alpha + 2, \alpha + 1, \alpha, \alpha - 1, \alpha - 2 \text{ and } \alpha - 3 \text{ degrees.}$$

Results are tabulated below:

| DEV | -3 | -2 | -1 | 0 | +1 | +2 | +3 | degrees |
|-------------------------|-------|-------|-------|-----------|-------|-------|-------|---------|
| α | 36.8 | 37.8 | 38.8 | 39.8 | 40.8 | 41.8 | 42.8 | degrees |
| $A \cdot x \cos \alpha$ | 37.52 | 37.03 | 36.52 | 36.00 | 35.47 | 34.93 | 34.38 | inches |
| D_L | -1.52 | -1.03 | -0.52 | <u>+0</u> | +0.53 | 1.07 | 1.62 | inches |
| ΔD_L | -0.49 | -0.51 | -0.52 | - | +0.53 | 0.54 | 0.55 | inches |

Similarly, turning around the right turning point:

$$D_R = 108 - (B \cos \beta), \text{ for } \beta, \beta(+1, \underline{=2}, +3)$$

| DEV | -3 | -2 | -1 | 0 | +1 | +2 | +3 | degrees |
|----------------|-------|-------|--------|-----------|--------|--------|--------|---------|
| β | 12.5 | 13.5 | 14.5 | 15.5 | 16.5 | 17.5 | 18.5 | degrees |
| $B \cos \beta$ | 109.4 | 109.0 | 108.53 | 108.00 | 107.48 | 106.91 | 106.31 | inches |
| D_R | -1.44 | -1.00 | -0.53 | <u>+0</u> | +0.52 | 1.09 | 1.69 | inches |
| ΔD_R | -0.44 | -0.47 | -0.53 | - | +0.52 | +0.57 | +0.60 | inches |

Above values show, that for each degree of heading change (turn of miner), we get approximately one-half inch of beam displacement. Since the sensor columns are spaced one-half inch apart, we have approximately +1 degree heading resolution on the rear sensor panel. The lateral resolution is 0.5 inch. The front sensor array (described in 4.2.2) gives us one-half degree angular (heading) resolution. These values appear to be sufficient for control of the miner along the laser beam.

- C. Angular turning speed of the miner with one track stopped. The center-to-center distance of the tracks is approximately 5'8". Each track is therefore $\frac{(5 \times 12) + 8}{2} = 34$ inches away from the miner centerline.

Assuming a turn at a track speed of 2 inches/second, we get:

Radius from turning point to opposite track:

$$R = 72 + 34 + 106 \text{ inches.}$$

Circumference of the circle with radius R:

$$C = 2 \pi R = 2 \pi 106 = 666 \text{ inches}$$

2 inches/second track speed would result in $\frac{666}{2} =$

333 seconds for a full turn of 360 degrees, or $\frac{360}{333} = 1.08$ degrees/second angular velocity.

The assumptions made for the foregoing calculations are best guesses and idealized. In reality, the turning speed of the miner, for instance, is probably less than the 1.08 degrees per second, due to track slippage, start-up or stopping time of the tram motors, and other causes. Similarly, other calculated values may change due to parameter differences or changes. The above calculations will be interpreted as approximate values only.

APPENDIX B

TECHNICAL DATA BROCHURES

1. Laser Light - See Coal Age, June 1974
2. Automatic Surveying*
3. Inertial Navigation System*

*See 1975, Litton Systems, Inc.