

A mining research contract report
FEBRUARY 1986

U.S. DEPARTMENT OF LABOR MSHA



00031615

AUTO-TRACK BRIDGE CONVEYER TRAIN FOR CONTINUOUS FACE HAULAGE

Contract J0333913
Foster-Miller, Inc.

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERI

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86-46



NOTICE

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SUBJECT INVENTIONS

No patentable inventions have resulted from work performed under this contract

1. Report No.	2.	3. Recipient's Accession No.	
4. Title and Subtitle Auto-Track Bridge Conveyor Train for Continuous Face Haulage		5. Report Date February 1986	6.
7. Author(s) D.D. Durrett and D.T. Atkinson		8. Performing Organization Report No. BMI-8500	
9. Performing Organization Name and Address Foster-Miller, Inc. 350 Second Avenue Waltham, MA 02254		10. Project/Task/Work Unit No.	11. Contract or Grant No. J0333913
12. Sponsoring Organization Name and Address U.S. Bureau of Mines Pittsburgh Research Center P.O. Box 18070 Cochrans Mill Road, Pittsburgh, PA 15236		13. Type of Report Final Technical Report	
14.			
15. Supplementary Notes			
<p>16. Abstract</p> <p>The Auto-Track Bridge Conveyor Train (ABCT) is a continuous haulage system designed for underground coal mines. The ABCT is made up of identical "units" each of which consists of a wheeled Mobile Bridge Carrier and a Bridge Conveyor. Microprocessors located on each carrier enable the entire train to follow precisely a predetermined course along the section's haulage route with minimal operator control requirements. Sensors determine each carrier's position with respect to a signal cable. This cable is automatically deployed on the mine floor as the system advances behind the continuous miner.</p> <p>This report summarizes system design efforts, prototype testing, and subsequent redesign and prototype modifications.</p>			
17. Originator's Key Words Continuous Haulage Face Haulage Automated Mining Mobile Conveyors		18. Availability Statement	
19. U. S. Security Classif. of the Report UNCLASSIFIED	20. U. S. Security Classif. of This Page UNCLASSIFIED	21. No. of Pages	22. Price

FOREWORD

This report was prepared by Foster-Miller, Inc. of Waltham, MA under United States Bureau of Mines Contract No. J0333913. This contract was administered under the technical direction of the Pittsburgh Research Center with Mr. August Kwitowski acting as Technical Project Officer (TPO). Mr. Joseph A. Gilchrist was Contracting Officer for the USBM.

Work on this project began in June 1975 under Bureau Contract No. H0155157 with Mr. William Mayercheck as TPO and Mr. Gilchrist as Contracting Officer. In November 1977, the contract was transferred to the United States Department of Energy (DOE) becoming DOE Contract No. DE-AC01-75ET11073. Technical Project Officer and Contracting Officer for DOE were Mr. Thomas Zemo and Mr. E. F. Callaghan, respectively. Responsibility for the contract was returned to the USBM in April 1983 at which time the current contract number was assigned.

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1. INTRODUCTION

In underground coal mining, face haulage is often the limiting factor in total section productivity. Most underground mines use shuttle cars which are loaded directly by the miner. When a car is full, it carries its load to the panel belt, dumps the coal and returns for another load. Normally, each section has two shuttle cars which pass along the haul route.

With shuttle cars in the system, the continuous miner is not truly "continuous." It must shut down between cars, thus losing potential production.

Continuous haulage systems are in use in the coal industry, but their applications are generally limited to mines in which shuttle cars cannot be employed. That means that continuous haulage is usually found in mining heights too low for shuttle cars.

Continuous haulage would be used more extensively except that systems currently available place even more constraints on the mining operation than do shuttle cars. Place changing with current systems is time consuming because the movement of all components must be carefully coordinated; simultaneous tramping of all units is extremely difficult using manual controls. Sections with continuous haulage are generally limited to three entries because the addition of more haulage units (to give longer reach) increases manpower requirements. Additional units also increase the complexity of equipment movement during mining.

This report describes development and preliminary testing of a new face haulage system which eliminates the problems normally associated with multi-unit continuous haulage systems. This system, shown in figure 1, is the Auto-Track Bridge Conveyor Train (ABCT).

The ABCT is a train of Mobile Bridge Carriers (MBCs) and bridge conveyors (bridges) equipped with an automatic guidance system. With only two operators (one at each end) an ABCT up to 500 ft long can track precisely along a guidance cable. This cable is laid down and retrieved automatically by the lead vehicle as it follows behind the continuous miner.

Development of the ABCT is documented in four sections of this report. These sections cover:

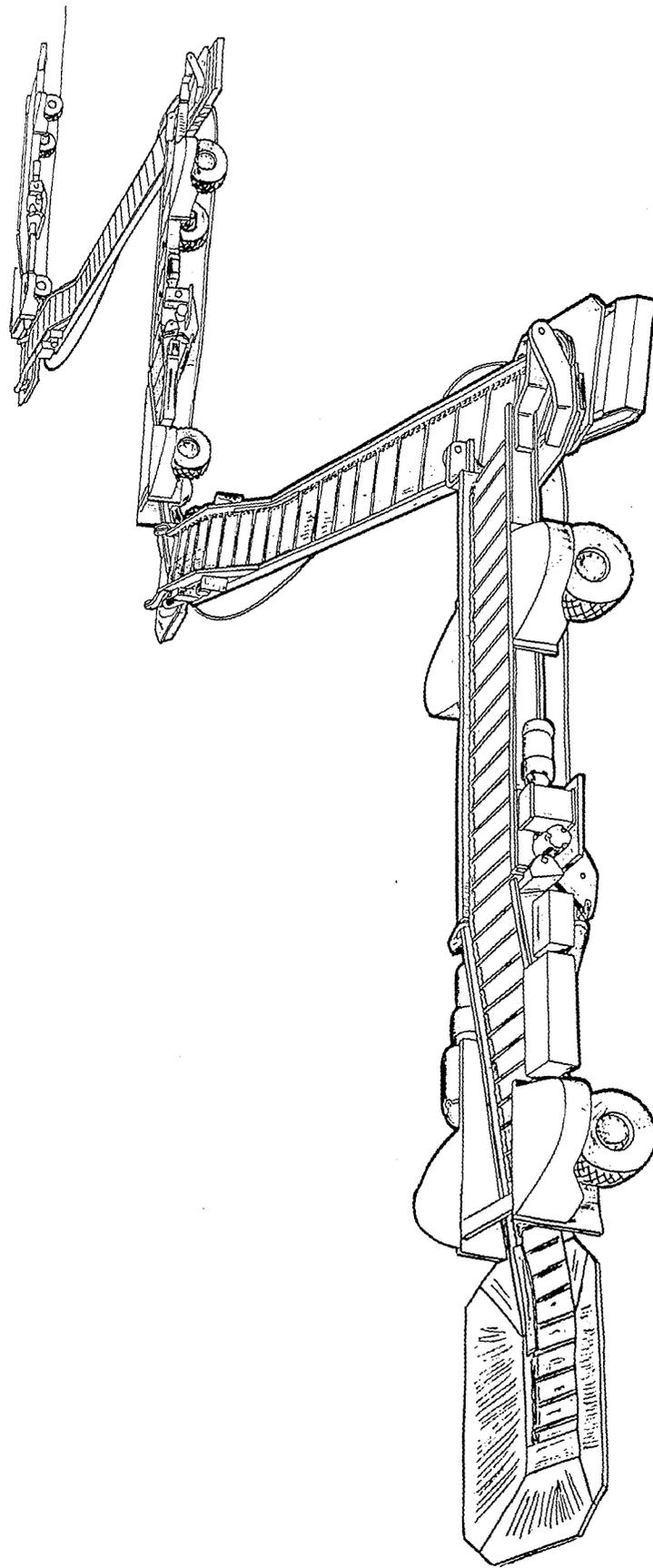


FIGURE 1. Auto-Track Bridge Conveyor Train (ABCT).

- a. Preliminary evaluations
- b. System design
- c. Critical testing
- d. Preparation for underground application.

Each of these sections is summarized below.

1.1 PRELIMINARY EVALUATIONS

In order to develop preliminary design criteria for the ABCT, Foster-Miller, Inc. (FMI):

- a. Evaluated past, current, and planned continuous haulage systems with both manufacturers and operators
- b. Evaluated cable guidance hardware used in the materials handling industry
- c. Performed tradeoff and engineering studies using the best available hardware and technology.

There are three major manufacturers of bridge conveyor systems:

- a. Long-Airdox
- b. Jeffrey
- c. West Virginia Armature.

Past and current designs were reviewed with each manufacturer. Operation of the hardware was evaluated at several mines with different roof and floor conditions and with different levels of operator skill and maintenance.

In addition, earlier model continuous haulage systems - the Mineveyor by Hewitt-Robins and the Moleveyor by Jeffrey - were reviewed for concepts that could be used and for shortcomings to be avoided.

All manufacturers of cable guidance equipment were similarly reviewed and evaluated.

Mechanical and electrical design tradeoff studies were conducted and several system designs were completed. Major design studies included:

- a. Dimensioning the system elements as a function of mine layout

- b. Wheel versus track suspensions
- c. Belt versus chain conveyors
- d. Placement of the guidance cable
- e. Control strategies.

Particular attention was directed toward areas that the equipment reviews had shown to be troublesome. Hardware to improve these areas was identified.

1.2 SYSTEM DESIGN

Based on the preliminary evaluations described above, a decision was made to design and test two prototype units (each unit consisting of one MBC and one bridge) prior to fabrication of the entire ABCT. Specifications for those first units are summarized below.

1.2.1 Mechanical Design

The overall design of the wheeled MBC is shown in figure 2, and the bridge is shown in figure 3. The two are joined together by means of the dolly at the outby end of the MBC. Fifteen feet of the bridge length can be slid under the carrier structure for storage or for transport as a module. Carrier-bridge pairs can be added to the train or removed as working conditions require. The MBC is 35 ft 1-1/2 in. long and the bridge is 25 ft 4-1/2 in. long.

The maximum height of the unit from the floor is 42 in. The MBC is equipped with a hinge near its center which permits vertical articulation of the unit to assist in negotiating a wavy bottom in low coal.

The conveyors are of dual chain type with forged flights, and are similar to existing chain continuous haulage systems. Driven by 20-hp electric motors at 300 ft/min, the conveyors are 30-1/2 in. wide and are rated for a maximum haulage capacity of 12 tons/min.

The wheel unit is driven by a vane-type hydraulic motor through a planetary reducer. The foam filled tire is a 28 in. diam Bearcat "Supersoft" mounted on a 15-in. rim. Maximum ground pressure exerted by the wheels is approximately 80 psi, compared with the 100 psi standard practice in shuttle car design.

Through a unique turntable bearing arrangement, the wheel pivots about its vertical axis for steering. This design eliminates interaction between the tram and

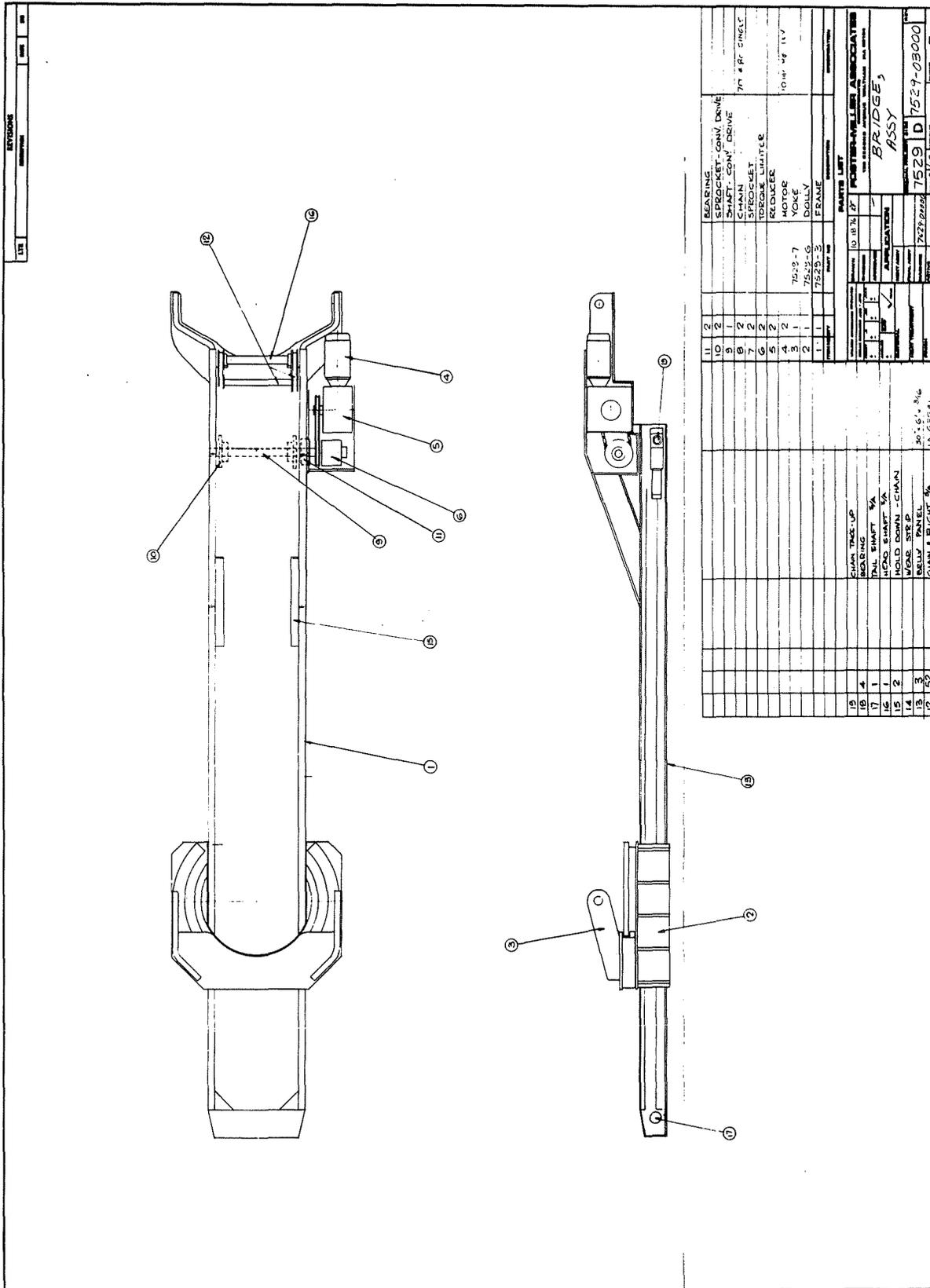


FIGURE 3. - Bridge assembly.

steering drive motors as would occur if the wheel pivoted about a king-pin. Steering power is provided by a hydraulic motor operating through a chain and sprocket drive.

Transfer points between conveyors are of an easily serviced rotary track design (see figure 4). The arrangement incorporates the best features of the designs studied during the preliminary evaluations. The under-slung dolly for carrying the bridge is a new concept, required in the automated system to make the motions of neighboring MBCs independent of each other.

1.2.2 Electric Design

The electrical system of the ABCT divides into three subsystems:

- a. The Power Distribution System, (PDS) consisting of heavy cables, connectors and explosion-proof boxes, which provides the main power to the MBCs, bridges and the continuous miner
- b. The Operator's Control System, (OCS) consisting of panel controls, relays, switches and interlocks, which provides manual control of the ABCT
- c. The Guidance Control System, (GCS) consisting of the electronic circuitry necessary to provide automatic guidance of the MBCs.

The PDS, using three 3-conductor cables deployed on each side of the ABCT, provides sufficient power to drive 500 ft of conveyor train, the associated hydraulic and control systems, as well as a 550-hp continuous miner. Provision is also made for hosing to provide water sprays at each transfer point and at the miner head. Quick disconnects are provided so that an MBC-bridge pair can be added to or removed from the train with minimum delay.

The OCS provides for orderly startup and shutdown of the system, both in normal operation and in emergency conditions. A local control box has been designed which can be plugged into any MBC, and which allows manual control of the steering and tramping functions. This control bypasses all of the automatic electronics and requires only that there be electrical and hydraulic power to the wheel units in order to operate. It is used for moving bridge-carrier pairs into position in the train and emergency operation during failures.

The GCS is a microprocessor-based programmable controller, using the same technology as found in hand calculators. Starting with inputs from sensor arrays

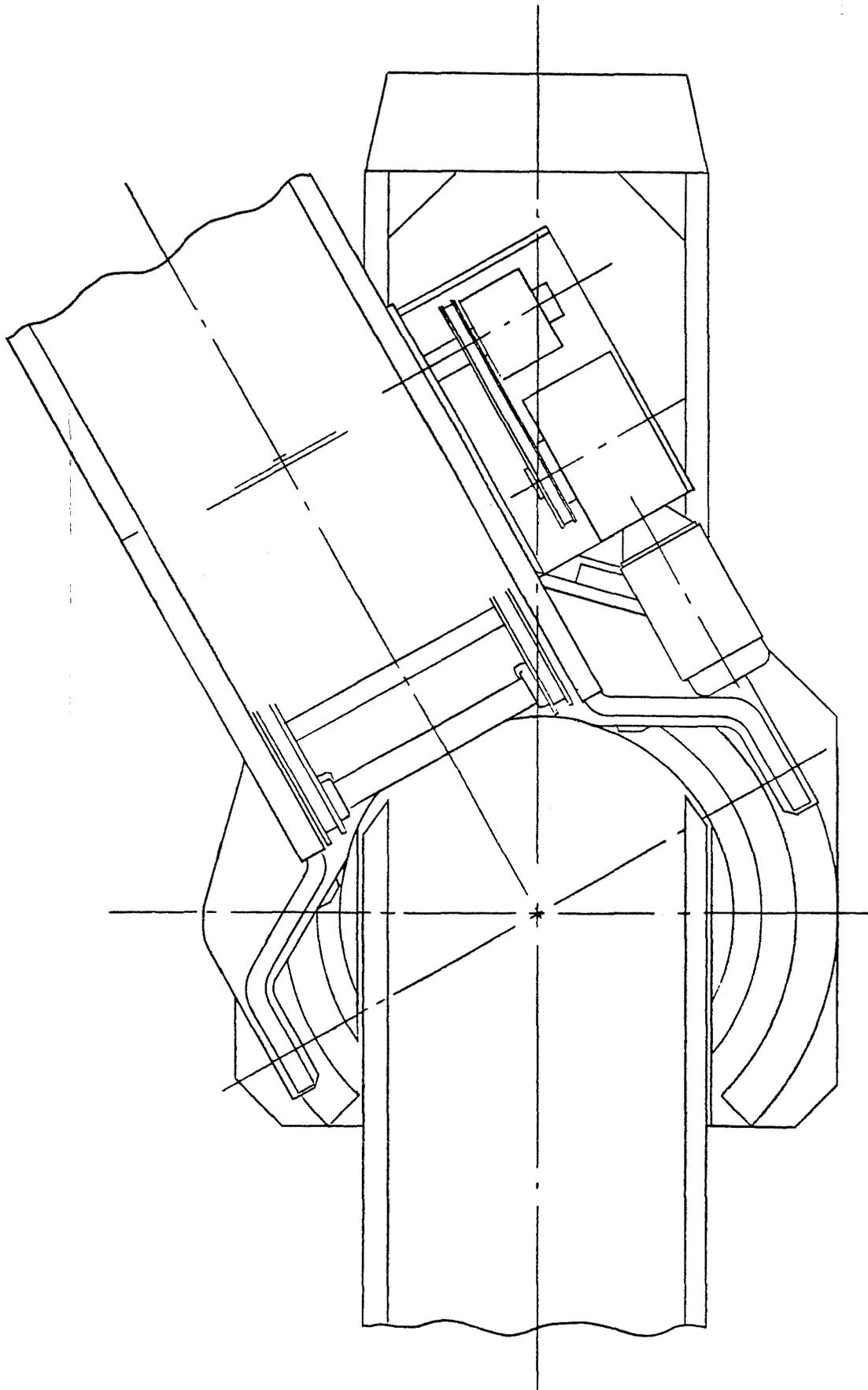


FIGURE 4. - Transfer point design.

mounted between the fore and aft wheel pairs, it produces signals which control the tramming speed and steering angle of each of the four wheels independently.

In underground operation, the processor will be invisible to the operators; the MBC will follow the cable around turnouts like any cable-guided warehouse or mail vehicle in current use. In the event of failure, service will be accomplished simply by replacing modular electronic enclosures.

1.2.3 Health and Safety

The health and safety aspects of the ABCT design were incorporated from the start. Specific provisions have been made for:

- a. Incorporation of sound-deadening materials in the conveyor pan structure
- b. Water-spray dust suppression at each transfer point
- c. Installation of panic bars, accessible from every point of the train, which stop all tram, steer and conveyor functions
- d. Installation of crossover switches on each MBC which disable all conveyor power when turned on, so that a man can safely climb over the conveyor at convenient points.

1.3 CRITICAL TESTING

Upon completion of the first two units of the ABCT, a series of tests were conducted to evaluate the design described above. The tests can be summarized as follows:

- a. Initial checkout at the manufacturer's facility
- b. Tramming tests at the Mine Surface Test Facility (MSTF) in Bruceton, PA
- c. Haulage tests at the MSTF

1.3.1 Initial Tests

A system checkout conducted at the Long-Airdox plant revealed certain design deficiencies which were corrected prior to shipment of the two units to the MSTF.

The first modification required a redesign of the cable deployment system. The pancake drive was modified

and relocated to eliminate problems with cable jamming and hang-up. Also the cable deployment sensors were reduced in size to provide better ground clearance.

The dolly had originally been designed with 5 ft of free travel along the bridge. Problems with interference forced a reduction of this zone to 39 in.

Haulage tests at Long-Airdox resulted in spillage at two locations. That problem was corrected by adding deflector plates.

Finally, running the system resulted in oil temperatures that were higher than expected. Adding a liquid-to-liquid heat exchanger to the hydraulic system eliminated that problem.

1.3.2 Tramming Tests

Tests were conducted at the MSTF over three types of floor conditions:

- a. Smooth
- b. Moderately rough
- c. Severe.

As a result of these tests, a number of modifications were made:

- a. Hoses were rerouted around the wheel units to prevent damage
- b. Yokes which hold the bridge centering wheels were "beefed up"
- c. Floor clearance was increased for the dolly
- d. All tires were filled with foam
- e. A diagnostics subsystem was added to the cable deployment system
- f. A plow was added just inby the guidance cable deployment system. The plow effectively cleared debris and accumulations of material from the path of the cable
- g. The shaft size was increased for the bridge support wheels.

During surface testing, conversations with industry officials indicated that the designated maximum tramming speed of 40 ft/min would have to be increased to 50 ft/min. Since that increase would require a redesign of major components, that work was left until after completion of all tests.

1.3.3 Haulage Tests

Upon successful completion of the tramming tests, haulage tests were conducted.

Early on, problems developed due to tight clearance between conveyor flights and structural members. In order to increase clearance for the conveyor chains and flights, cross braces were removed from beneath the conveyor pan. Eliminating the braces allowed testing to continue, but it meant that some redesign would be needed prior to fabrication of the rest of the ABCT.

During the haulage tests, a total of 2,500 tons of material was moved. The peak, sustained haulage rate was 9 tons/min.

1.4 PREPARATION FOR UNDERGROUND APPLICATION

The surface tests described in the previous section led to a redesign of the two existing ABCT units prior to fabrication of additional units.

The most critical modification was an increase in the maximum tram speed to 50 ft/min. To achieve the higher rate, the four stepper motors on each carrier were replaced with larger ones, a larger hydraulic pump was installed, the motor driving the hydraulic pump was increased from 50 hp to 75 hp, and the oil cooling system was upgraded. Component testing showed the new tram system to be capable of up to 60 ft/min, should that speed ultimately be needed.

To obtain a haulage capacity of 12 tons/min, two modifications were made. First, the conveyor drive was upgraded from 20 hp to 30 hp. Second, cross braces beneath the pan were redesigned to give more clearance for the conveyor chain.

Other design modifications included:

- a. New flight design
- b. New dolly limit switches
- c. Provision for adjustment of the plow height.

Once the redesign was completed, the two existing units were modified and three additional units were fabricated by Long-Airdox. Final assembly of all five units took place in FMI's facility at Saxonville, MA.

In anticipation of underground operation of the prototype, five-unit version of the ABCT system, FMI sought the necessary MSHA approvals for the electrical systems. Two types of approvals were required:

- a. Explosion-proof (XP) enclosures
- b. Intrinsically Safe (IS) systems.

XP certification was relatively straightforward in that MSHA reviewed each enclosure design and explosion-tested an actual enclosure built to that design. Although the process was extremely time consuming, it held no major surprises for the parties involved. XP approvals were granted by MSHA.

IS certification, on the other hand, proved to be a major problem in terms of both time and money. MSHA's IS approval process is geared toward evaluation of relatively minor changes to previously approved systems. The ABCT presented MSHA officials with something totally new (new, at least to the mining industry). Over three years after the application was filed, MSHA still had made no decision on the systems involved.

1.5 CONCLUSIONS AND RECOMMENDATIONS

Tests of components and/or complete ABCT units have demonstrated that the system can:

- a. Follow automatically a predetermined course through mine entries
- b. Tram at speeds up to 50 ft/min
- c. Convey coal at 9 tons/min for sustained periods.

Unfortunately, the development program is not finished.

While the prototype vehicle was never trammed at more than 40 ft/min, subsequent design changes have increased the maximum speed of the ABCT. The tramping motors have been run under load at 50 ft/min on a hydraulic test stand. The wheels were also rotated at this speed while raised from the ground.

The 9-ton/min haulage rate was confirmed in surface tests. Those tests are described in section 4.2.4.2.

Subsequent changes to the conveying system (e.g., redesign of conveyor flights, 50% increase in conveyor horsepower, and redesign of conveyor supports in increase flight clearance) indicate a current haulage capacity in excess of 12 tons/min.

The ABCT has the potential for displacing shuttle cars and/or other continuous haulage systems as the preferred form of face haulage by increasing the productivity of current mining systems. The ability to avoid excessive downtime by simply removing a faulty unit from the system is a great advantage. Replacing current, manually-operated face haulage systems with an automated system will reduce haulage accidents by reducing human exposure to moving haulage equipment.

Additional work required to complete development of the ABCT is as follows:

- a. Finish assembly and system checkout of the existing five-unit ABCT
- b. Conduct extensive surface testing of the five-unit system at the METF
- c. Finish acquisition of the necessary MSHA approvals for the ABCT's electronic systems (see section 5.3.2 for further recommendations on this subject)
- d. Negotiate for, and conduct, underground trials of the ABCT
- e. Perfect the overall system based on the experience gained during the underground trial
- f. Introduce the mining industry to the resulting system and its individual components; specifically, the guidance system.

The ABCT system must be completed. The work to date and its resultant advances in automatic guidance have applications throughout the underground mining industry. However, until the system can be demonstrated, the fall-out to industry may never occur.

FMI further recommends that the finalized system be loaned to an underground coal mine on a long-term basis in exchange for records on productivity and operating costs. This will show a continuing commitment by the Government towards advancement of the coal mining industry.

2. PRELIMINARY EVALUATIONS

FMI developed preliminary design criteria for the ABCT based on the best available hardware and technology. Past, current, and planned bridge conveyor systems were reviewed and evaluated. Discussions were held with both manufacturers and mine operators. Tradeoff and engineering studies were performed using existing hardware where possible along with state-of-the-art control systems. The result was a set of design criteria for a haulage system requiring minimal manpower for operation, yet capable of reliable performance in the harsh mining environment.

This section details the process of criteria selection in two sections:

- a. Section 2.1 describes existing hardware along with applications within the mining industry
- b. Section 2.2 discusses FMI's tradeoff studies for conveying systems and for guidance systems.

2.1 REVIEW OF EXISTING HARDWARE

Conventional bridge conveyor systems have two basic configurations:

- a. Two bridge conveyors with a mobile bridge carrier in between which affords approximately 130 ft of reach from the miner at the working face to the panel belt. This three-element arrangement is customarily used in a three entry mining plan (see figure 5)
- b. Three bridge conveyors and two bridge carriers arranged in alternating fashion to provide about 200 ft of reach (see figure 6). This five-element system is ordinarily found in a five entry development plan although a specific cut sequence in a three-unit advance might sometimes call for this longer face haulage configuration.

The bridge conveyor closest to the working face is attached to a custom saddle hitch which must be added onto the boom conveyor of either a miner or loader-conveyor. This is often the source of major problems when the boom cannot accommodate the increased load due to the bridge and the coal on it.

The outby end of the inby bridge rests on a dolly which can travel along the inby end of the mobile bridge

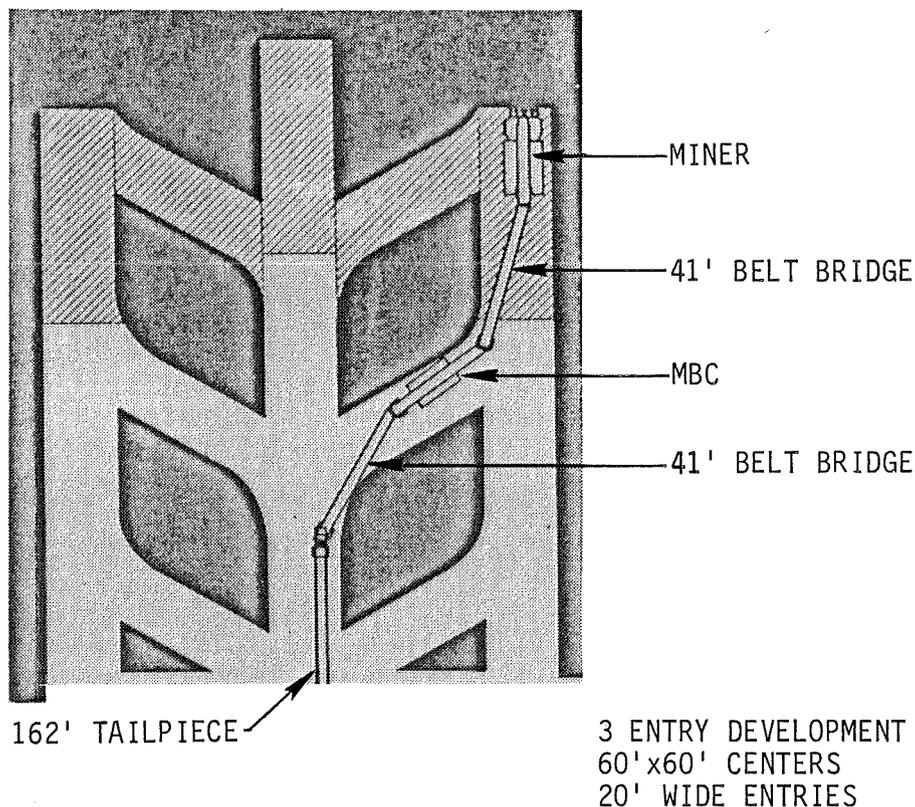


FIGURE 5. - Entry mining plan with 3-element bridge conveyor bridge carrier haulage system.

carrier in order to compensate for motions of the inby equipment. The operator in the mobile bridge carrier trams forward or back to accommodate this dolly shift.

The last bridge conveyor in the chain of haulage equipment has its outby end resting on a dolly that rides atop a static room conveyor. A special belt tailpiece (see figure 7) supports this dolly for 100-150 ft to allow the complete train to be stored alongside the panel belt at start-up or during a major place change.

Available bridge conveyors have the following general characteristics:

- a. Length ranging from 30 to 45 ft/conveyor
- b. One of two types of conveyor:
 1. Belt types which are normally 36 in. wide, run at 400 to 500 ft/min, and haul 8 to 10 tons/min
 2. Chain types which have widths up to 28 in., run at 300 ft/min, and deliver 8 tons/min with peaks up to 11.

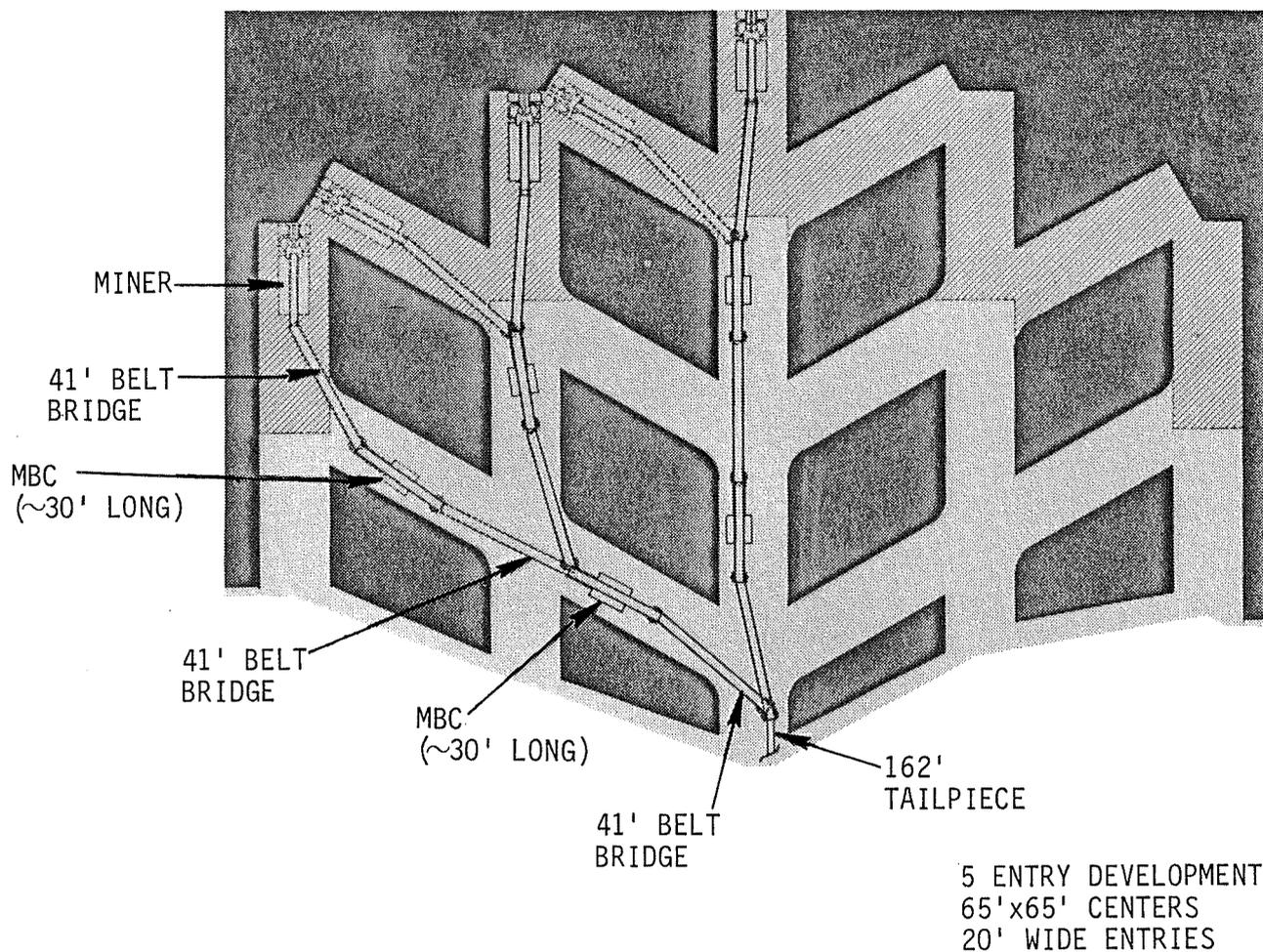


FIGURE 6. - Entry mining plan with 5-element bridge conveyor bridge carrier haulage system.

- c. Independent electric or hydraulic motor drive for each conveyor.

Bridge carriers possess conveyors identical to their bridge units and have the following additional characteristics:

- a. Independent drive motors for propulsion
- b. Crawler tracks for locomotion.

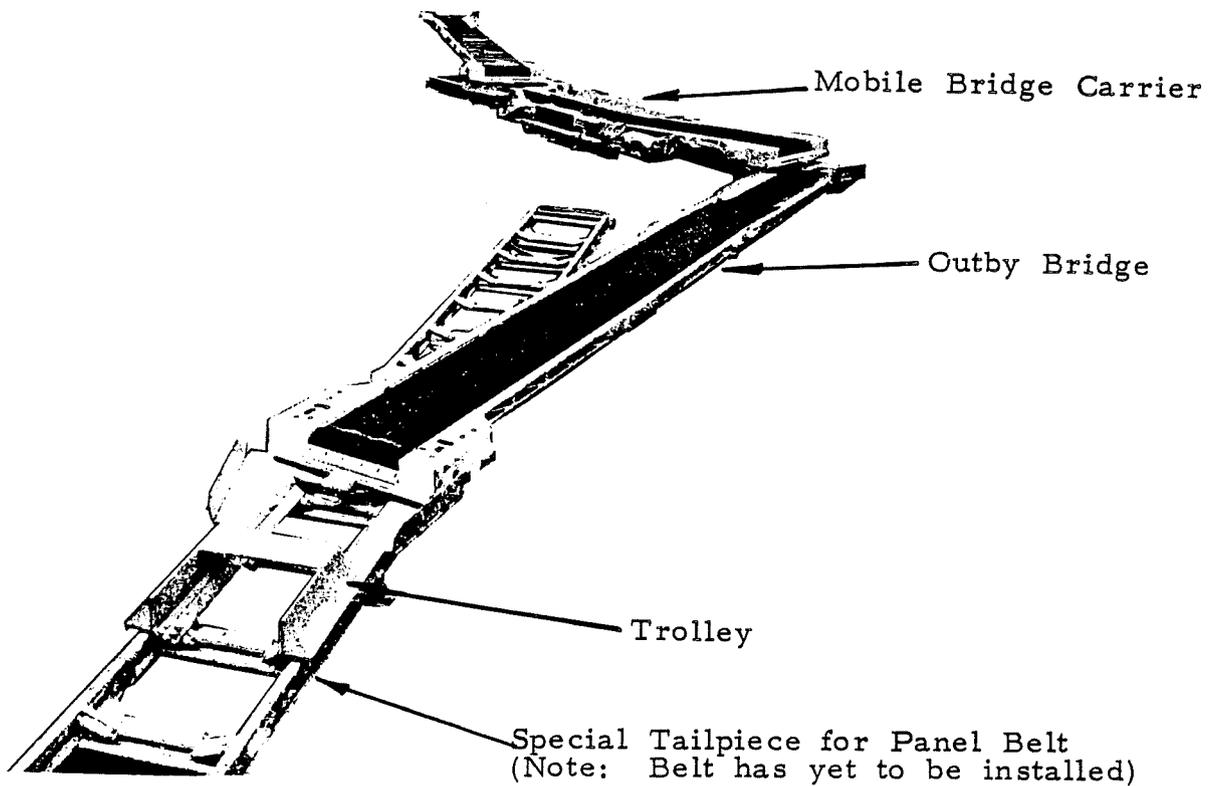


FIGURE 7. - Outby bridge connection (trolley mounted) to special panel belt tailpiece.

Bridge conveyors are currently manufactured by three companies:

- a. Long-Airdox
- b. Jeffrey Manufacturing
- c. West Virginia Armature (WVA).

Specific features of the different equipment are described below. A critique of each system is provided to point out those problems that we have sought to overcome

in designing the ABCT. The critiques also point out features of existing systems that were considered for incorporation into the ABCT.

2.1.1 Long-Airdox Company

The Long-Airdox system has four primary components arranged in cascading sequence behind a continuous miner as shown in figure 8. These components are:

- a. A "Piggyback" bridge conveyor (PBC)
- b. The mobile bridge carrier (MBC)
- c. A second "Piggyback" conveyor
- d. A special tailpiece for the panel belt.

All components are hinged at both ends for negotiating turns.

2.1.1.1 System Description

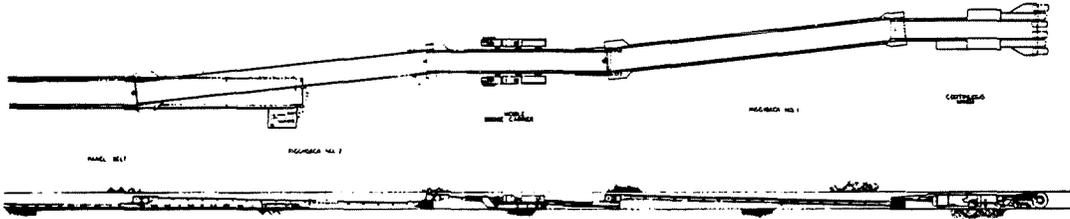
The MBC's crawler track suspension system is located in the middle of the conveyor length. Each crawler is independently powered and the hydraulic tramming system provides variable speeds up to 55 ft/min with effective steering control for the small incremental motions required to negotiate tight corners.

The MBC conveyor is driven by two electric motors through gear reducers on each side of the head shaft. The belt itself is a proprietary material made of a special weave, all polyester carcass.

The inby PBC couples through a hinge pin to a trolley, which can traverse about 5 ft along the MBC to smooth out tramming operations. The outby PBC is suspended by a similar hinge pin at a fixed location under the MBC discharge boom. The MBC is articulated in the vertical plane so that each end may be raised or lowered to compensate for rolling bottom or rough top.

The PBC's conveyor is almost identical to that of the MBC with a similar belt and belt drive system running over a flat pan support to minimize overall system height for low coal operation. Support of the outby end of the most outby PBC is achieved by terminating the inby end of the panel belt in a special tailpiece which is a rigid frame, troughed, roller unit with dolly tracks on each side on which the PBC trolley rides. The tailpiece comes in 9 ft sections with vertical articulation provided by a pinned joint between sections. This joint allows the completed tailpiece to conform to undulations in the floor.

THE FULL DIMENSION SYSTEM



The Full Dimension continuous haulage system is a series of conveying equipment arranged in cascading sequence behind a continuous miner, with all moving units hinged at each end for negotiating turns and with provision for the entire system to telescope in relation to the panel belt conveyor. The basic system consists of the following:

1. Continuous miner.

The miner discharges onto Piggyback bridge conveyor #1, the receiving end of the latter being supported by a vertical hinge pin on the discharge boom of the miner.

2. Piggyback bridge conveyor #1.

Piggyback #1 receives material from the miner and discharges it onto a mobile bridge carrier. The discharge end of Piggyback #1 is attached to a vertical hinge pin on a dolly which rides on tracks on the receiving end of the mobile bridge carrier (the dolly allows for variations in the travel of the miner and the mobile bridge carrier).

3. Mobile bridge carrier.

The mobile bridge carrier is a crawler mounted unit provided for supporting Piggybacks #1 and #2. It takes the discharge from Piggyback #1 and in turn discharges onto Piggyback #2. Both the receiving and the discharge ends of the mobile bridge carrier are adjustable in the vertical plane for ease in moving and following the seam undulations. The receiving end of Piggyback #2 is supported by a vertical hinge pin on the discharge boom of the mobile bridge carrier.

4. Piggyback bridge conveyor #2.

Piggyback #2 discharges onto the panel belt conveyor, hence its discharge end is attached to a vertical hinge pin on a dolly which rides on tracks along the elongated tail section of the panel belt conveyor.

5. Panel belt conveyor.

The panel belt conveyor is equipped with a special tailpiece incorporating tracks to accommodate the movement of the dolly supporting the discharge end of Piggyback #2. This tailpiece must be long enough to "swallow" the entire Full Dimension string of equipment including the continuous miner.

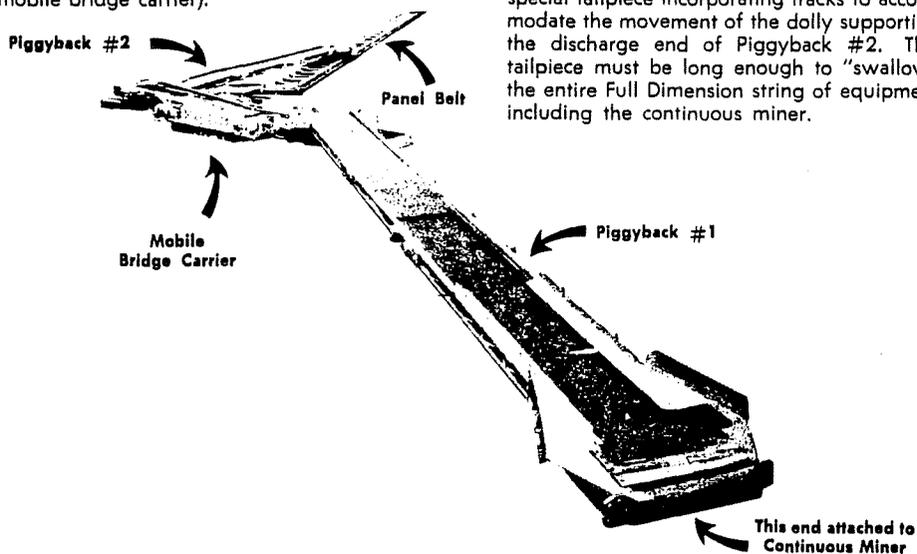


FIGURE 8. - The Long-Airbox "full dimension" continuous haulage system.

2.1.1.2 Critique of the Long-Airdox System

Structurally, the flat, torsionally flexible pan frame for the two conveyors is quite adequate and provides the necessary clearance for operation in low coal. The inby end pivot pin connection, however, is broken quite frequently by:

- a. Driving the inby PBC back against the MBC while they are turned at 90° to each other
- b. Retreating the inby PBC too rapidly and running the trolley against its stops before the MBC operator can tram his unit back and accommodate the retreat motion.

The outby pivot also suffers from the same problem. Many mine operators have modified these pins by increasing their diameter, but there is a limit beyond which the mating straddle frame becomes the weak link in the system.

The MBC crawler drive train is a lightweight system when compared to those used for continuous miners, feeder breakers, or tram cars. The main drive shaft and the crawler pads do not stand up to the loads imposed upon them in the poor environment and low maintenance conditions encountered.

The conveyor belts on the PBC and MBC are particularly vulnerable in low coal seams for a variety of reasons. Alignment of the belt between head and tail pulleys must be accurate if the system is to work successfully, but the flexible framework which supports the belt is often run into the top, bottom, or rib, causing distortion and run out of the belt. Also fines can pack between the belt and pan along its length, changing the tensioning across the belt width. Sharp rock, which sometimes must be taken when the top is poor, damages the belt or causes detramming due to uneven loading. If these pieces of rock are sizable, they become trapped in the straddle frame at the transfer point, stalling the belt completely. Any of these conditions can cause the belt to fail by breaking, jamming, or wearing excessively.

Cable handling during the compression of the PBC over the MBC is accomplished by means of a 2-1/2-ft-diam pulley suspended horizontally under the conveyor by a large, garage door-type spring. This arrangement was intended to maintain cable tension as the cable pays in and out. However, cable weight varies as the amount of cable suspended changes, and so does the effective spring tension. The net result is a system that is impossible to

adjust. On all units observed, the operators had given up and allowed the pulley and cable to drag in the bottom.

When the Long-Airdox system is operating in a reasonable environment with an experienced crew, it will outperform either the Jeffrey or WVA equipment. However, these conditions rarely exist in low coal seams and, consequently, overall system reliability is poor.

2.1.2 Jeffrey Manufacturing Company

Jeffrey's "Low Seam Continuous Haulage System" (see figure 9) offers a choice of two systems for use in low to medium seams, both of which mate with a number of different continuous miners and/or room conveyor systems.

2.1.2.1 System Description

The 506-C5 Double Bridge Carrier (DBC) and 94-L Bridge Conveyor (BC) are used with the 101 MC Helimatic or with other low seam miners in seam heights of 48 in. or less. The system capacity is rated at 4 tons/min.

The 524 DBC and 523 BC mate with the 120-L Heliminer or other comparable miners for working thick seams. Overall system capacity is rated at 8 to 11 tons/min.

Both systems have the following common features:

- a. Twin chain conveyors with full width crossflights
- b. Swiveling connections on both DBC and BC units, similar to those on the Long-Airdox equipment, for adaptability to various mining plans
- c. Dolly design connections similar to Long-Airdox between the BCs and DBC for system compression during operation
- d. 120 ft of reach for a 3 element system, 180 ft with 5 elements
- e. Fully automatic cable and water hose handling.

Both of Jeffrey's low and medium seam, 3-element, continuous haulage systems are operated by one man. The basic components are the two unmanned BCs and a single manned DBC. The 5-element system for additional reach requires an additional operator.

There is little difference between the application of either the Jeffrey system or the Long-Airdox equipment discussed previously. The most obvious difference in

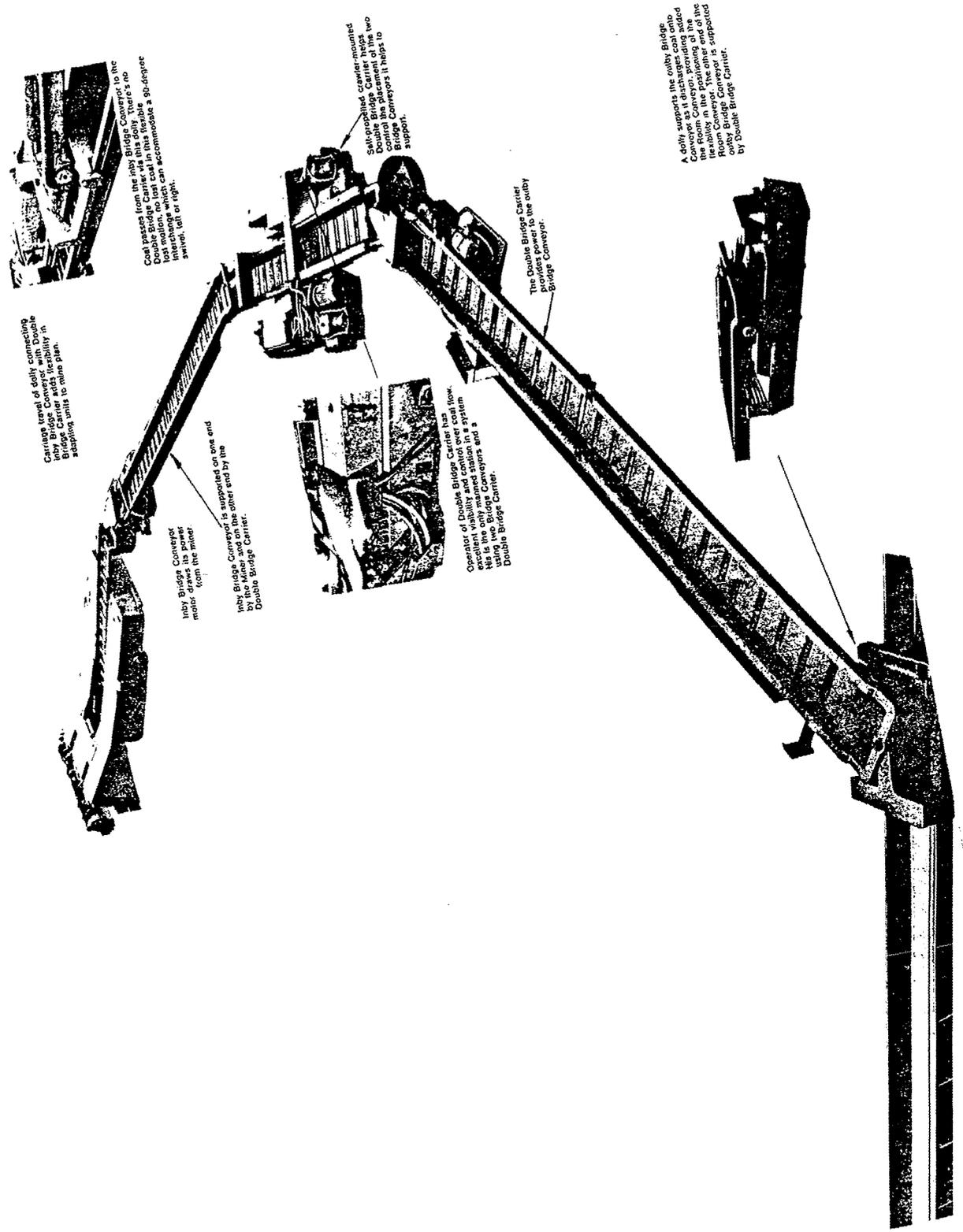


FIGURE 9. - The Jeffrey "low seam" continuous haulage system.

component selection is the use of the twin chain conveyor with crossflights running on a steel pan instead of the belt. Apart from that, the two designs have all of the same components arranged in a slightly different manner.

The BC and DBC conveyors are identical structurally except for the bridge trolley on the inby end of the DBC. The circular receiving end of the BC is much wider than the conveyor line itself and this, along with the comparatively narrow (27 in. chain versus 36 in. belt) width of the conveyor, helps to reduce spillage at the transfer points. The smaller width and greater pan depth makes for a rugged conveyor frame. This same solid structural design is also evident in the crawler track suspension system.

2.1.2.2 Critique of the Jeffrey System

The narrow, deep pan structure used in the chain conveyor frames results in a strong framework, making it apparent that the overall structural design of the Jeffrey machine is a well thought out and well built system.

The main weak point is, once again, the pivot pin connection between the BC and DBC, as is the case with the Long-Airdox system. Also, the narrow chain conveyor trough leads to a transfer point which is more restricted than the belt conveyor designs and consequently causes more jams when roof material is taken.

The crawler drive is well conceived, owing in large part to Jeffrey's experience with the design and development of continuous miners.

The chain conveyor is a stronger, more positive means of hauling coal and is far less prone to breakdown than any of the belt systems. Individual flights do get broken, but generally do not stop the line. In addition, replacement of a flight is easier than making a belt splice. The one criticism of chain systems is that they are noisy when running empty or when not tensioned correctly.

Cable service loops are trained in a trough which is mounted alongside the bridge. This system keeps the cable out of trouble. The cable pays in and out of the trough and can be checked visually by the operator in this exposed position.

The Jeffrey units do not have the capacity of either the Long-Airdox or WVA systems in terms of tons/min moved, but they do run more reliably, especially in adverse

conditions. In terms of overall productivity, they are, therefore, capable of moving more coal.

2.1.3. West Virginia Armature Company

WVA's "Full Flow Haulage" system (see figure 10) is an articulated belt conveyor arrangement comparable in appearance and layout to those manufactured by the preceding companies. Two BCs, a crawler-mounted MBC, and a portable belt conveyor (called the "Long John") combine to form a 4-element system which can accommodate thin (as low as 30 in.), medium, and high seam continuous miners with throughput capacities up to 15 tons/min.

2.1.3.1 System Description

The BC is a low profile unit designed for application to virtually any coal seam higher than 30 in. Carrying a 36 in. belt, the BC comes in standard lengths of 30 and 45 ft, but each unit is sectionalized so that the length can be altered for a variety of mining development plans. The BC is driven by an electric motor and supported by a stainless steel pan to reduce overall height in an almost identical manner to that used by Long-Airdox. Belt speed is not usually affected by this arrangement due to a low relative coefficient of friction between the components; however, coal ingestion between belt and pan is a major source of belt jamming. A spirally shaped tail pulley cuts down dust generation while accomplishing the belt cleaning operation.

The MBC ranges in length from 30 to 40 ft and has a built-in hydraulic height adjustment for the receiving and discharge ends in order to compensate for varying seam thickness and changing roof and floor conditions. Each crawler is powered directly by a high torque electric motor, which enhances position control and maneuverability. The 36-in. belt has electric motor drive with components identical to those used on the BC for the sake of simplified inventory. A separate motor-pump combination powers a hydraulic system and a hydraulic cylinder for elevation of the inby and outby ends. The MBC frame serves as a track at the inby end on which the inby BC dolly rides. The MBC carries the outby BC suspended from its discharge end.

This equipment is also very similar to the Long-Airdox system previously discussed.

The "Long John" portable conveyor provides the outby anchor point in a manner very similar to the Long-Airdox special belt tailpiece. It is different, however, by virtue of its utilizing a completely independent belt and

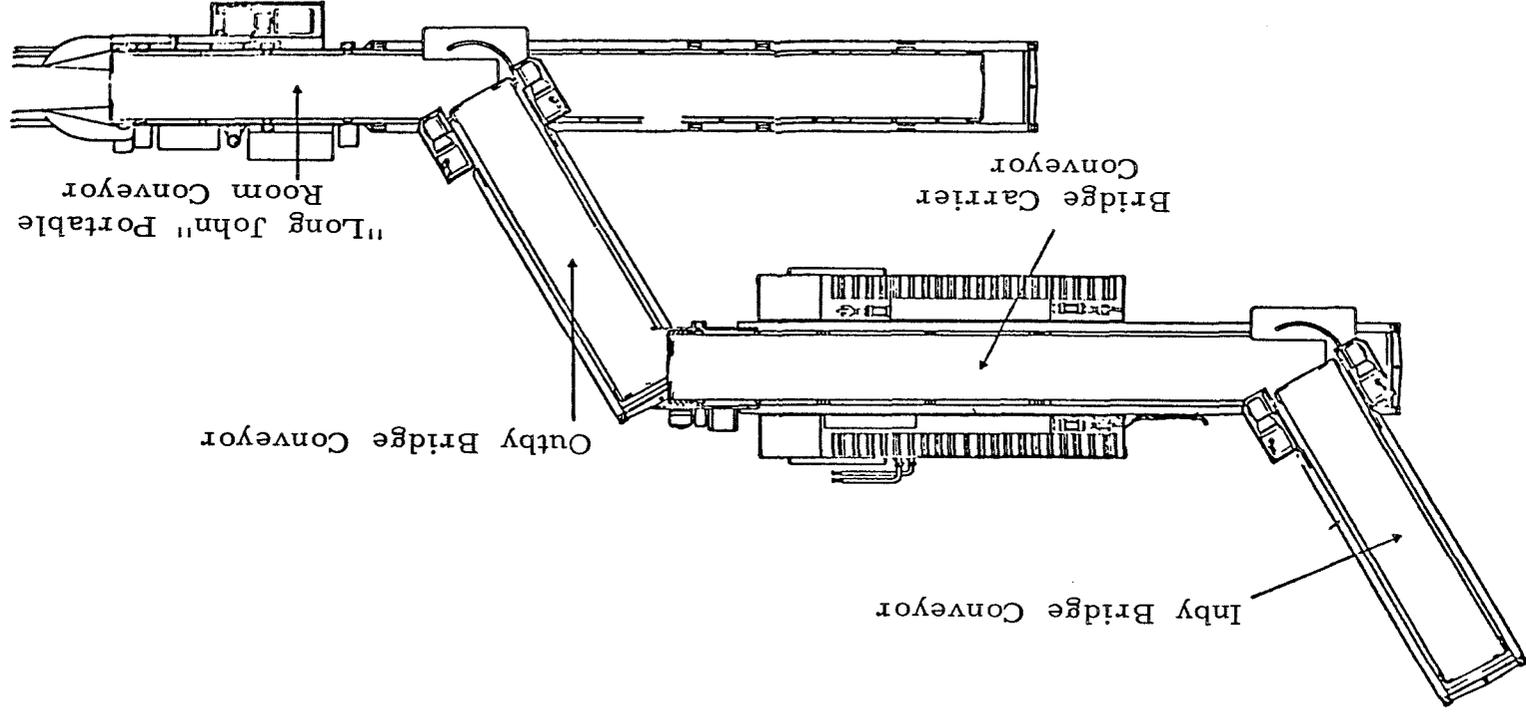


FIGURE 10. - Layout of WVA's "full flow haulage system."

belt drive, which accepts coal from the most outby bridge and discharges it onto the standard panel belt. The 120 to 150 ft long conveyor is coupled to the panel belt tail section by a pin lug in conjunction with a hydraulic anchor jack such that any disturbance of the "Long John" will not disturb the critical panel belt alignment.

2.1.3.2 Critique of the WVA System

The WVA continuous haulage system is similar in many respects to the Long-Airdox equipment and is subject to the same shortcomings. One area that shows improvement is the transfer point pivot, which uses a large diameter bearing track outside of the coal path instead of a fragile pin whose location aggravates the jamming problem.

The standard framework utilizes a flat pan structure to minimize height and, as a consequence, is torsionally flexible. This flexibility, as in the Long-Airdox system, leads to belt training problems whenever the frame is run against the top, bottom or ribs.

The belt is similarly vulnerable to sharp rocks cutting the surface or wet fines packing between pan and belt causing uneven tensioning, jamming and breakage.

The crawler sprockets on the suspension are twice the diameter of those used on the Long-Airdox and Jeffrey systems. Consequently, a significant obstacle can deflect the pad across its width causing the sprocket to walk out of the track. In addition, crawler pad backup is poor.

2.1.4 Alternative Systems

The following discussion covers several engineering concepts which have been developed as alternatives to the mobile conveyor systems for continuous haulage presented above. Of the many approaches examined, only four were of interest to this program:

- a. The Joy Serpentix Conveyor
- b. The Joy Flexible Conveyor Train
- c. The Hewitt-Robins Mineveyor
- d. The Jeffrey Moleveyor.

The first two systems are special flexible conveyor belt arrangements while the others are cascading conventional conveyor belt systems.

Additional work has taken place on the above systems since our original investigations. While the systems, themselves, have not changed substantially, additional references are available to the reader including:

- Peabody Coal Company's Final Report on the Serpentix Conveyor
- The Department of Energy's Final Report on the Joy Flexible Conveyor Train
- Jeffrey Mining Machinery Company's Final Report on their "MUCH" system.

2.1.4.1 The Serpentix Conveyor

The Serpentix concept, originally developed in Germany for above ground applications, is a conveyor that can operate around fixed turns. It employs a spinal arrangement of 8 ft long, flexible vertebrae sections, built up from a number of formed steel pans vulcanized to a convoluted belt and separated by resilient spacers (see figure 11).

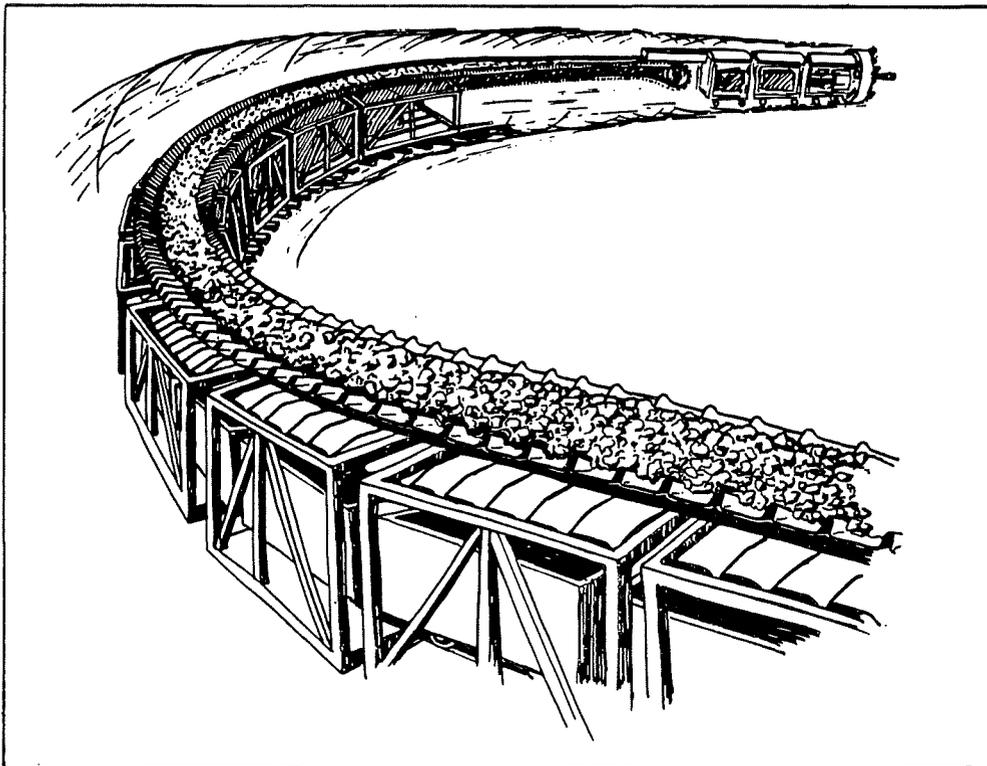


FIGURE 11. - The Serpentix concept

The Joy Manufacturing Company has obtained the rights to develop the Serpentix system for deployment in underground bedded deposits in the United States. The Peabody #10 coal mine near Taylorville, IL conducted a working on-line test of the Serpentix conveyor. In that application, the complete mechanism was supported by a roof-mounted monorail system.

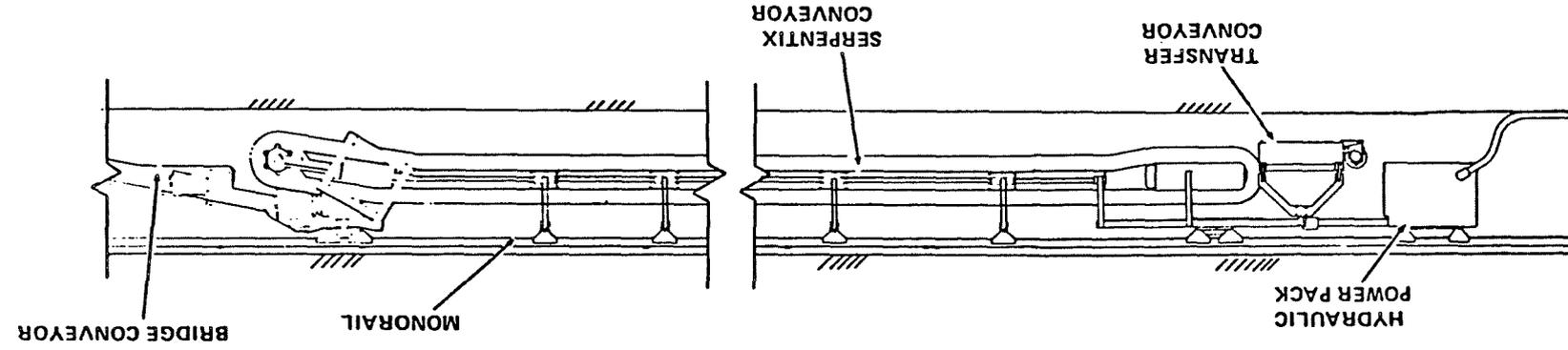
Components of the Serpentix system used at Peabody #10 are depicted in figure/12 and are briefly described below:

- a. The crawler mounted, hydraulically powered tram car, which is stationed directly behind the miner
- b. The ruggedly built bridge conveyor, which serves as a drawbar between tram car and the inby end of the Serpentix conveyor
- c. The Serpentix conveyor with vertebrae supported on a spine bar track that passes through the vertical and horizontal center of the upper and lower belt lines and allows relative lateral flexure under guidance while maintaining vertical integrity
- d. The cross transfer conveyor, which transfers coal from the Serpentix conveyor to a panel belt running parallel to it in the entry
- e. A 36-in. wide, conventional rope-supported panel belt.

Two associated components, essential for system operation are:

- a. A roof-hung monorail track, which supported the Serpentix conveyor in the Peabody #10 installation
- b. The hydraulic power jack, also supported from the monorail.

The 200-ft Serpentix unit installed in Peabody no. 10 turned 60° and 90° corners without difficulty while operating at an average belt speed of 400 ft/min and with throughput capacity on the order of 8 to 9 tons/min in a 7-ft seam. The system was successfully used to develop a five entry mining plan with entries on 60-ft centers, and crosscuts on 70-ft centers at 60° to the entries; all 22 ft wide. Production figures quoted increased peak outputs from 800 tons/shift with shuttle cars to 1100 tons/shift with Serpentix.



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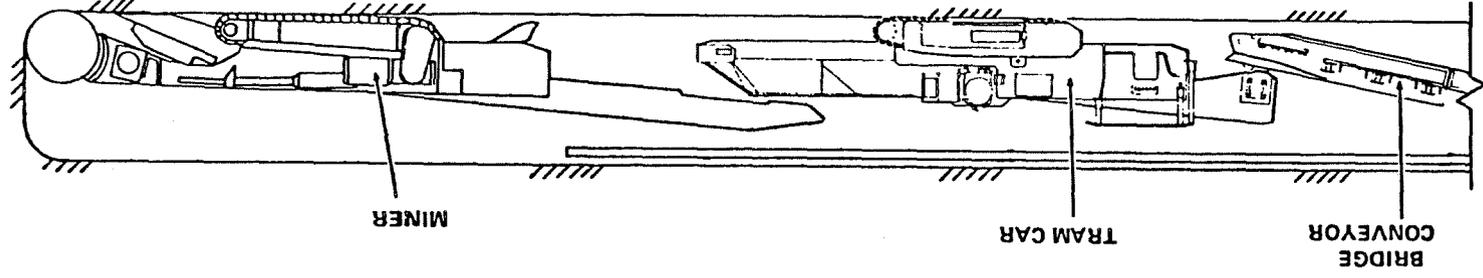


FIGURE 12. - Serpentine conveyor at Peabody #10 Mine in Taylorville, IL - a side view of system components.

The advantages of the Serpentix conveyor are:

- a. An already proven, consistent carrying capacity of 8 to 9 tons/min, or 800 tons/shift
- b. The use of a dual purpose tram car for handling surge flow and relieving the miner of the conveyor constraints
- c. A highly maneuverable system which tracks well with the miner due to:
 1. The match of tram car speed with that of the miner
 2. The positive guidance feature of the monorail track.
- d. Haulage capability on all corners, which matches straightaway capacity, without regard to system configuration or loss of product
- e. 200 ft of reach, which makes it comparable to present alternative haulage systems and offers the potential for extension to 400 ft or more
- f. A safe system since overall movement is slow and the path of motion well defined due to the monorail.

The major disadvantages are:

- a. The height requirement of 7 ft to avoid damage to the convoluting belt and the large diameter pulley on the bottom side of the drive sprocket at the inby end.
- b. Spillage at the inby transfer points; i.e., the tram car, bridge conveyor, and inby end of the Serpentix
- c. Noise levels in excess of 100 dBA
- d. Difficulty in handling large pieces of coal
- e. High cost for both initial installation and maintenance.

These problems have been identified by Peabody and Joy, and improvements are expected.

2.1.4.2 The Flexible Conveyor Train (FCT)

The FCT is an experimental continuous haulage device built by the Joy Manufacturing Company. The FCT uses a 36 in. wide continuous belt, made by B.F. Goodrich, which is capable of lateral bending in a serpentine fashion (see figure 13). It is mounted atop sequentially arranged conveyor "cars." With this flexible belt arrangement, the FCT is designed to haul coal around three 90° turns at the rate of nearly 12 tons/min.

Figure 14 represents one of several FCT layouts. Altogether, there were 39 conveyor cars, one inby unit consisting of a hopper and belt drive unit, and one outby tractor. The latter vehicle handled coal crossover conveyance from the continuous haulage system to the panel belt and also included the belt drive, belt take-up, cross conveyor, and tram mechanism. Difficulty with FCT corner negotiation, where the cars would hang up on the rib, resulted in field installation of guidance rollers at the turns.

After 40 production shifts of testing, the following advantages of the FCT system were affirmed:

- a. The capacity and capability to haul more coal than with current shuttle cars
- b. Elimination of fast moving shuttle cars and trailing cables for enhanced safety in the mine

Several desired improvements were also identified:

- a. The need for reduced spillage:
 1. Fines caught in the ribs of the serpentine belt are then carried back and dumped onto the mine floor
 2. At coal transfer points between cross conveyor and panel belt
 3. Improved belt wiper required.
- b. Orientation of coal flow coming from the cross conveyor so that it is parallel to panel belt rather than at right angles
- c. Greater traction for the outby tractor

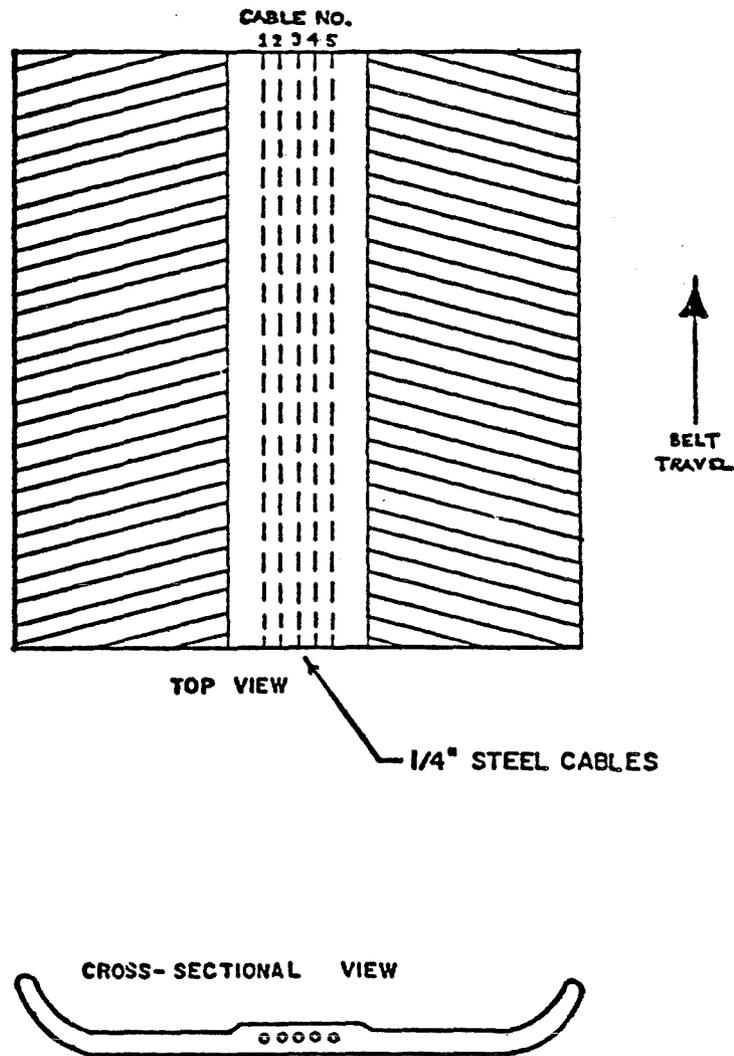


FIGURE 13. - Schematic of B.F. Goodrich serpentine belt used for flexible conveyor train (FCT).

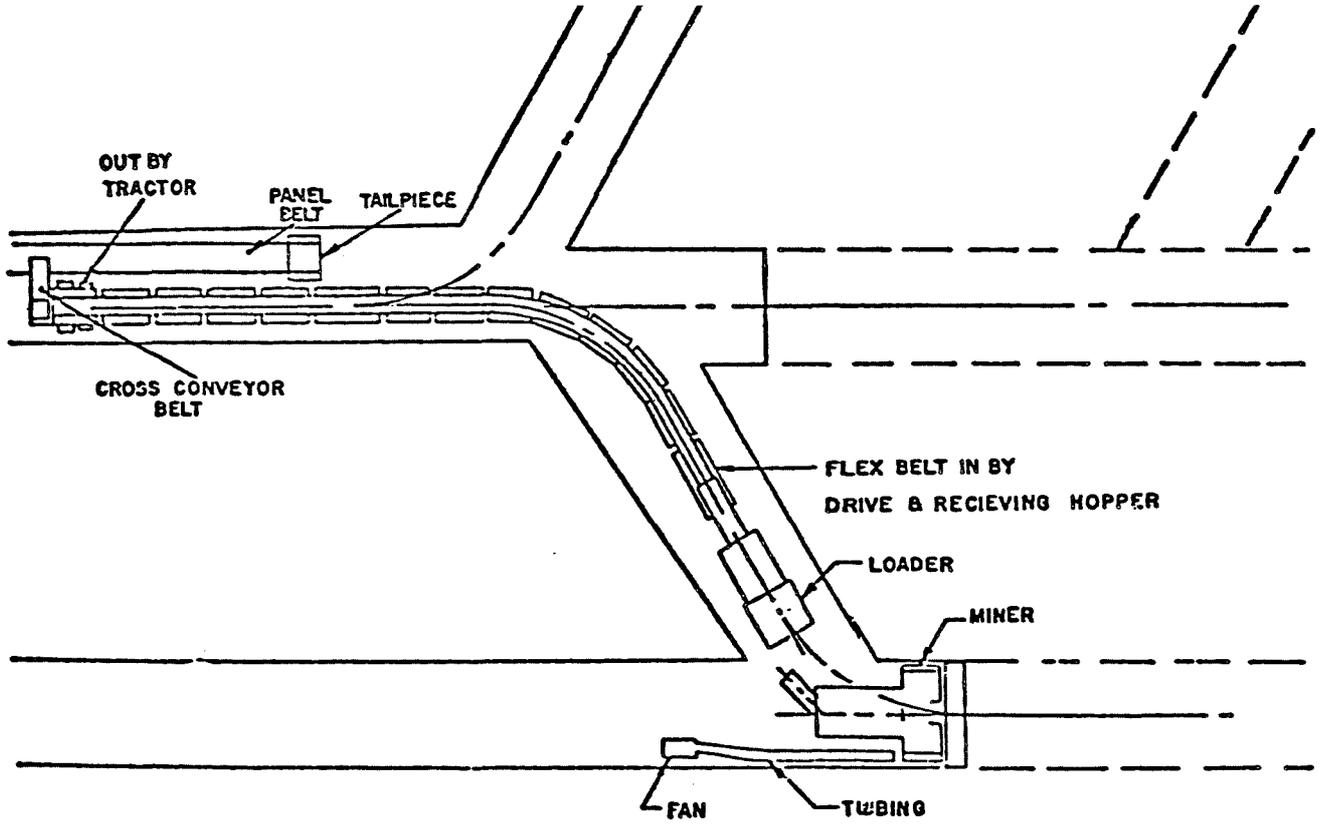


FIGURE 14. - FCT general layout for entry advance mining plan.

- d. Design of a standard width shuttle car for use as an inby vehicle:
 - 1. Capable of pulling the FCT
 - 2. Having a standard boom compatible with FCT inby hopper
 - 3. Equipped with a quickly detachable, hydraulic winch for short distance movements.
- e. Addition of a breaker built into the conveyor
- f. Reduced noise levels at the operator's platform on the outby tractor.
- g. Standard turn roller for use along the ribs.

2.1.4.3 The Mineveyor

The Mineveyor is a mobile bridge conveyor system first built over 20 years ago by the Hewitt-Robins Company and tested on a shortwall section at Eastern Associated Coal Company's Federal No. 1 in Grant Town, WV (see figure 15). The key feature of this design was the absence of any mechanical connection between miner and bridge system and, likewise, between bridge system and panel belt for the purpose of ensuring maximum flexibility.

The principal system components are:

- a. The bridge conveyor system normally composed of three to five 2-wheeled, self-powered conveyor units (see figure 16), each piggybacked onto the succeeding outby unit
- b. A 4-wheeled discharge cart, also self-powered, at the outby end
- c. A low profile, extensible panel belt conveyor with side guide rails to steer the mobile bridge discharge cart as it travels and discharges mined materials.

The main characteristics of the mobile bridge conveyor units are:

- a. Standard length of 32 ft for each identical conveyor bridge and a combined length of 192 ft
- b. Conveyor width of 36 in.
- c. Overall height of 4.75 ft

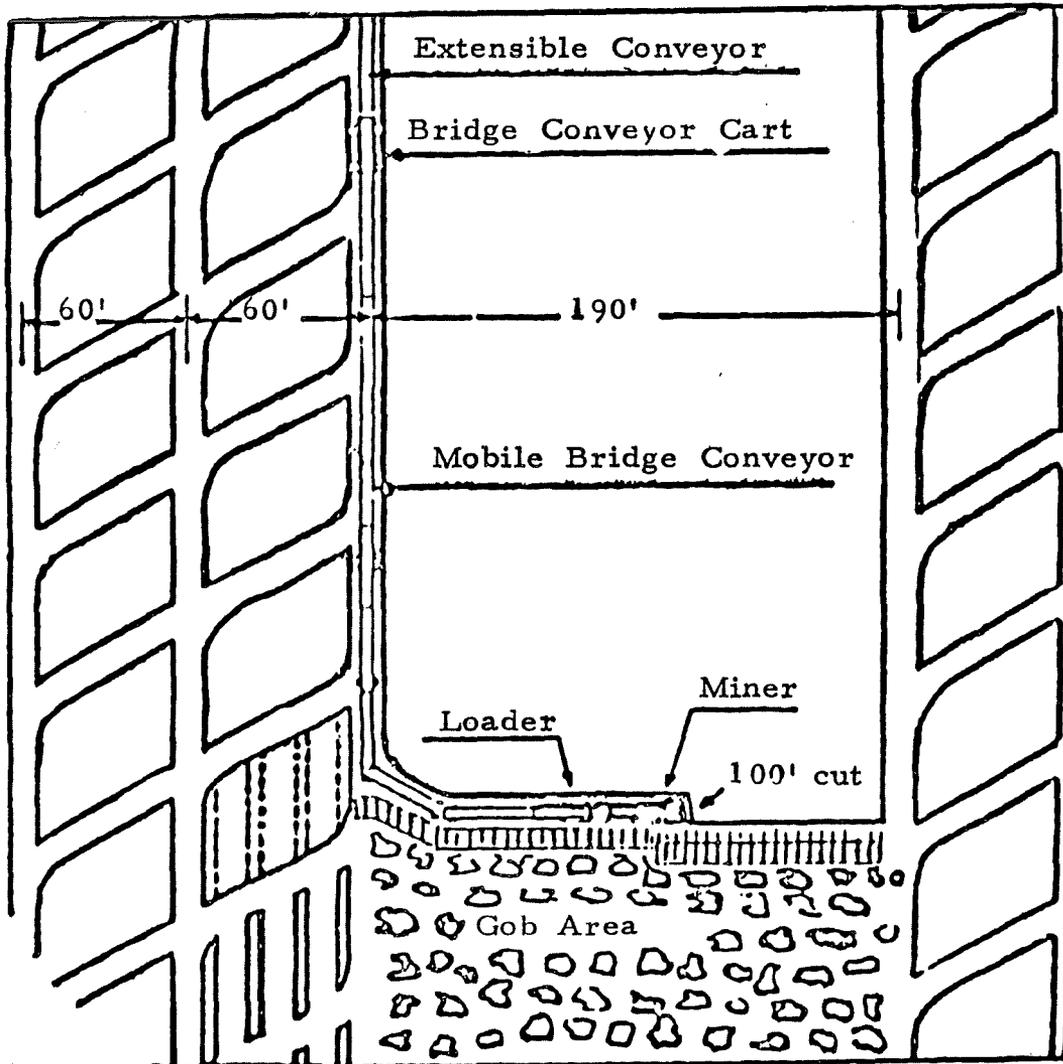


FIGURE 15. - Application of Mineveyor continuous haulage system to Eastern Associated Coal Company's shortwall section at Federal #1 Mine in Grant Town, WV.

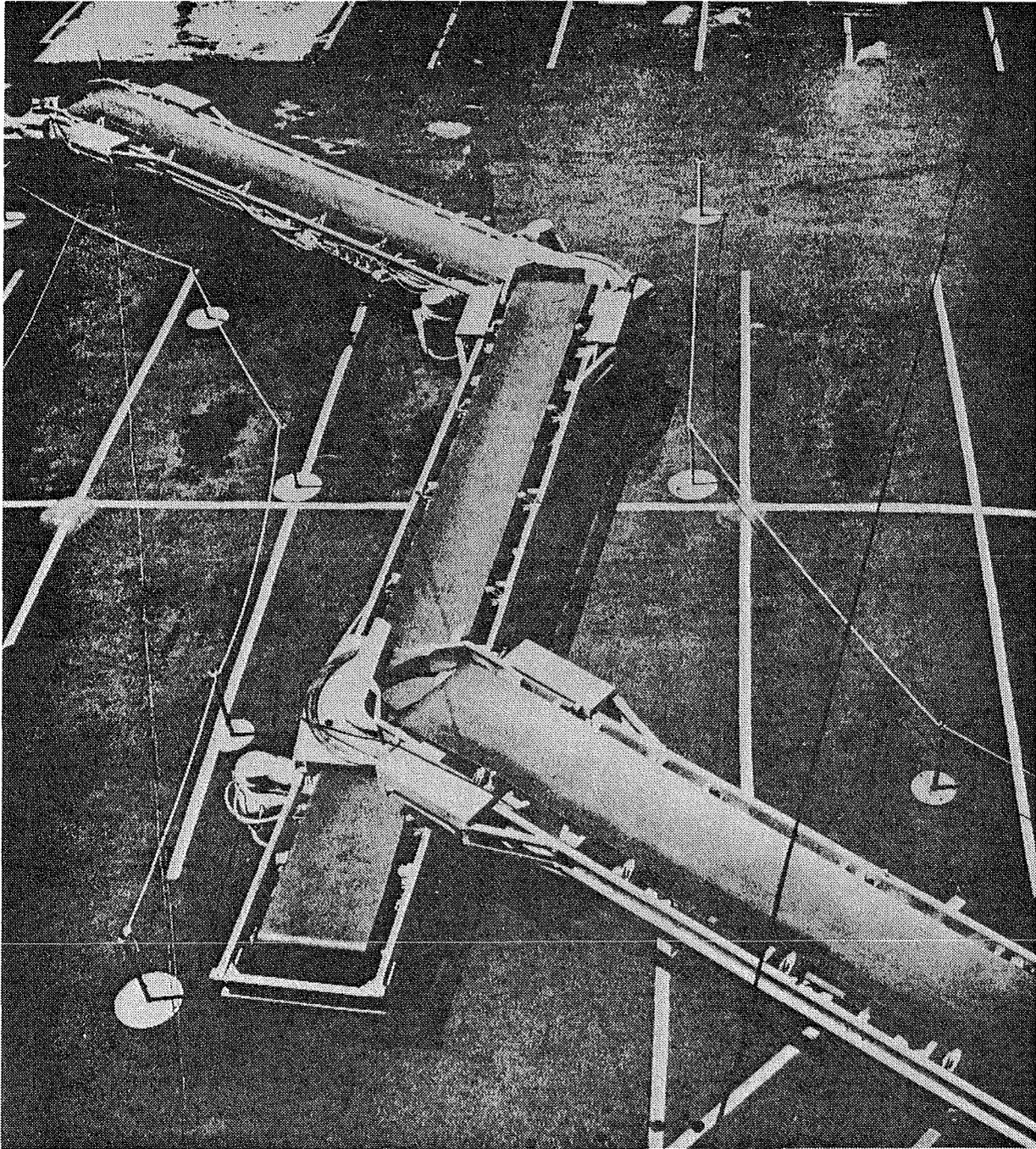


FIGURE 16. - Mineveyor bridge conveyor units.
(usually 2 to 5 in series).

- d. Average throughput capacity of 450 tons/h
- e. Center point mounting of each of the pneumatic tired wheels at the inby end of each conveyor. Wheel movement is independently and hydraulically trammed and steered on each unit with a full 90° swing capability to left or right
- f. A pivot connection between adjacent bridges with the outby end of each unit supported by the inby end of the next outby unit
- g. Telescoping action between bridges resulting in up to 15 ft of compression between any two units
- h. Trimming speed up to 40 ft/min.

The discharge cart has the following specific features in contrast to the bridge units:

- a. An automatic tracking system activated by guide rollers which maintain contact with the side rail frame of the extensible panel belt conveyor. The cart was designed to always remain straddled above the low profile, extensible panel belt
- b. A yoke mounting between the discharge cart frame and the wheel supports which keeps the cart conveyor level while the wheels ride over floor irregularities.

The extensible conveyor has three primary components:

- a. A crawler-mounted head section with a belt storage unit mounted on skids or crawlers
- b. A low height (18.5 in.), 12-ft long tail crawler, which has independently powered crawler tracks for fast belt extensions and ease of alignment (see figure 17)
- c. A low profile side rail intermediate structure (16 in. high) to provide a pair of guide rails for discharge cart steering.

Mineveyor operation is handled by two men, each of whom controls three vehicles at the inby and outby ends respectively. Identical control stations, mounted on the middle units for each group of three bridges, are positioned on both sides of the unit to give the operator a choice of vantage point. The man at the outby end also controls the hydraulically operated, discharge cart chute for directing coal flow onto the panel belt.

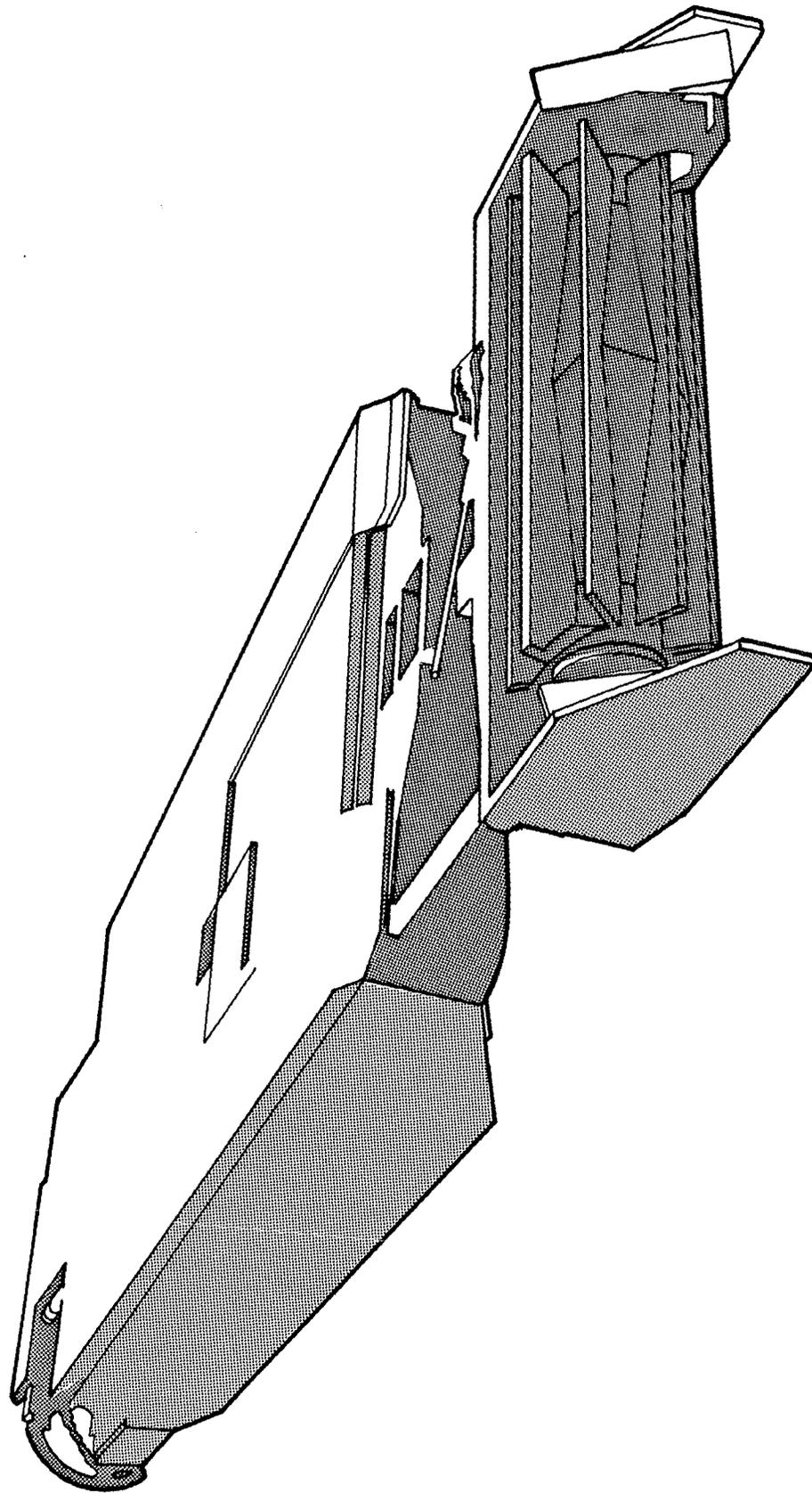


FIGURE 17. - Mineveyor, hydraulically controlled,
cat-mounted extensible belt conveyor, tail crawler
with adjustable tail pulley.

Advantages and disadvantages of the Mineveyor system cannot be realistically assessed due to its limited use in mining applications. Our last report was that the Eastern system is not currently operating.

2.1.4.4 The Moleveyor

The Moleveyor continuous haulage system, designed and developed over 30 years ago by the Jeffrey Manufacturing Company, consisted of twelve connected, 4-wheeled carts, each with an individually powered conventional conveyor running along its length (see figure 18). The Bethlehem Steel Company is the last known user of the rugged Moleveyor, which never gained acceptance within the mining industry due most likely to its high initial cost. Only a few production units were ever built and little published information on their performance has survived.

The principal Moleveyor vehicle characteristics were (see figure 19):

- a. 15-ft long intermediate cars with 4-wheel drive and interconnecting steering linkages between cars for tracking. Angular articulation of cars relative to one another reached a 45° angle and achieved a turning radius of 18 ft
- b. End cars of the train also equipped with 4-wheel steering
- c. Evolution from a belt to a chain conveyor for greater reliability
- d. Low height in order to operate in seams 25 in. or higher
- e. Winches on every other car for position adjustment due to the tracking problems encountered on bad bottom
- f. A short conveyor section at the discharge end that could swing and elevate hydraulically to transfer coal onto the panel belt at the most efficient angle.
- g. Throughput capacity on the order of 4 tons/min
- h. Overall system reach of 200 ft.

Jeffrey's layout drawings of the Moleveyor illustrate a complex design for the unit vehicle with involved linkages and substantial on-board machinery. Capital

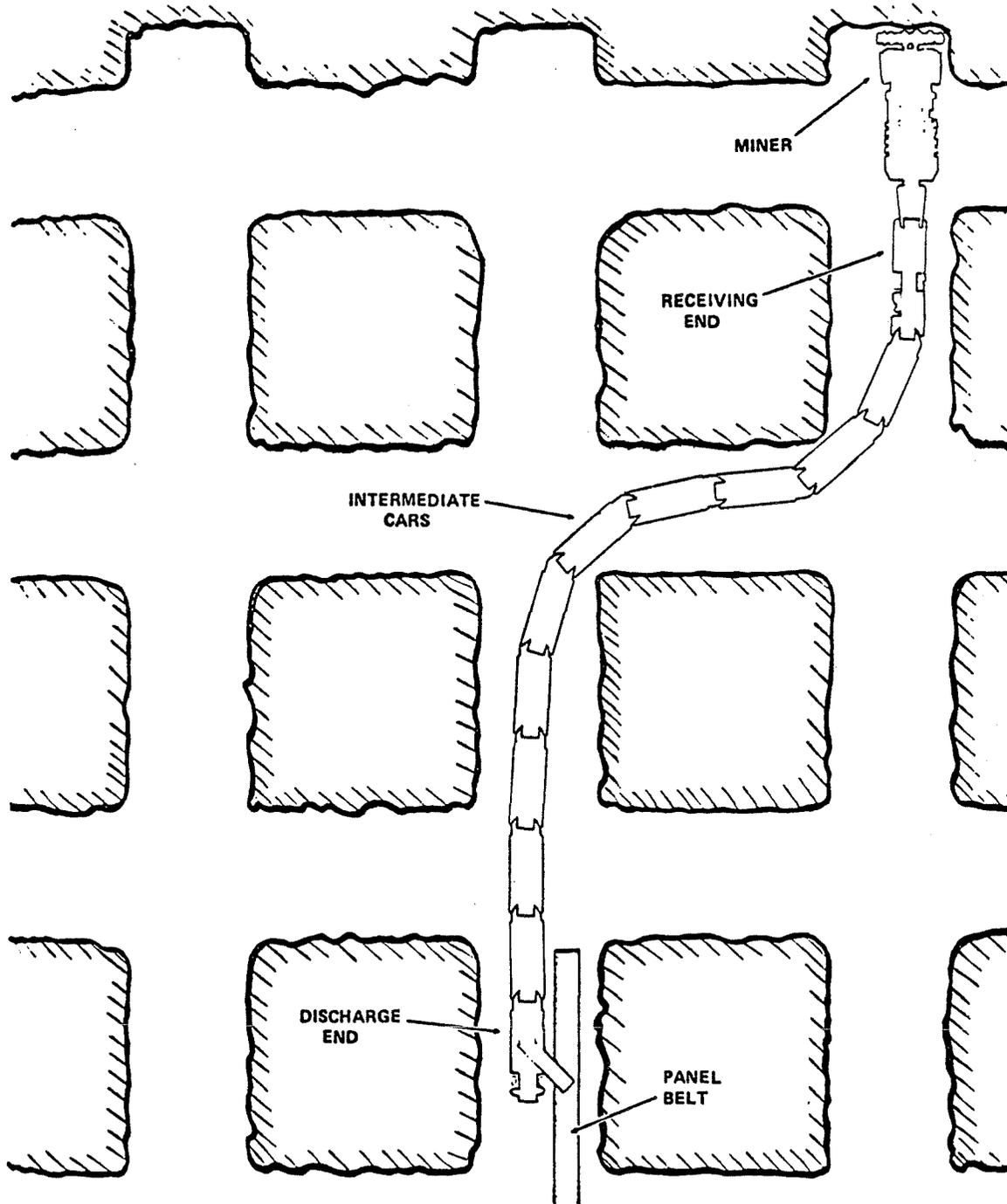


FIGURE 18. - Moleveyor plan view.

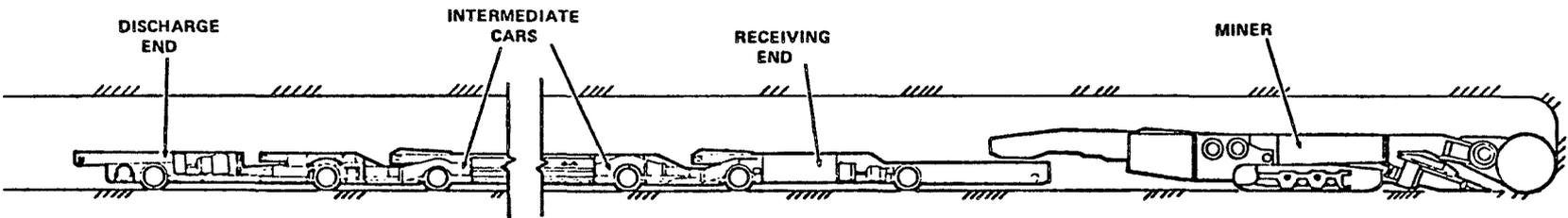


FIGURE 19. - Jeffrey Muleveyor side view.

investment for a haulage system of this type was prohibitive for the degree of improvement offered over shuttle cars. In addition, system availability and maintenance problems were reportedly severe.

The principal drawbacks of the Moleveyor system were:

- a. Limited ground clearance due to the small vehicle wheels. Bad floor conditions created an especially difficult situation for system movement
- b. Tracking difficulty with the intermediate cars on corners.
- c. Insufficient mobility to cope with frequent system moves between entries
- d. Dust generation, spillage, and carryback resulting from the transfer points
- e. A poor surge capacity due to the small receiving hopper at the inby end.

2.1.5 Conclusions from Equipment Review

A summary of the equipment reviewed is provided in table 1. A more detailed description of each system is contained in the Phase I Report.

2.1.5.1 The Conveyor System

Before a fully automated continuous haulage system that advances and retreats with miner movement becomes operational, overall improvements in the conveyor systems are an essential prerequisite to ensure more reliable performance. Chain conveyor systems offer a definite superiority over belts in low coal conditions (where continuous haulage clearly offers the most advantage). The chain systems break down because of:

- a. Trimming
- b. Cable and structural problems associated with transfer points
- c. Miner connections to the swing boom.

TABLE 1. - Equipment review.

LONG-AIRDOX

Classification: Crawler-mounted conveyor units; belt haulage; commercially available

Maximum tram speed: 55 ft/min (higher speeds optional)

Haulage capacity: 10-12 tons/min

Minimum seam height: 30 in.

Problems: Belt misalignment, Poor cable handling system

JEFFREY

Classification: Crawler-mounted conveyor units; chain haulage; commercially available

Maximum tram speed (506-C5 DBC and 94-L BC): 40 ft/min; (524 DBC and 523 BC): 80 ft/min

Haulage capacity (506-C5 DBC and 94-L BC): 4 tons/min; (524 DBC and 523 BC): 8 to 11 tons/min

Minimum seal height (506-C5 DBC and 94-L BC): 30 in. (524 DBC and 523 BC): 36 in.

Problems: Relatively low capacity of the smaller units, high noise levels

WVA

Classification: Crawler-mounted conveyor units; belt haulage; commercially available

Haulage capacity: up to 15 tons/min

Minimum seam height: 30 in.

Problems: Poor reliability

TABLE 1. - Equipment review (continued).

SERPENTIX

Classification: Roof mounted flexible belt; prototype installation; transfer of foreign technology

Haulage capacity: 8 to 9 tons/min

Minimum seal height: 7 ft

Problems: Spillage, noise, inability to handle large pieces of coal, need for roof-mounted support system

FCT

Classification: Flexible conveyor supported by 2-wheeled conveyor "cars," experimental prototype

Haulage capacity: 10 to 12 tons/min

Problems: Spillage, difficulty in tracking around corners

MINEVEYOR

Classification: 2-wheeled conveyor units; belt haulage; limited production (no longer in use)

Maximum tram speed: 40 ft/min

Haulage capacity: 8 to 10 tons/min

Minimum seam height: 60 in.

MOLEVEYOR

Classification: 4-wheeled conveyor units; belt haulage; limited commercial production (no longer available)

Haulage capacity: 4 tons/min

Minimum seam height: 25 in. (reportedly)

Problems: Limited ground clearance, tracking difficulty, slow tramming, spillage, poor reliability.

Belt systems have added problems with belt breakage and stalling due to:

- a. Misalignment
- b. Overloading
- c. Entrapment of wet fines
- d. Frame distortion.

Chain conveyors are well received in mines because they are less susceptible to breakdown. This preference is evident in conversations with operators.

The conveyor pan and structure associated with a chain system can be narrow and deeper than a belt unit, because the angle of repose of the product need not be considered. This results in a stronger structure with better inertia characteristics relative to the bending stresses which result from contact with the top, bottom and ribs.

2.1.5.2 The Crawler Track Suspension System on the Bridge Carrier

None of the three available systems (Long-Airdox, Jeffrey and WVA) is particularly maneuverable due to the short crawler track/long conveyor combination, which results in amplified swings at each end of the carrier for small steering corrections. Although claims are made for 90° cross cut, 18-20 ft wide entry operation, most proposed development plans show 60° corners or entry widths greater than 20 ft. Most operations visited during our research of existing equipment used both 60° cross cuts and 22-24 ft entries.

The crawler suspension systems on the Long-Airdox and WVA equipment received criticism relative to their reliability. Single sprocket pad drives with inefficient pad backup lead to deflection and gob-off of the track. Lack of space in low coal has forced compromises in drive train components resulting in breakdowns in the transmission.

2.1.5.3 Transfer Points

Transfer points and their associated bearings are a major source of jamming and breakdown in current systems. The WVA approach, on the other hand, is a step in the right direction, and the adoption of a four-bar linkage is an attempt to further improve conditions at transfer points. There is no restriction in the path of coal discharging from the bridge onto the carrier, and correct sizing of the link bars and pivot pins ensures sufficient flexibility without sacrificing positional accuracy.

2.1.5.4 Cable Handling

None of the systems reviewed dealt with a major cable handling requirement which is apparently unique to the ABCT. The ABCT must transmit all electrical and water power along the complete train via linked units. These units must collapse upon each other to foreshorten by more than 25%. In operation, there will be no guarantee of the order in which the train will be organized. Therefore, each unit must be capable of transmitting total power over its extended length and accommodating the extra loop resulting from compression.

Since the ABCT must accommodate total power requirements on each and every leg of the conveyor train, control and protection of the cables is an absolute necessity. No existing system has a satisfactory design.

2.2 TRADEOFF STUDIES

The objective of the tradeoff study was to arrive at a set of preliminary hardware choices which fulfilled the system requirements and offered the best overall solution to the operating problems described in our conclusions to the hardware review (section 2.1.5).

2.2.1 The Mechanical System

The design choices made during the mechanical engineering study phase considered both the original specifications of the proposal, and other requirements uncovered by the study of existing hardware. Also considered were the increased demands placed on the conveyor structure by the automatic tracking requirements. The principal areas considered early in our tradeoff study were:

- a. Conveyor sizing and type, in particular the choice between chain and belt types
- b. The geometry of the conveyor vehicles including
 1. The length of the vehicles
 2. The location of the ground support points along the length of the mobile carrier.
- c. The type of ground suspension
 1. Crawler tracks
 2. Wheels

- d. Transfer point and pivot design
 - 1. Pin type
 - 2. Track type
- e. Methods of handling the power cables
 - 1. Spring mount on side of vehicles
 - 2. Cable reel
 - 3. "Catrac" or Bretby chain carriers
 - 4. Spring and pulley underneath vehicles
 - 5. Loose, on floor
- f. Whether to carry miner power along the ABCT.

2.2.1.1 Conveyor Type and Size Studies

Examination of the relative advantages of chain versus belt as a basic conveyor revealed the following significant points:

Advantages of Chain

- a. Can be made narrower for the same coal carrying capacity
- b. Positive drive; has some capability of breaking up jams
- c. Reduced gob-up and carry back
- d. Less maintenance; more easily repaired
- e. Less spillage
- f. Less fire hazard
- f. Requires lower driving torque
- g. Greater durability
- h. Slower operating speed for same capacity.

Advantages of Belt

- a. Quieter operation
- b. Lower initial cost

- c. Lighter weight
- d. Possibility of providing length variation by "looping" the belt.

Mine operators came out in favor of chain. That fact and an evaluation of the factors enumerated above led us to choose chain for the initial design work.

Better stress distribution and durability are obtained from the dual strand scraper flight design. The only advantage of the central strand pattern, that of transverse flexibility, is not required. The dual strand design was chosen.

2.2.1.2 Vehicle Geometry

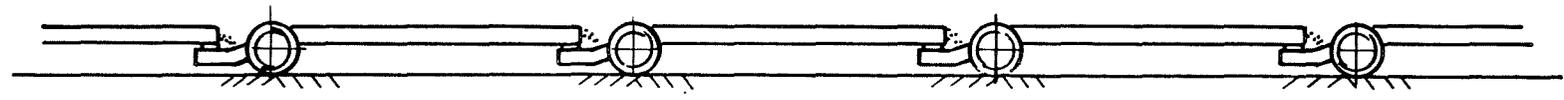
Two basic concepts of train design were examined. The first was the "cascading" or "piggyback" design, in which a sequence of identical vehicles are coupled together as shown in figure 20(a). The appeal of this design is considerable: all units are identical, leading to minimum requirements for spares; if a section fails it can be removed from service and the train closed up with a minimum loss of length. One disadvantage, that the unsupported end of an uncoupled section would need a separate service vehicle to support it, was not considered insurmountable.

However, the fact that the angular tracking attitude of each section is defined by the location of the next inby section led to very difficult guidance problems, problems to which we did not find a workable solution.

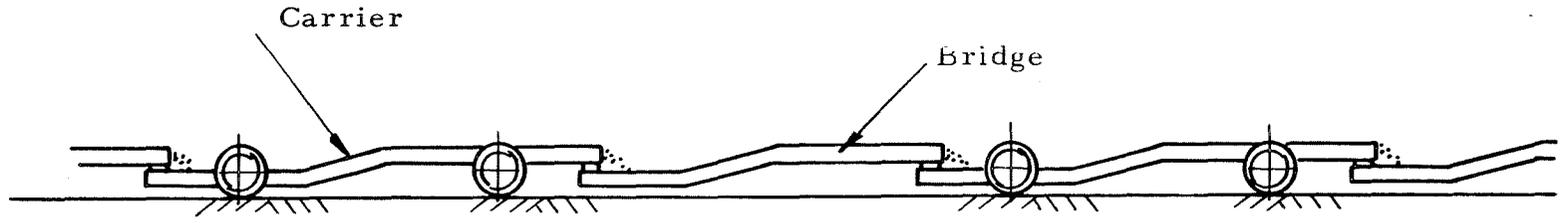
Most of the work was therefore concentrated on the second concept, the more conventional "bridge and carrier" design shown in figure 20(b). This led to much simpler guidance systems, as each carrier is positioned independently of its neighbors. The bridges provide connection between them without dictating any positional requirements.

To give good definition of the angular position of the bridge carrier, it was apparent that two cable sensor arrays were needed, separated from each other by a substantial fraction of the vehicle length. This is illustrated in figure 21. Locating the ground suspension points at or near the sensors yields the simplest guidance strategy and also minimizes the chance of the conveyor running over the guidance cable.

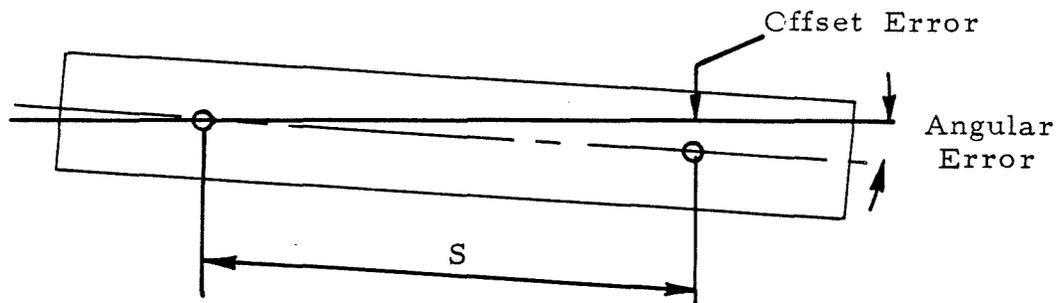
FIGURE 20. - Two methods of articulating conveyors.



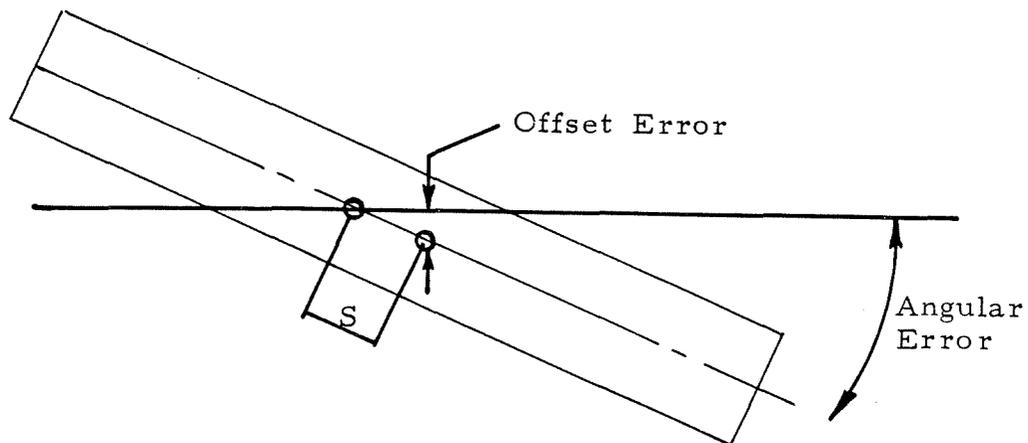
(a). - Sequence of "piggyback" or "cascade" conveyor units.



(b). - "Bridge and carrier" design.



(a) Large spacing "S" between sensors maintains good angular alignment of conveyor for a given sensor offset



(b) Small spacing "S" gives rise to large angular error for the same sensor offset

FIGURE 21. - Effect of sensor spacing on conveyor angular position accuracy.

The limiting envelope of the conveyor vehicle was determined by performing the graphical exercise of holding the vehicle stationary and moving the mine plan past it. This produced a waisted boat shaped (or "Coke-bottle") profile. A typical outline is shown in figure 22. This shape suggested that the ground suspension points should be placed outboard of the conveyor itself in the widened sections.

Several patterns for cable deployment were examined. First an attempt was made to define an optimum layout which would give maximum length conveyor sections, then a number of simple straight line and arc patterns were considered. Finally, the pattern laid by a lead vehicle similar in geometry to a shuttle car was examined. In all cases it was found that there was very little variation in the total "bridge plus carrier" unit length that could be used regardless of how the cable was laid (provided the sensor locations on the carrier were chosen so as to be consistent with the cable pattern).

2.2.1.3 Suspension System

The choice of wheels or tracks for the suspension system was closely tied in with the compression requirements. The large amount of operating compression initially specified (30% was the original design goal) required that the bridge section of the conveyor be able to pass over more than half the length of the MBC. This also required that it be able to pass over the suspension units on the carriers. In low coal this would severely limit the height of the suspension units and dictate the use of very low profile crawler tracks. Evaluation of this system (which would involve as many as forty small track frames) with equipment manufacturers and mine operating personnel led us to believe that there would be a severe reliability and maintainability problem.

An original aim of this conveyor design was to accomplish a 30% (design constraints later reduced that to just over 25%) compression of the total extended length in order to minimize the storage area required beside the panel belt.

However, typical miner movements during operations are limited to the 10-15 ft range, while place-changing requires "backing up" 100 to 200 ft. Only a limited amount of operating compression is required while mining is in progress.

One approach to system contraction was to provide all the compression in the first few inby units (which would use track suspension) and to use wheels on all remaining

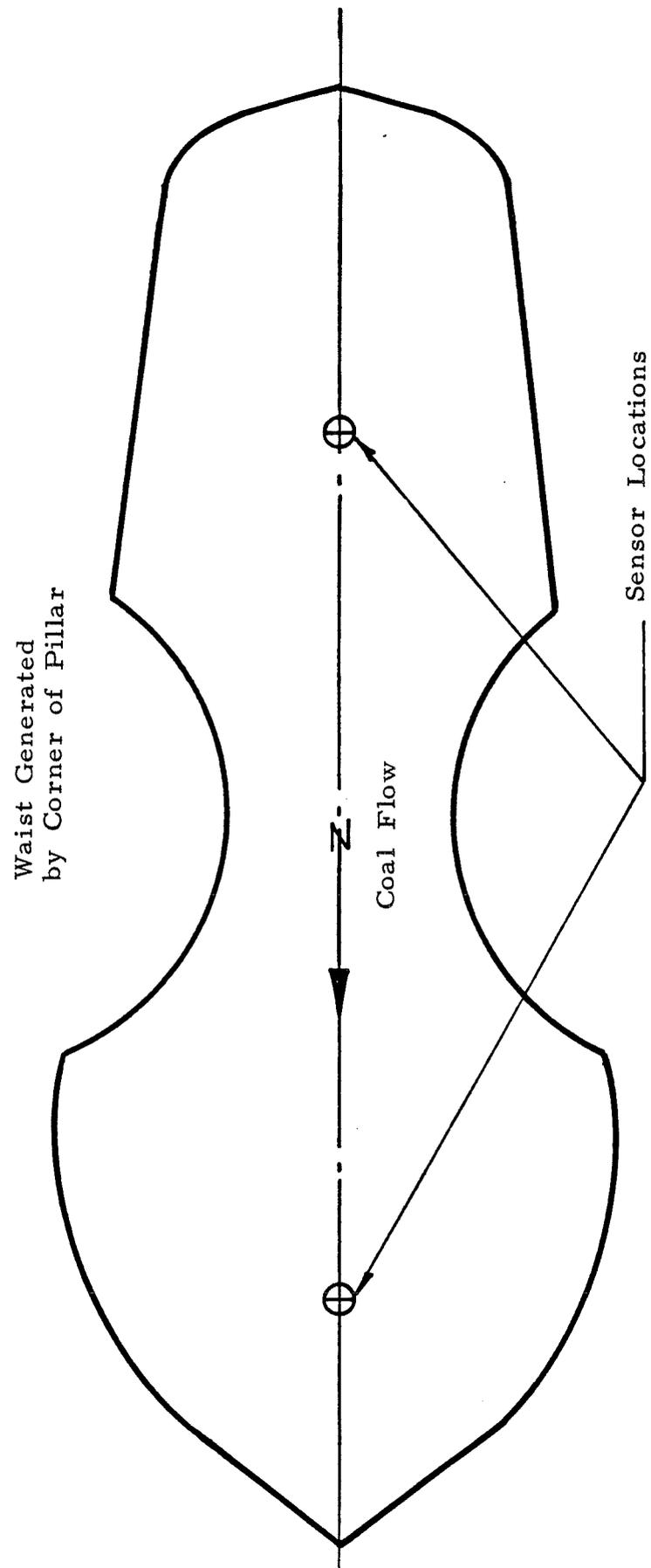


FIGURE 22. - Typical limiting envelope of mining pattern around conveyor vehicle.

sections, which would not be compressible. This design represented a less than ideal compromise, having four different types of conveyor sections and two different suspension units, and making no provisions for reduced storage length.

The selected approach was to permit each bridge to slide relative to its adjacent carrier by 39 in., giving a total operating compression of 29 ft on a train of nine units (5%). This decision to limit the compression to 39 in. on any individual vehicle established the possibility of using a wheeled rather than a tracked carrier vehicle, as the interference between bridge and wheel at large angular offsets can be eliminated.

In addition, for storage in a straight entry (as alongside the panel belt), more compression could be provided by sliding the bridge between the wheels on the carrier. This would be limited to a manually initiated operation which would be permitted only when a bridge is in a straight line with its mating carrier. In this way, a stored length of less than 75% of the extended length could be attained.

2.2.1.4 Transfer Points

Existing designs for transfer points generally relied on a single center pin pivot with built-in clearance to accommodate angular misalignment in the vertical direction. That system suffered from a number of drawbacks mechanically, but the major fault observed was the necessity that the pivot be located directly within the discharge trajectory of the inby conveyor, thus placing it in the worst place for generating a jam if an oversize piece of material came along.

The chosen transfer point design uses the principal of a pivot working around a virtual center. It is in many ways similar to the "Camtrack" pivot used by WVA and described in section 2.1.

2.2.1.5 Power Cable Routing

The ABCT concept presented problems with cable routing and handling because of the large number of units required to span the full 500 ft reach from the face back to the panel belt. The free length generated by relative motions of adjacent conveyor sections would be from 12 and 15 ft at each pivot point.

The fact that all power is routed through each of the conveyor units dictated that each cable have connectors at every interface so that individual conveyor sections might

be moved separately to a new location or for servicing. The multiplicity of cables and connectors was not a simple problem, but it was decided to carry all cables on the ABCT. We felt that this approach offered the best potential for trouble-free operation.

2.2.2 Guidance System Tradeoffs

The basic principle behind guidance of the ABCT system is that the lead vehicle of the train, whether miner or utility car, pays out a small, intrinsically safe cable onto the floor as it moves during operation, and each subsequent mobile bridge carrier is equipped so as to:

- a. Sense the position of the cable with respect to the vehicle
- b. Steer its wheels so as to keep the vehicle centered over the cable.

In this way, if the cable is properly located on the floor, the train will follow the lead vehicle, forward and reverse, around any number of corners to the appropriate place in the section.

2.2.2.1 Requirements for the Guidance System

The guidance system tradeoff study was concerned with:

- a. A definition of the requirements of the guidance system
- b. A determination of the best place to install the cable, i.e., roof, ribs, floor, etc.
- c. A determination of the best means by which the sensor could detect the cable position
- d. A determination of the extent to which available hardware could be used.

In brief, the guidance system must allow the MBCs to steer the train through straight runs and any number of 90° turns along its length in response to the prior motion of the inby vehicle.

Specifically, the inby vehicle installs a cable to be followed by the rest of the train. The location of this cable is used by sensors on the mobile vehicles as a reference for guidance. The basic design requirements for the system were:

- a. The path of the mobile vehicles must be simply related to the cable location - preferably identical. Complicated instructions or calculations to derive the vehicle motion from the cable location should be avoided
- b. The sensors must be capable of detecting offset of the vehicle location from the cable. The detection scheme used must be simple and independent of signal strength from the cable should the signal generator amplitude vary. It should also be independent of the distance from the cable in directions other than the offset being detected; for example, if the cable is on the floor, the height of the sensors over the cable should not affect the horizontal offset information
- c. The sensors must be immune to electrical noise in the cable
- d. The cable must be easily installed and adjusted (if necessary). It must be recognized that the cable could be twisted along its length, and that such twisting must not affect the guidance
- e. The operation of the sensors should not be affected by the presence of dust, water or other material likely to be found in a coal mine. The sensors and cable must be protected from the general mine environment. Although the system should be designed such that the train does not tram over the cable, the cable must not be so fragile as to be damaged by this occurrence
- f. The system must operate when the vehicles move in both the inby and the outby directions.

2.2.2.2 Cable Deployment

Conceptually, the inby vehicle could install the cable on the roof, ribs or floor, and the sensors would, if properly mounted, be able to derive guidance information from it. Each of these potential locations was examined.

Cable Mounted on the Roof

The advantages of roof-mounting the cable were that it could not be run over or kicked, it could be placed at a consistent distance from the roof, and with some additional complication, at a consistent distance from the floor.

Disadvantages included the fact that cable hangers would be required and these would either have to be driven into the roof formation or attached to the roof bolts; the sensors would be exposed at the top of the vehicle; and the cable and its hangers would be in a position vulnerable to damage by the machinery or its load.

Rib and Corner-Mounted Cable

A cable mounted on the rib or a pair of cables mounted on both ribs presented no real advantage over the roof-mounted cables discussed above. It was at least as vulnerable and would probably require hand-installation. Considering that the conveyor would need to turn both left and right, the treatment of these cables at turnouts became a problem. Indeed, when a cable is not mounted at the desired centerline of the train, more particularly when it is well displaced from it as is the case with rib mounted cables, guidance of the vehicle around turns becomes very complicated. Mounting the cable in the corner between the ribs and the roof did not offer any advantage over the rib mounting.

Cable Laid on the Floor

Floor-deployed cable presented some significant advantages:

- a. If required at all, cable fasteners could be installed easily
- b. The sensors and cable would be in the most protected position available - under the train. (Provided the cable sensors are placed centrally between the tram wheels, it was possible to eliminate the likelihood of the conveyor running over the guidance cable.)
- c. Even though no cable deployment system could guarantee a consistent vertical distance from sensor to cable, floor deployment provided the greatest consistency - the distance would primarily be defined by the radii of the tires (or tracks) which support the vehicle. Only undulations of the floor between the tire contact areas would cause variation.

Floor-deployed cable had some disadvantages:

- a. The cable is subject to water and tramming damage
- b. If not anchored, it is easily moved accidentally.

The advantages of floor-deployed cable outweighed those of all other approaches, and this location was assumed in subsequent considerations. The guidance system has a limit control to shut down tramming activity if the cable is too near the wheels of the vehicle so as to avoid tramming over the cable.

2.2.2.3 Sensor-Cable Interaction

Of the approaches in use for exciting the cable so that the sensors can detect its position, two were readily applicable to this situation:

- a. High frequency current; typically through a pair of wires
- b. Low frequency current through a single wire.

In both cases, the sensors used would be coils wound on magnetic iron.

The high-frequency approach, which is used on most of the current warehouse guidance schemes, would use the strength of the signal voltage induced in each of two sensors mounted equidistant from the vehicle centerline. When the voltages balanced, the vehicle would be on course, and the voltage imbalance would be proportional to displacement from the cable for a narrow region about the center.

This approach had the advantage that the current loop could be closed by means of the second wire under the vehicle. (Typically, 300Ω, TV antenna wire can be used.) However, since the field pattern produced by this wire is that of a dipole, received signal strengths would be weaker, for a given cable current, than for a single conductor.

The principal disadvantage of this approach was that guidance information would be signal amplitude dependent - the strength of the difference voltage from the two sensors depends on the vertical distance of the cable from sensor plane as well as upon the displacement of the sensors from the centerline. Further, dipole cable, if twisted, would induce weak signals at points along its length where the field produced by the cable did not align with the sensors. These would have been difficult problems to handle in a coal mine with a "temporary" cable.

The low frequency, single cable approach would use the fact that the magnetic field produced by a cable is circular, centered around the cable. By judicious location of sensors on the vehicle and some signal processing,

the displacement of the vehicle centerline from the cable could be determined independently of the vertical distance of the sensors from the cable. The single cable also would make the system insensitive to twisting.

This approach suffered from the disadvantage that some means must be found to close the circuit for driving current through the guidance wire. This could be solved by carrying a shielded conductor on the train, along with the power cables. The guidance cable, stored on reels on the inby vehicle could be deployed as needed and excited by rotary transformers.

2.2.2.4 Existing Hardware

A number of companies are in the business of automating equipment for warehouse inventory picking, business office mail delivery, or handling of supplies in hospitals. In these applications, guidance is achieved through installation of a wire in a 1/2-in. cut in the floor. Magnetic sensors on the vehicle detect displacement from the cable and steer it.

The wheels of the vehicle are arranged in tricycle fashion, the front wheel providing both steering and locomotion. The sensors are located directly behind this wheel. The implementation of guidance and control of the vehicle is considerably simplified by this arrangement, in that only one wheel need be controlled, and this control can be a simple "turn right," "turn left" pair of commands, with a dead band unresponsive to small displacements to guard against oscillations.

In a coal mine, the situation is quite different. The floor is rough, so that the cable cannot be a constant distance from the sensors, and the vehicle can rotate about its roll axis with respect to the cable.

Furthermore, an MBC requires four-wheel drive to achieve accurate positional control as well as mechanical stability and load bearing qualities. Four-wheel drive improves the positional accuracy of the vehicle, but requires two sensors, one at each wheel pair. Optimal control of the wheels necessitates sensing both displacement and angular orientation of the cable with respect to the centerline of the vehicle. These guidance and control problems represent relatively simple extensions of existing technology.

3. SYSTEM DESIGN

The previous section described FMI's evaluations of existing hardware and the reasoning behind various features of the ABCT. It was decided that two double-units (i.e., two Mobile Bridge Carriers (MBCs) and two Bridge Conveyors (bridges)) would be fabricated and subjected to critical testing. One of the two MBCs was modified to serve as the lead vehicle for the ABCT for both the two-unit critical test and, later, for the full-system test.

Only two double-units were built for initial testing since it was assumed (correctly) that the first test would dictate some design changes. The strategy was to test and modify the first two units as needed. Later units would be fabricated with any modifications already incorporated.

This section details the design of those first two double-units. Modifications that resulted from testing are described in sections 4 and 5.

3.1 THE MECHANICAL SYSTEM

The mechanical aspects of the ABCT consist primarily of the MBCs and the bridges. The key subsystems are the conveyor chain, the transfer points, the wheel units, the hydraulic system, the electrical power distribution system and the guidance cable deployment system. The design of each of these elements is discussed in detail in this section.

3.1.1 Overall Configuration

The overall appearance of the ABCT is shown in Figure 23. The equipment is basically a train of conveyor pairs, each pair consisting of a wheeled unit called an MBC, or carrier, and the transition unit, called the bridge. The overall design of these units is shown in Figures 24 and 25. Successive units are pivoted together by means of rotary turntables enabling the train to negotiate turnouts. Articulation angles of up to 70° are available. In addition, the pivot between an inby MBC and the adjacent outby bridge is mounted on a dolly which can slide freely for a distance of 5 ft (later design constraints reduced this to 39 in.) along the bridge.

The combination of these rotary and sliding motions provides freedom for adjacent units to move independently of each other. Each carrier unit trams in response to a signal generated as the dolly reaches the end of its travel along the next inby bridge.

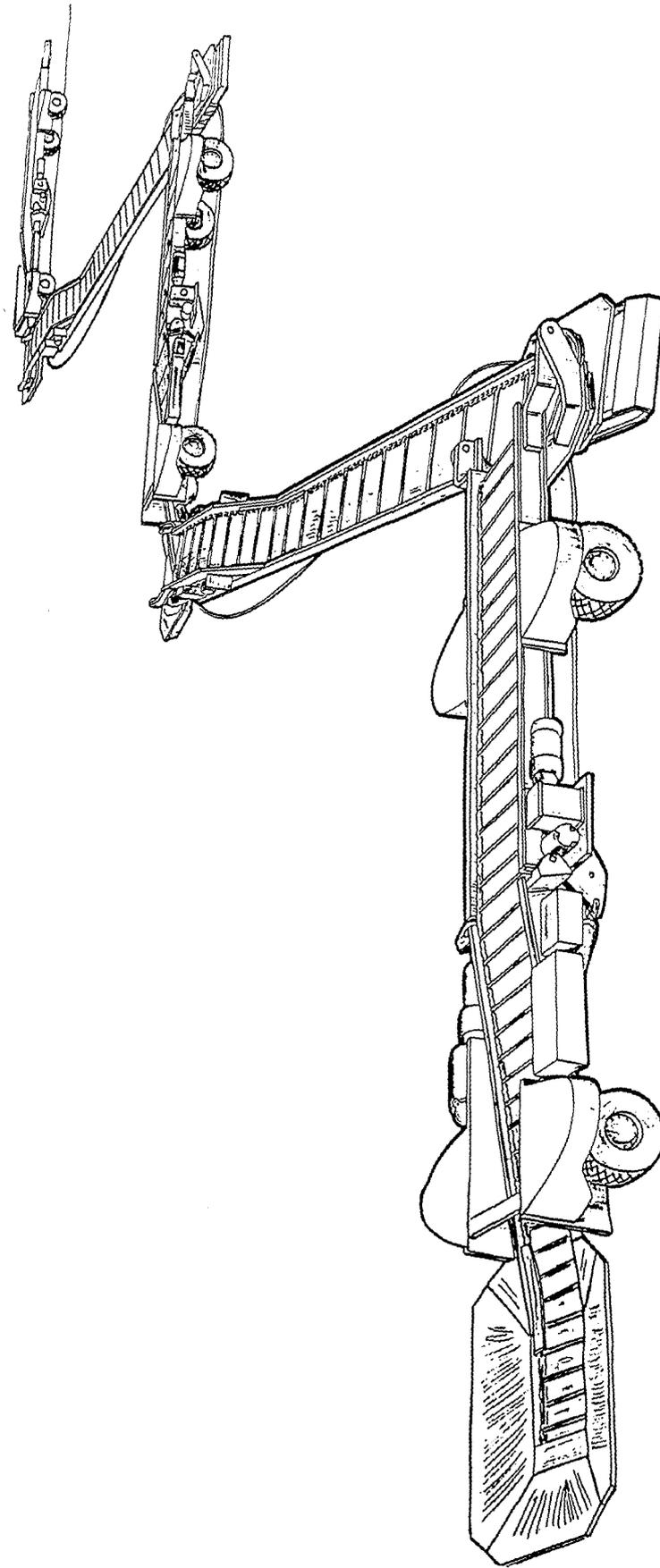
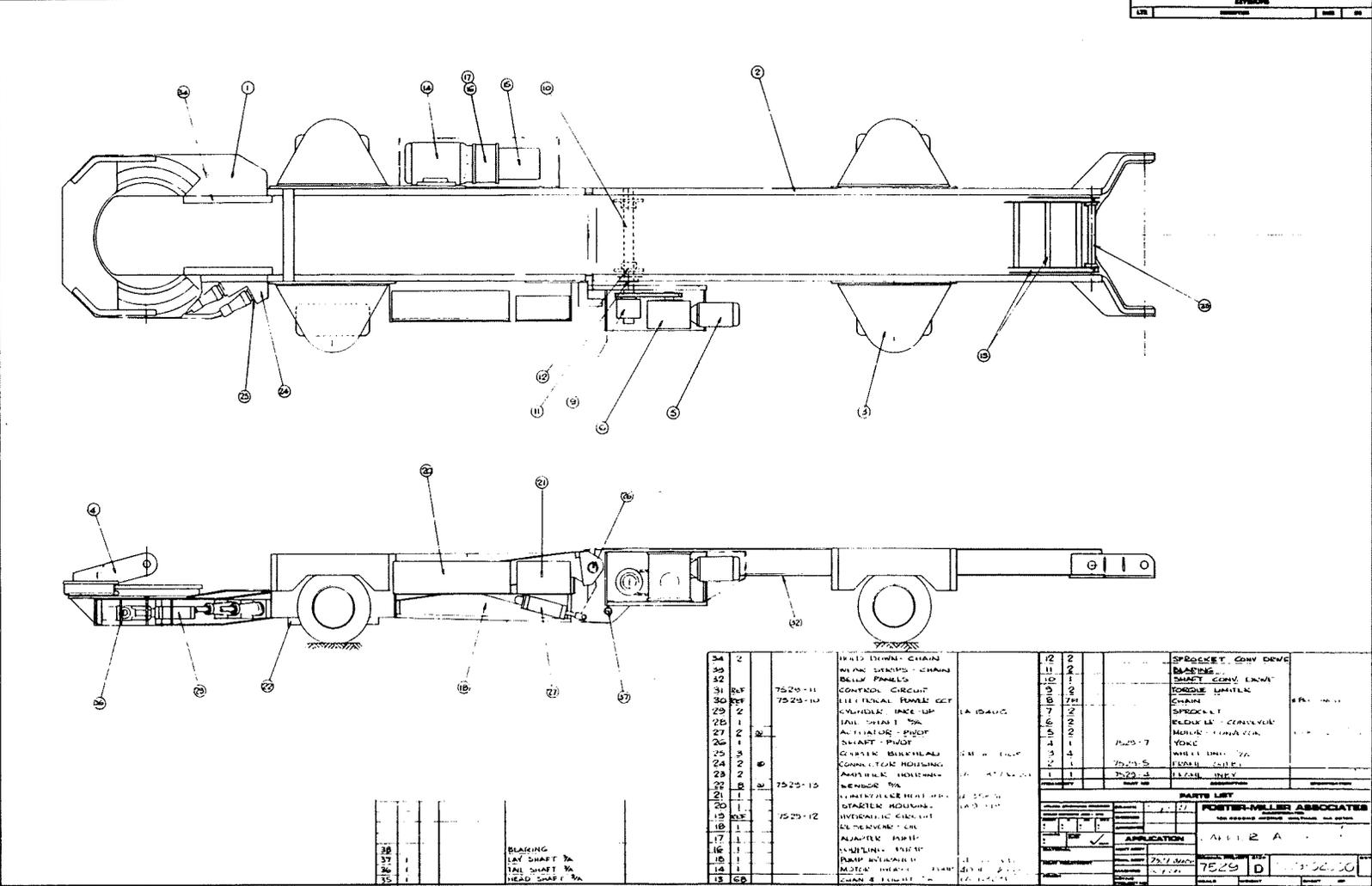


FIGURE 23. - Automated Bridge Conveyor Train.

FIGURE 24. - Carrier assembly.

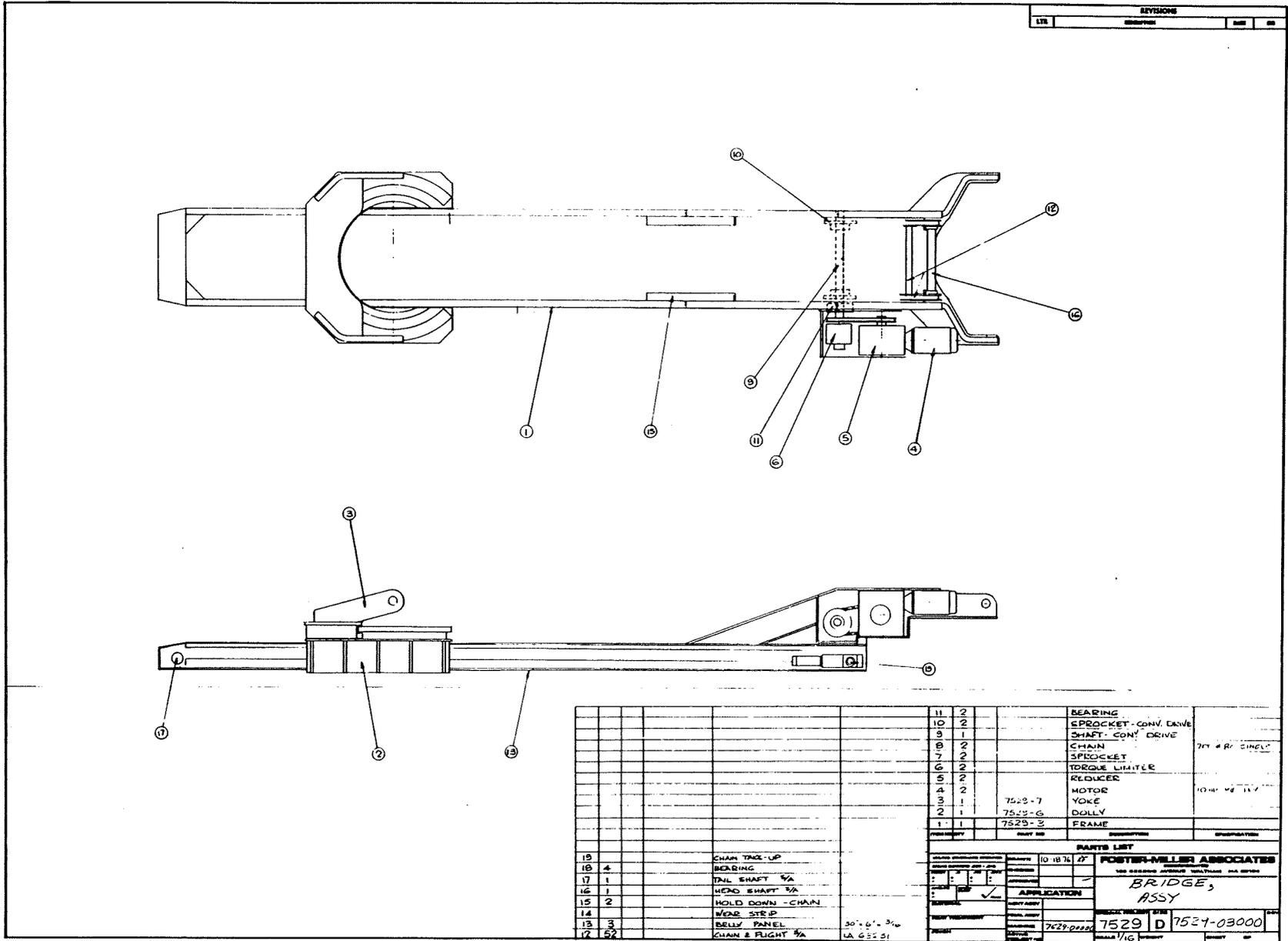


QTY	DESCRIPTION	UNIT	QTY	DESCRIPTION	UNIT
2	HEAD DOWN CHAIN		2	SPROCKET CONV DRIVE	
33	WAX SPROCKETS - CHAIN		2	BLANKING	
32	BELOW PANELS		1	SHAFT CONV DRIVE	
31	CONTROL CIRCUIT		3	ROCKE LIMITER	
30	EXTERNAL POWER GEF		7/8	CHAIN	
29	CYLINDRICAL TAKE-UP	LA 15AUC	7	SPROCKET	
28	TAIL SHAFT 1/2"		6	BEARING - CONVEYER	
27	ACTUATING ARM		5	BEARING - TAKE-UP	
26	SHAFT - PUMP		4	YOK	
25	GRATE BUSHING	GM H 1007	3	WHEEL UNIT 72	
24	CONNECTOR HOUSING		2	FLANG SHAFT	
23	ACTUATING HOUSING		1	FLANG INLET	
22	SENSOR 1/2"				
21	CONTRACTOR HEAD PER				
20	STAPLER HOUSING	LA 15AUC			
19	INTERNAL CIRCUIT				
18	EX-SENSORS - CIR				
17	ALUMINUM PART				
16	LIMITING ARM				
15	PUMP MOTOR 1/2"				
14	ROCKE DRIVE FLANG				
13	CHAIN 4 TAKE-UP				

QTY	DESCRIPTION	UNIT
38	BLANKING	
37	KEY SHAFT 3/4"	
36	THE SHAFT 3/4"	
35	HEAD SHAFT 3/4"	

PARTS LIST	
FOSTER-MILLER ASSOCIATES	4112 A
7529	D

FIGURE 25. - Bridge assembly.



Almost all of the power and control equipment is mounted on the carrier. The bridge is merely a transition conveyor providing coal haulage between carriers and allowing freedom of movement around corners. Both the bridge and the carrier are equipped with 20 hp electric motors driving a chain conveyor through right-angle reducers and chain drives.

Tramming and steering are accomplished hydraulically, using separate motors for each function at each of the four wheels. Hydraulic power is obtained from a pump driven by a 50-hp electric motor mounted on the side of each carrier. Associated valving and filtering are mounted near the supply, together with a heat exchanger to provide cooling of the hydraulic fluid. A wedge-shaped reservoir is mounted beneath the inclined part of the carrier structure.

On the side of the carrier opposite the hydraulic power supply are located the main starter and central control enclosures. The wheel units are bolted separately to the main structure.

Irregularities in the floor are accommodated through torsional compliance in the conveyor structure. Additional allowance for floor unevenness is provided by a horizontal hinge at the center of the length of the carrier. An actuator at this hinge allows the center of the carrier to rise or fall by 18 in. relative to the ends. If necessary, the allowance can be increased to 36 in.

As far as possible, common structural design and common components have been used on the bridge and the carrier. The framework employs standard structural steel sections and flame cut plate; machining has been kept to a minimum. In this way, costs of fabrication have been minimized. In no case, however, have performance and reliability been compromised for the sake of economy.

3.1.2 The Mobile Bridge Carrier

The carrier consists of two main weldments (see figures 26 and 27). Each is composed of two 10 by 2-1/2 in. rolled steel channels spaced 30 in. apart. These, in turn, are tied together by the conveyor pan and a number of ties welded across the bottom of the framework. They are equipped with appropriate side plates to carry the wheel units, the hydraulic power supply, the conveyor motors and reducers, and the electrical enclosures.

These two weldments are jointed about midway between the wheel centers by a hinge which allows a 10° flexure to compensate for rolls in the mine floor. The hinge pin runs across the conveyor just below the pan or deck, the top of the pin filling the joint between the two sections of the pan. A pair of hydraulic actuators, one on each side of the MBC, couple the two halves of the frame and resist the bending moment at the hinge. They also serve to adjust the amount of angular deflection at the hinge.

At the end of the outby section, two arms welded to the side members form a wide clevis which attaches to the corresponding yoke brackets on the dolly turntable described below. This attachment provides the coupling to the adjacent outby bridge. The pins which couple this clevis to the turntable brackets are designed to be readily withdrawn. Removal of these pins provides a convenient method of uncoupling adjacent bridge and carrier units for servicing or reorganization in the mine. The pins are placed directly above a diameter passing through the transfer point center; such placement ensures the dolly hanging level from side to side when the bridge and carrier are oriented at a substantial angle to each other.

A U-shaped plate supporting the carrier turntable is welded at the end of the inby section of the carrier. The rotating part of this turntable forms the yoke which couples to the clevis on the next inby bridge unit.

3.1.3 The Bridge

The structure of the bridge unit is basically the same as that of the carrier. The main weldment is shown in figure 28. Two side members of the 10 ft by 2-1/2 in. structural channel are spaced 30 in. apart by means of the conveyor pan and cross ties placed at intervals along the structure. At the outby end, two arms form a clevis identical to that at the outby end of the carrier. This clevis couples to the yoke on the carrier turntable as described below.

Just behind the clevis arms are the mounting brackets for the conveyor drive motor and reducers. These brackets are similar to those provided on the carrier.

Along the length of the straight sections of the side members are mounted guide rails which enable the dolly to travel approximately 15 ft along the bridge.

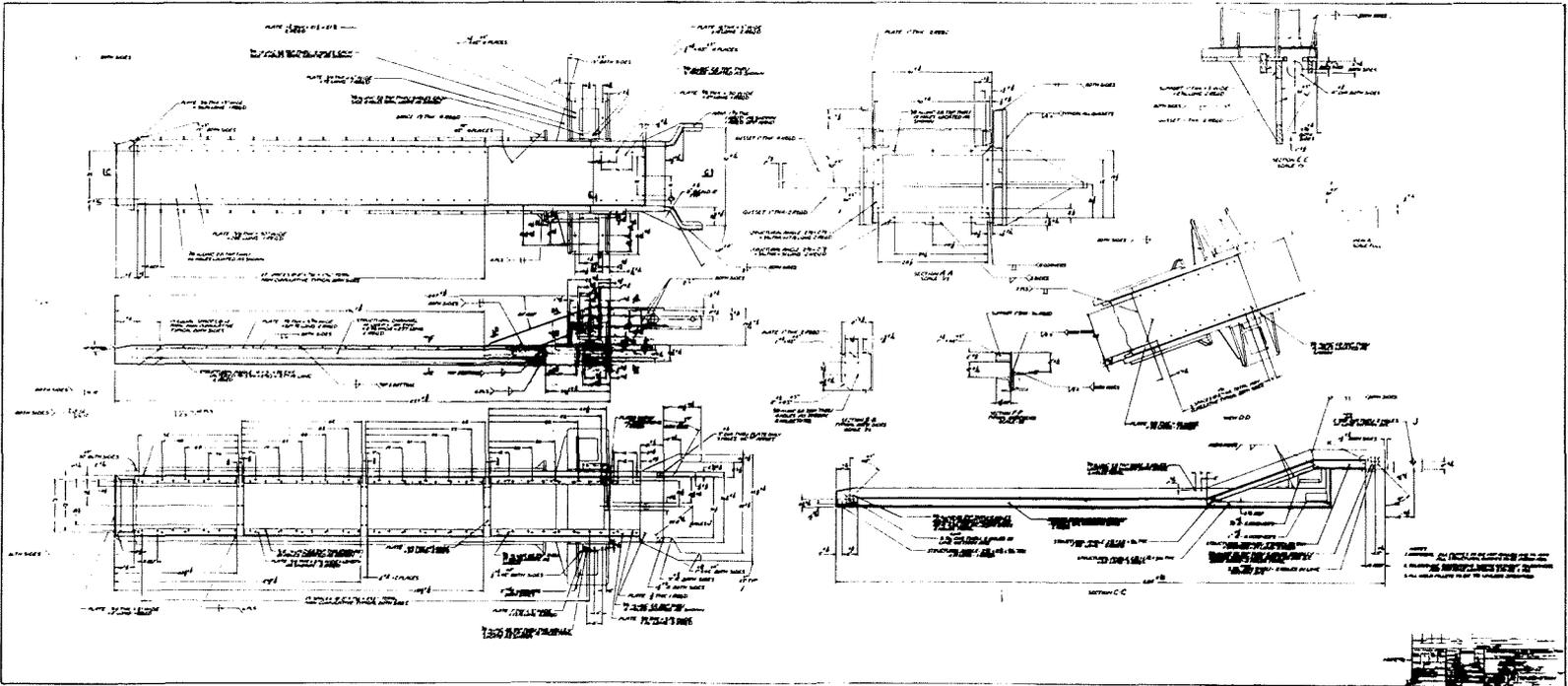


FIGURE 28. - Bridge weldment.

3.1.4 The Chain Conveyor

The chain used in the conveyor consists of heavy duty, 2-in. pitch roller chain made by Long-Airdox for use in their chain conveyors. When carrying coal, it moves at 300 ft/min.

The chain runs on hardened wear strips which are screwed to the conveyor pan. Screws have the advantage that the strips are readily replaceable in the event of wear and that acoustic insulation can be incorporated between the strip and the pan.

Head, tail, and idler shafts are equipped with toothless pulleys (see figure 29). The amount of space available requires relatively small sprocket pitch diameters. Consequently, the number of teeth on conventional sprockets would be too few for satisfactory operation.

Drive to the chain is through conventional 15-tooth hardened sprockets on a cross-shaft mounted in roller bearings. This shaft is chain-driven through a torque limiting sprocket from a motor reducer. The torque limiting device provides protection to the motors and reducers in the case of conveyor jam or failure of a motor.

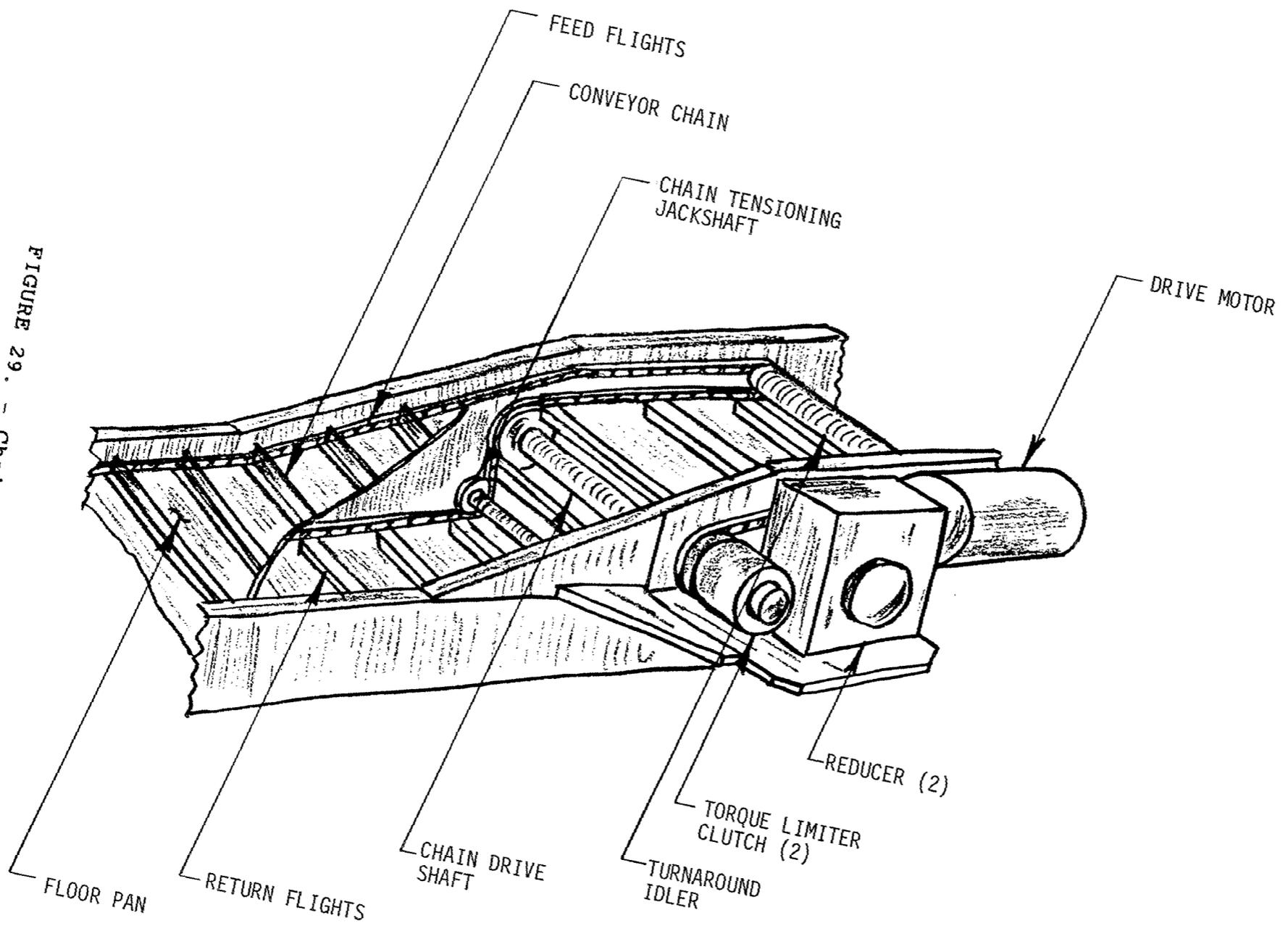
Chain tensioning is provided by a pair of hydraulic cylinders acting upon the tail shaft on the carrier and upon the idler shaft on the bridge. Pressure is applied to these cylinders with a grease gun.

The conveyor chain is assembled using Long-Airdox's standard practice, from subassemblies consisting of a flight plus two sections of chain (see figure 30). The cross section of the conveyor structure showing the chain in place is in figure 31. Substantially, identical chain layouts are used in both bridge and carrier.

3.1.5 The Transfer Points

Articulation between adjacent bridge and carrier units is accomplished by means of mating curved tracks constituting a rotary bearing, allowing the upper (yoke) part to turn relative to the lower (turntable) part. A cross section of the assembly is shown in figure 32; the yoke member is illustrated in figure 33. The turntable structure forms part of the dolly in one case and part of the carrier in by weldment in the other. These are shown in figures 27 and 34.

FIGURE 29. - Chain handling.



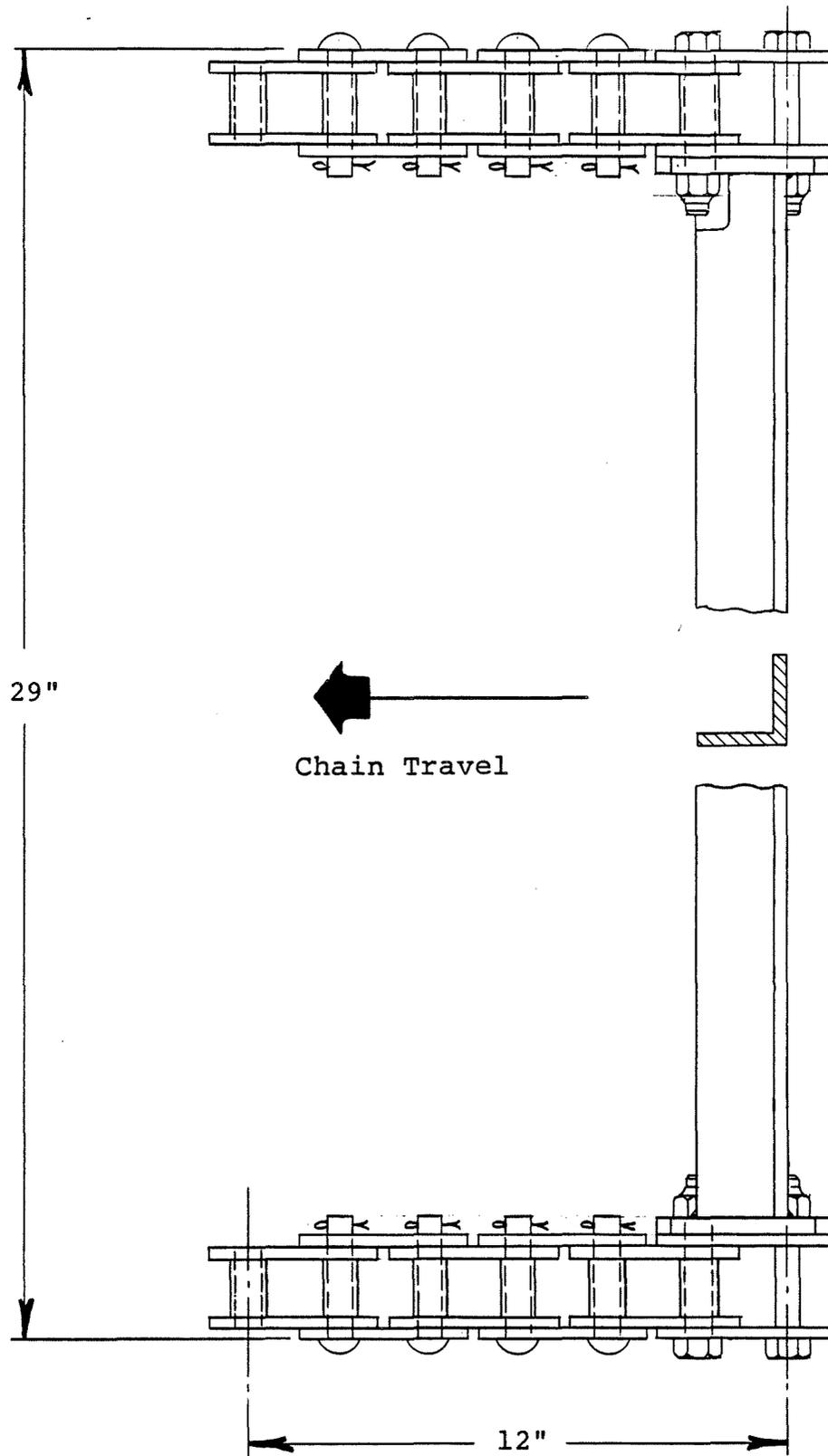


FIGURE 30. - Conveyor chain construction.

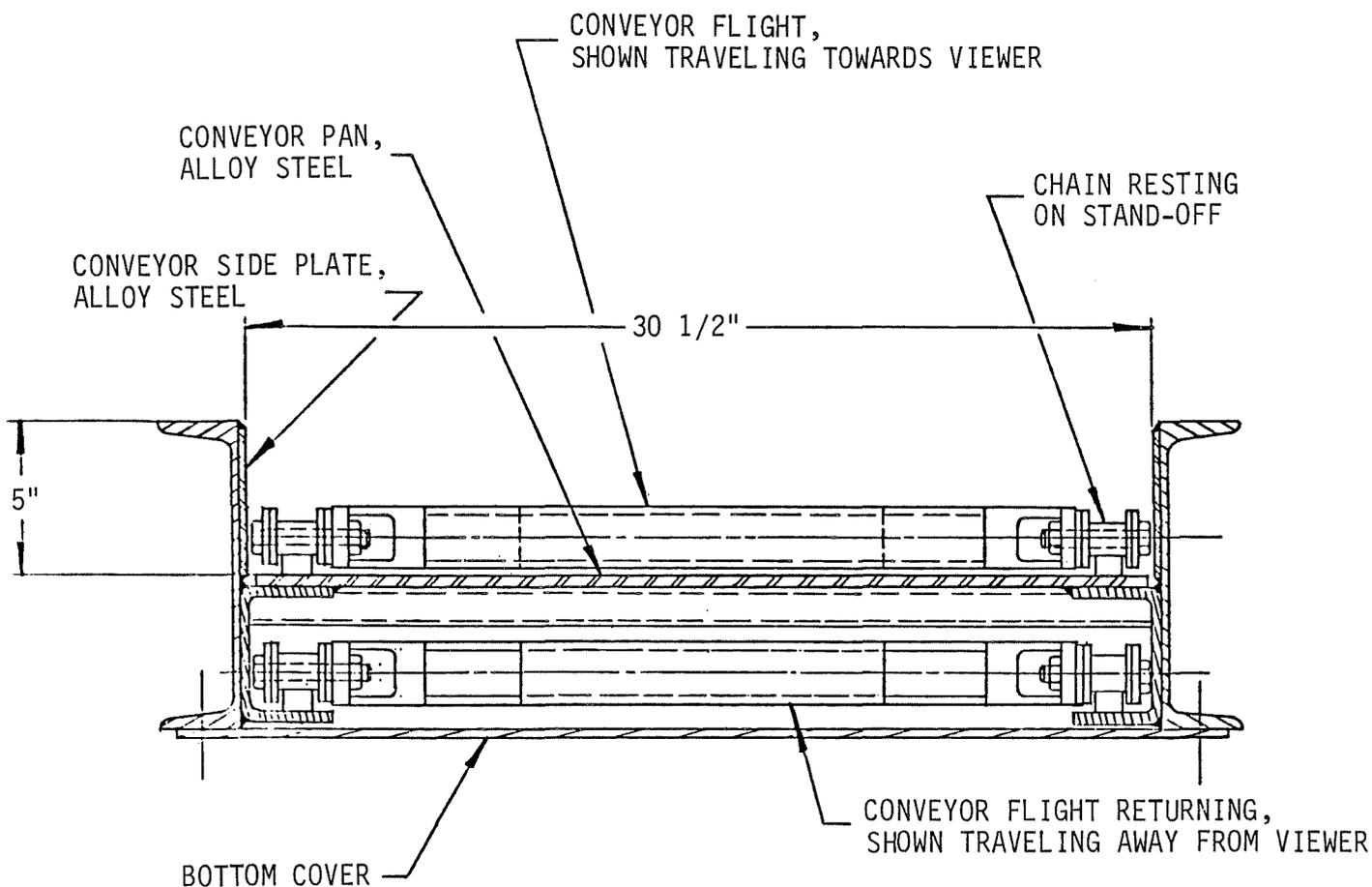


FIGURE 31. - Cross section of conveyor structure.

Where the structure forms part of the dolly, the rotary joint must carry the weight plus coal load in tension while, as part of the inby weldment, it carries the load in compression. The load varies with the amount of coal being carried and with the position of the dolly on the bridge; the maximum is calculated at 4,800 lb.

Radial positioning between the upper and lower members is achieved by a series of curved blocks attached to the upper member which move in a circular groove provided in the lower member. These blocks are mounted using solid spherical bearings so that they may align freely with the

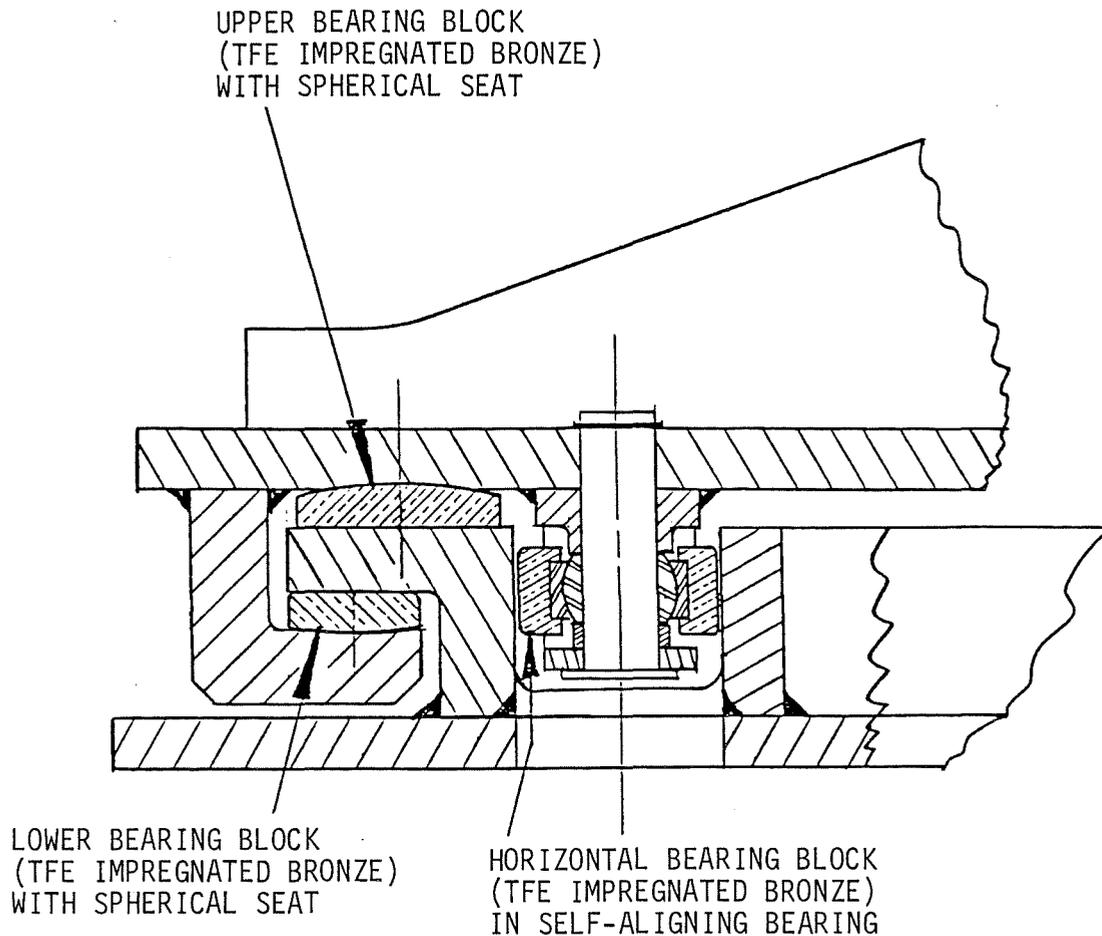


FIGURE 32. - Cross section of rotary bearing transfer point

groove. The vertical load is carried by the interlocking L-shaped tracks provided with self-aligning bearing pads of self-lubricated material (Teflon impregnated bronze). Assembly of the rotary joint is accomplished with the inby unit disconnected. The upper member of the joint slides radially into the lower member to interlock the L-shaped tracks. The curved blocks may then be pushed into their correct location and secured with the locating pins.

The theoretical trajectory of coal being transferred from one conveyor unit to the next is shown in figure 35. The head shaft is located 20 in. from the center of the

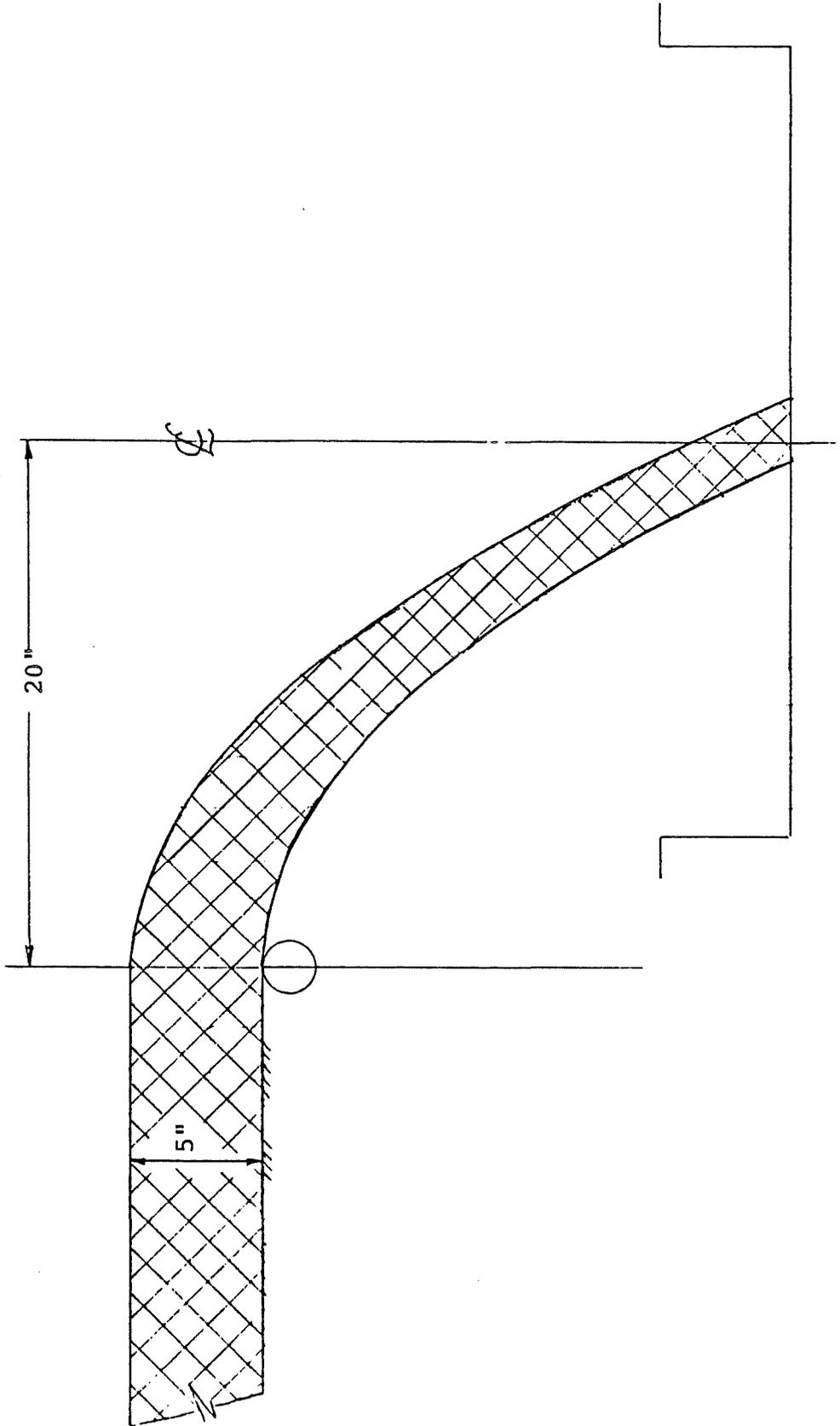


FIGURE 35. - Coal trajectory transfer point.

rotary joint so that coal is dumped approximately in the center of the receiving conveyor pan when the two units are substantially at right angles to each other.

In practice, the coal will tend to spread as it falls and also will continue to roll across the receiving pan after it has stopped falling. To minimize the risk of spillage at the transfer points, the sidewalls of the receiving conveyor are locally raised higher, and rubber skirts are fitted around the rotary joint.

3.1.6 The Wheel Units

Each wheel unit is a separate structure which is attached by bolts to the main frame of the carrier. The wheel unit design is shown in figure 36. The wheel is driven by a hydraulic motor coupled to the wheel by a planetary gear reducer.

The reducer selected is made by Warner Gear Division, Borg-Warner Corporation. It was chosen after an extensive survey of available equipment as being extremely rugged and sufficiently compact to fit into the required 15 in. rim size. The tire chosen is the 28 in. diam Bearcat "Supersoft."

To provide the steering motion, the wheel and tram motor assembly is mounted on a bracket suspended from a 16.56 in. diam rotary crane bearing, Rotek part number A8-17P3D.

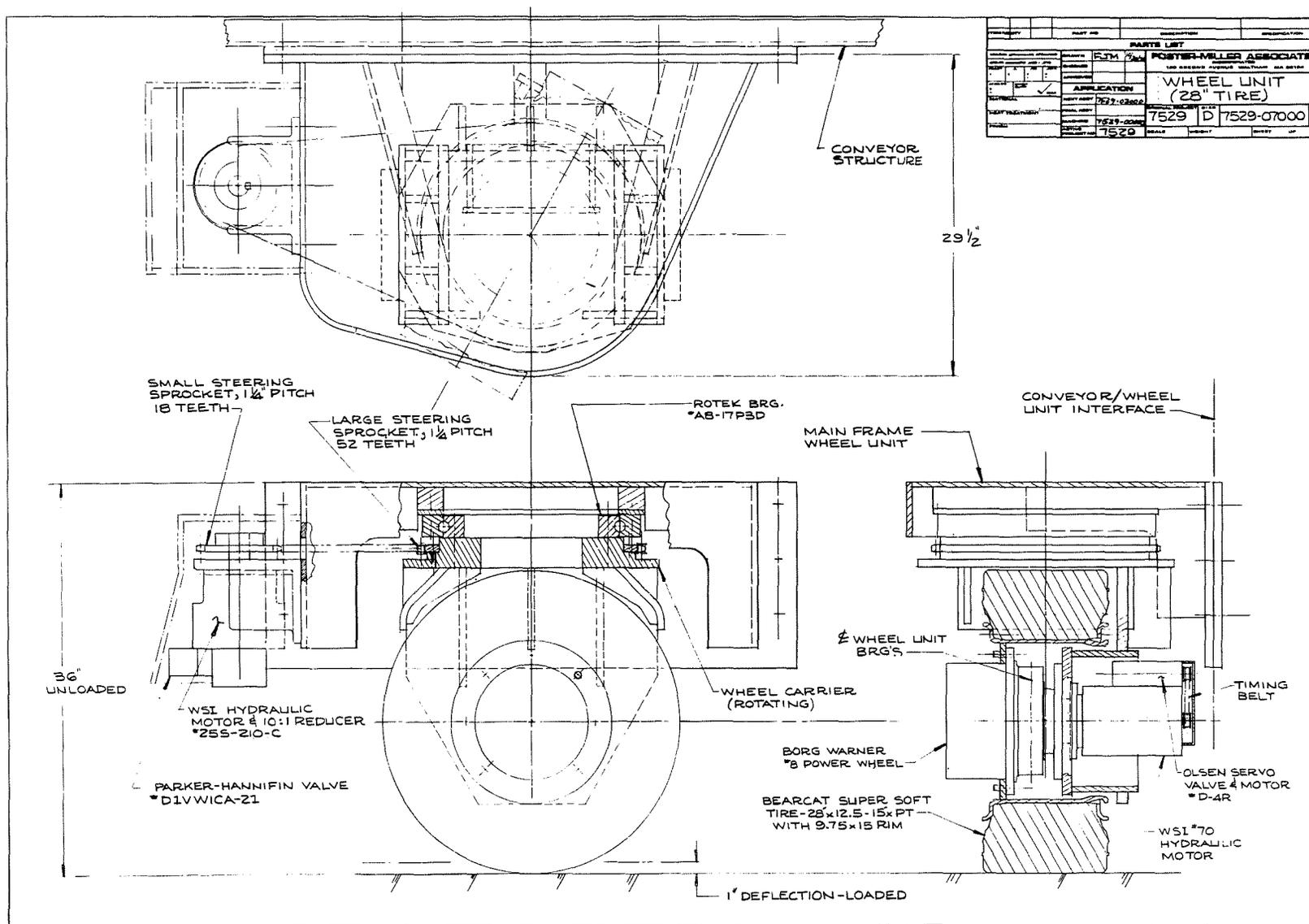
The bearing is placed so that the wheel pivots about its vertical centerline, minimizing the interaction between steering and tramping functions. In this way, the steering mechanism does not need to overcome the tractive effort generated by the tram motor, and the wheel velocity is not affected by the rate at which the steering angle changes. These effects would have to be compensated if an offset kingpin steering arrangement were used.

The steering force is applied through a 1-1/4 in. pitch roller chain and sprocket drive from a hydraulic motor and gear reducer mounted to the side of the wheel unit frame. Chain take-up is provided by a manual adjustment of the motor position.

3.1.7 The Hydraulic System

Hydraulic power is used primarily for driving the tramping and steering motors. The system operates at a 1,500 psi line pressure which may be increased to 1,800 psi if an increase in torque is necessary.

FIGURE 36. - Wheel unit.



DESCRIPTION	PART NO.	QUANTITY	REVISION
PARTS LIST			
POSTER-MILLER ASSOCIATES			
100 BROAD AVENUE, MULTNOMAH, OR 97148			
WHEEL UNIT (28" TIRE)			
APPLICATOR	7529-0200A	D	7529-07000
DATE	7529-0200		
BY	7529		

Phosphate-ester fire resistant fluid is used to eliminate the requirement for a fire control system.

3.1.7.1 Hydraulic Power Supply

A single, fixed displacement gear pump is driven by a 50-hp electric motor at a speed of 1,200 rpm. Since the demand for oil is practically constant when the carrier unit is tramping, and practically zero at other times, a simple unloading scheme is applicable. In the circuit of figure 37, a pressure compensated unloading valve is used to maintain constant pressure during the operating (tramping) phase. During stationary periods, an electrically operated dump valve returns the total flow of the pump to the tank.

Oil is distributed on a demand basis through hydraulic tubing and hose to the four wheels. Line sizes are shown in the circuit diagram of figure 37.

Filtration is supplied by a strainer on the suction pipe, a 10-micron full-flow filter downstream of the pump, and a 74-micron full-flow filter in the return line.

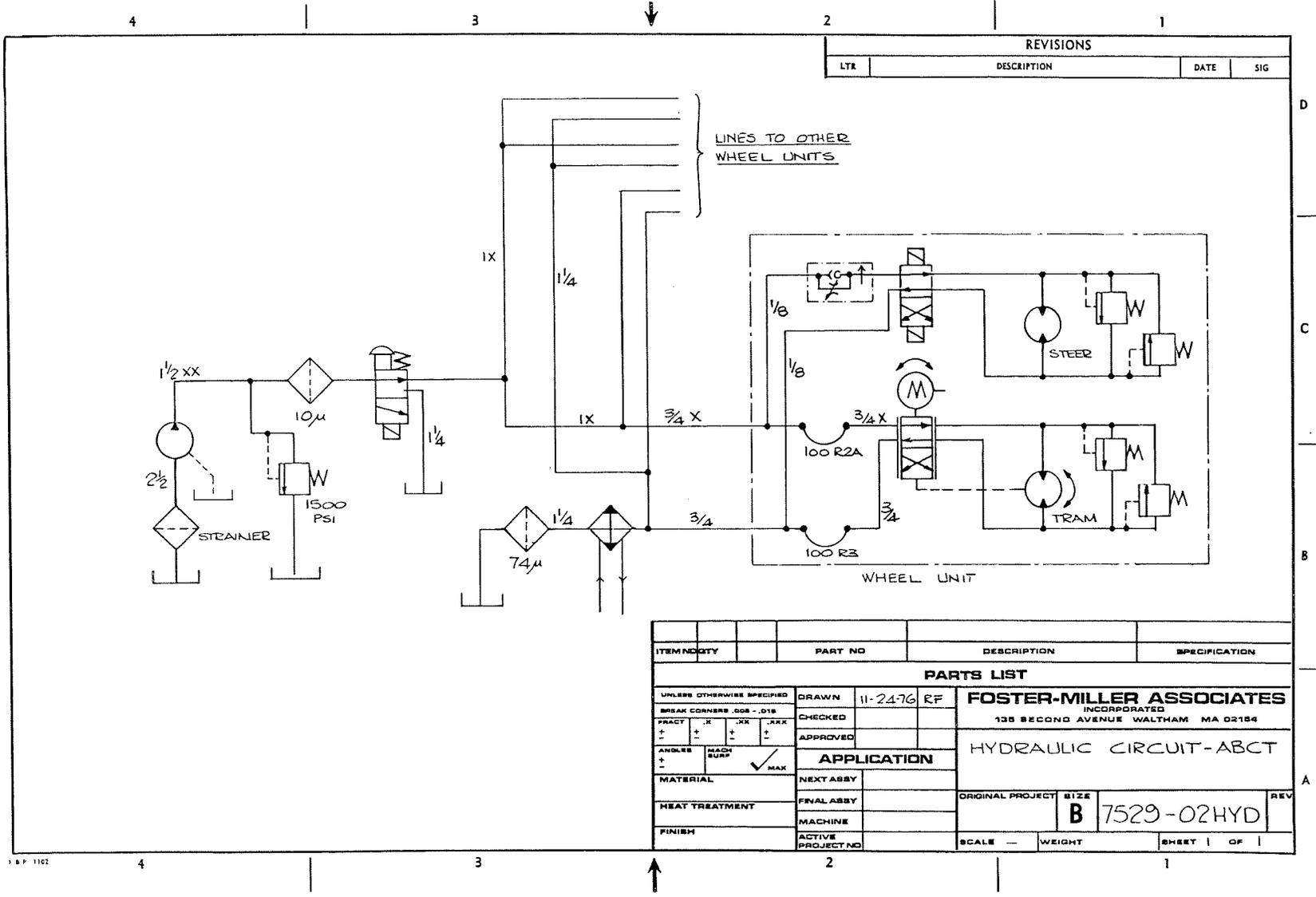
The reservoir has a capacity of 70-gal. Initial estimates indicated this volume to be adequate to dissipate the anticipated heat. Preliminary testing of the MBCs showed a need for a heat exchanger. This addition is detailed in section 4.1.

3.1.7.2 Tramping Drive

The drive motor, made by the Fluid Power Division of Washington Scientific Industries, Inc., is an electro-hydraulic stepper motor. The operation of the motor involves a nulling principle in which the electric stepper motor actuates a hydraulic valve, the opening of the valve being proportional to the angle of rotation of the motor. The hydraulic motor then turns in response to the opening valve. As the motor turns, it recloses the valve until an equilibrium condition is attained.

Thus, the rotation of the hydraulic motor is tightly coupled to the rotation of the stepper motor, and the steady state speed of the motors is identical. There is an angular lag between the shafts of the stepper motor and the hydraulic motor to allow the valve to pass sufficient oil at an appropriate pressure drop to correspond to the wheel speed and torque demand. The valve, when fully open, requires a lag of 75° between the stepper and hydraulic motors. This lag corresponds to an angle of less than 2° at the wheel, so the effect of the lag is, in practice, negligible.

FIGURE 37. - Hydraulic circuit - ABCT.



REVISIONS			
LTR	DESCRIPTION	DATE	SIG

ITEM QUANTITY	PART NO	DESCRIPTION	SPECIFICATION
PARTS LIST			
UNLESS OTHERWISE SPECIFIED		DRAWN 11-24-76 RF	FOSTER-MILLER ASSOCIATES
BREAK CORNERS .008 - .015		CHECKED	INCORPORATED
FRACT .X .XX .XXX		APPROVED	138 SECOND AVENUE WALTHAM MA 02154
ANGLES MACH SURF		APPLICATION	
MATERIAL		HYDRAULIC CIRCUIT-ABCT	
HEAT TREATMENT		ORIGINAL PROJECT	REV
FINISH		SIZE B	7529-02HYD
NEXT ASSY		SCALE -	WEIGHT
FINAL ASSY		SHEET OF	
MACHINE			
ACTIVE PROJECT NO			

1 1/2 XX

4

3

2

1

D
C
B
A

The generators producing the pulse streams to drive the stepper motors are housed in the electrical control enclosures mentioned in section 3.1.2. The frequencies are controlled by the signals from the microprocessor (see section 3.2.4). These generators also provide a ramp characteristic which establishes a fixed acceleration and deceleration time for all four wheels; in this way they provide equal tractive efforts during acceleration and deceleration.

3.1.7.3 Steering Device

Steering is accomplished by turning each wheel independently about its vertical axis. This turning is done by a chain drive wrapped around a large sprocket attached to the steering bearing. The chain is driven by a 2.5 in.³ displacement vane hydraulic motor working through a 10:1 reducer. The overall design is shown in figure 36.

The ratio between the hydraulic motor and the steering sprocket is 28.9. Consequently, the motor is capable of producing over 1,200 lb-ft of torque at the wheel. This torque is sufficient to turn the wheel against ground friction even when the carrier is not tramming.

The setting of the steering angle is made by a simple position feedback system using a four-way solenoid valve. The valve is controlled by comparing the steering angle instruction from the microprocessor with the actual wheel position, and driving the motor to make the two equal (see section 3.2.4).

The maximum rate of change of steering angle is limited to 5°/s by means of a pressure compensated flow control valve (fig. 37). The flow rate while changing steering angle is 0.3 gpm.

3.1.8 Power Distribution System

3.1.8.1 Current Demand

Electrical power is supplied to the conveyor at 1,000 V, 3 phase. This relatively high voltage was selected in order to reduce the current flow and hence the size of the cables.

The total power demand for a carrier-plus-bridge double section is broken down in table 2. The following assumptions were made in calculating the current demand:

TABLE 2. - ABCT power requirements in KVA

	(Starting)	Rated	Time average	Power factor
Bridge conveyor motors	80 ¹	17	12	0.8
MBC conveyor motors	80 ¹	17	13	0.8
MBC hydraulic supplies	160 ¹	42	20	0.8
Lighting	3	3	3	1
Control and guidance	2	2	2	1
Total		81	50	

Current Demand in amperes

Peak (worst case)	116.0 A
Rated	57.8 A
Time average (for each bridge/carrier pair)	35.4 A

The total, time average demand for ten bridge/carrier pairs is therefore 354 A; allowing 330 A for the continuous miner, the overall demand is 684 A.

¹Only one starting current will be allowed at a time in the ABCT.

- a. The continuous miner's peak demand occurs during sumping; at this time, the conveyor should be tramming only slowly, so that no more than one or two sections of the ABCT should be moving simultaneously. Conversely, when many sections of the conveyor are tramming, as in place changing, the miner will not be cutting coal, and its demand will be low.
- b. The start-up surge current is limited by starting the motors sequentially. The surge to one motor passes before the next is started.

3.1.8.2 Distribution Cables and Wiring

Electrical power is carried along the conveyor by three conventional portable cables; each is a 3/0 AWG, three-conductor with grounds. Each has a 75°F ampacity of 243 A for a total of 729 A, representing a 7% reserve over requirement.

At the outby end of each carrier-bridge pair, the cables are equipped with explosion-proof cable couplers, Mine Service Equipment drawing number 1D-65 (see figure 38). These couplers are available in a smaller shell size than those supplied by most other manufacturers, and are thus better suited to the cable size being employed.

At the other end of the carrier-bridge pair, the cables terminate in explosion-proof enclosures equipped with three bulkhead connectors, which make power available to the inby parts of the conveyor. Within these enclosures, the three cables are all connected to the same set of three-phase bus bars. At these bus bars, a smaller cable is tapped off (no. 8 AWG, 3 phase), which carries current to the main starter/distributor enclosure. Schematics of the circuits are given in section 3.3.

The main starter/distribution enclosure is an explosion-proof box (fig. 39 and 40) containing the starters for the hydraulic power supply motor, the bridge conveyor motor, and the carrier conveyor motor. It also contains the main breaker and a transformer (4 kV.A) supplying 115V ac, 1 phase, for use in the lighting and control circuits. In addition, the ballast circuits for the area illumination fixtures are carried in this enclosure. Solid state starters are used in order to conserve space and weight.

3.1.8.3 Motors

The motor used on the conveyor drive is of a high starting torque design (NEMA design C) to ensure breakaway of the conveyor even when starting fully loaded with coal. The hydraulic pump motor is a standard (NEMA design C) high resistance rotor design, which is well suited to the reciprocating pump drive.

3.1.8.4 Central Control System Packaging

Power at 115V ac is carried to the central control enclosure. This enclosure contains the microprocessor and its associated power supplies. Since the microprocessor interface, CPU and memorycards are mounted in a card file, individual cards may be readily removed for replacement in the event that service is necessary.

FIGURE 38. - Mine Service Equipment Co. cable connector.

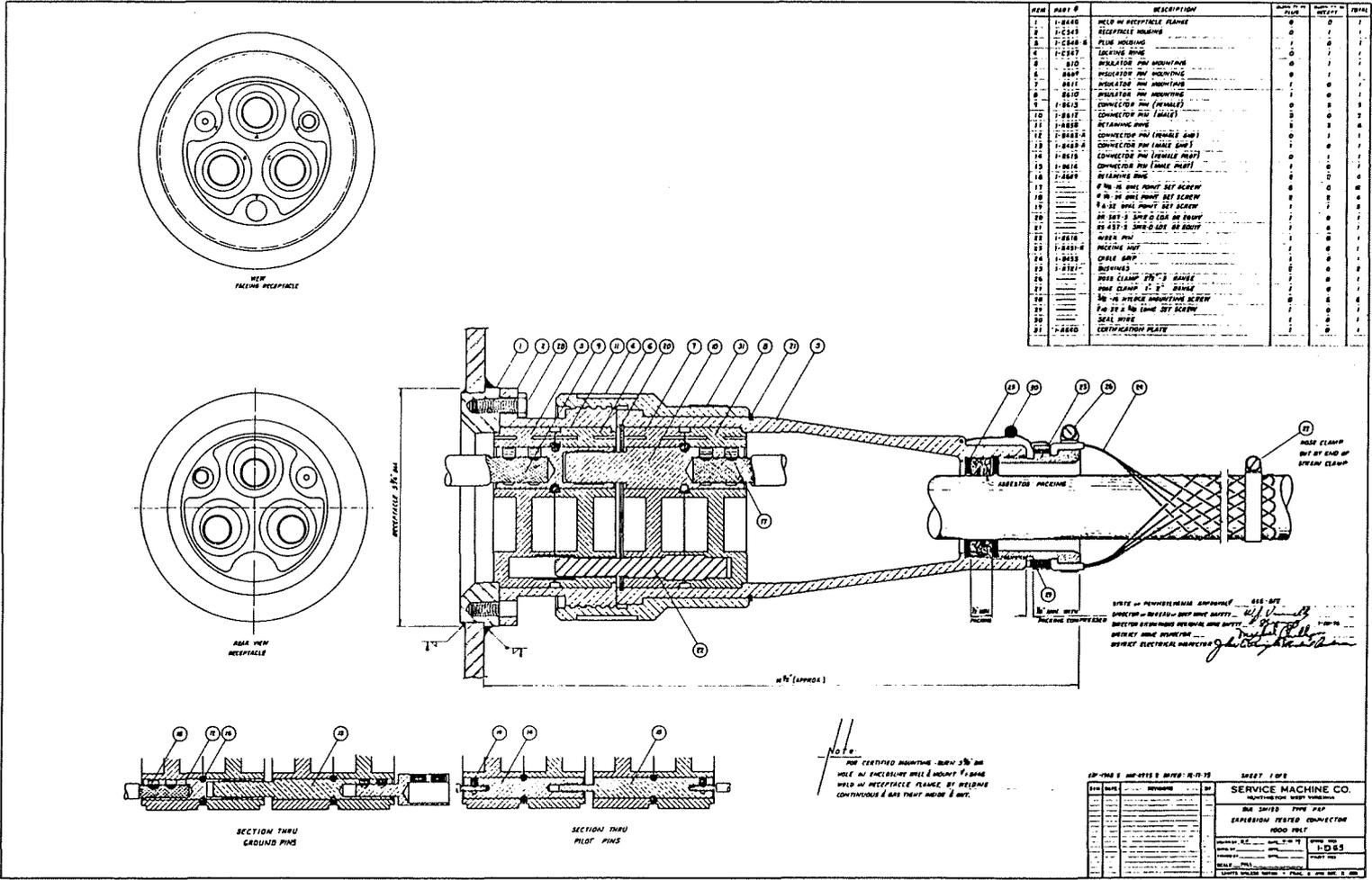
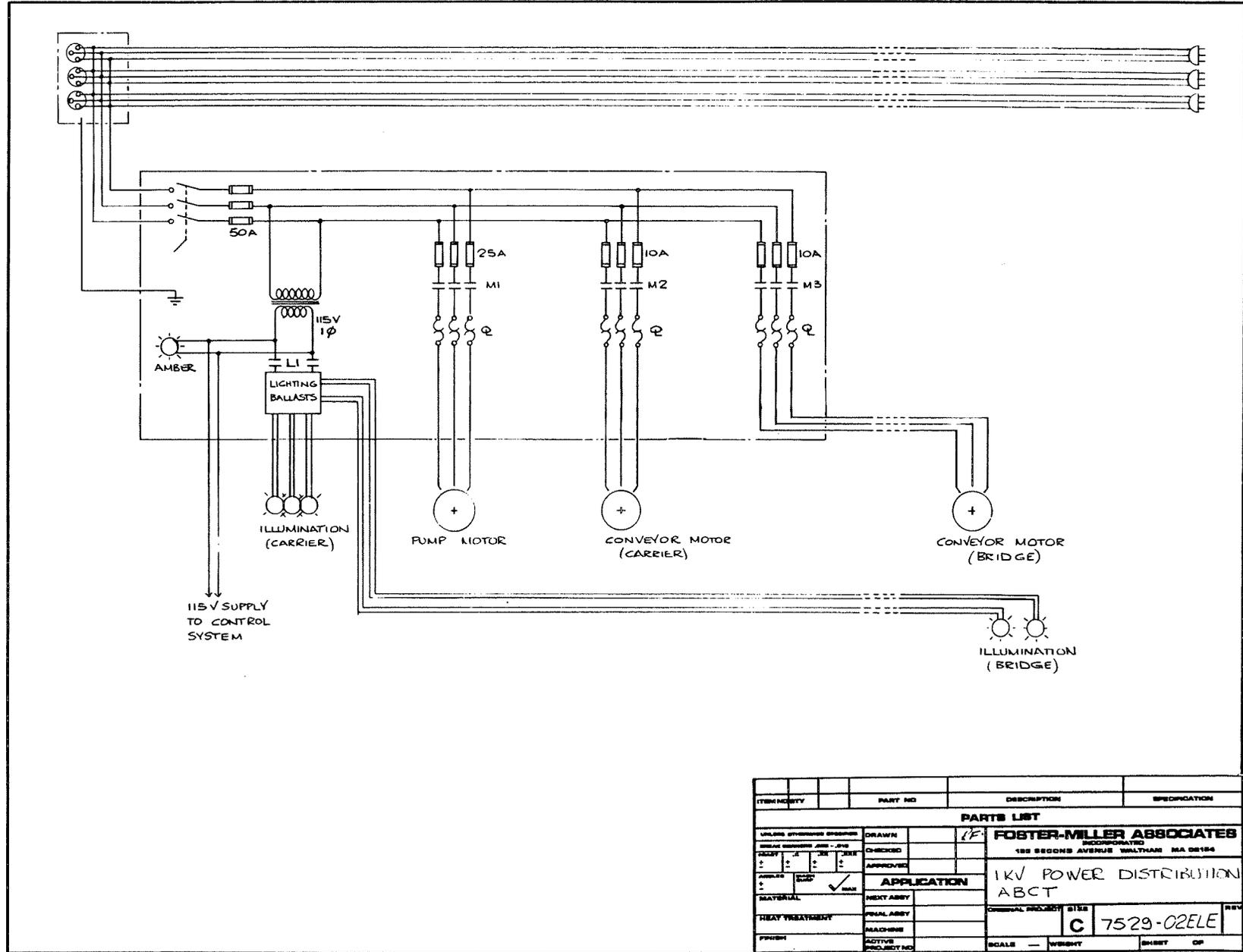


FIGURE 40. - Starter enclosure schematic.



ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
PARTS LIST			
DRAWN		FOSTER-MILLER ASSOCIATES INCORPORATED 188 BECON AVENUE WALTHAM MA 02154	
CHECKED			
APPROVED		APPLICATION 1KV POWER DISTRIBUTION ABCT	
MATERIAL			
NEXT ASBY		ORIGINAL PROJECT SIZE C 7529-02ELE	
RETRY TREATMENT			
FINISH		SCALE — WEIGHT SHEET OF	

P.S.P. 133

Control signals are carried to and from the central control enclosure by means of multiconductor cables housed in a rigid steel conduit. These cables terminate at two small local control boxes, one near the inby wheels and one near the outby wheels. Within these enclosures the signals from the sensors are amplified, rectified and prepared for transmission to the central control enclosure. The local control boxes also contain the circuitry which amplifies the signals from the control interface to power level signals capable of driving the valves controlling the hydraulic tramming steering motors. All the local control electronics are packaged in modular fashion so that individual boards can be replaced in the event of failure.

All explosion-proof enclosures were selected from MSHA-approved, standard designs of the Long-Airdox Corporation. Interconnection between the enclosures is by means of steel conduit, either rigid or, where necessary, flexible. The enclosures are provided with the required sealing glands to meet Schedule 2G.

3.1.9 Power Cable Handling

Three power cables and one water hose are carried, two on each side, throughout the length of the ABCT. Described in this section is the way in which these cables and the hose are deployed along the length of a typical bridge-carrier pair.

In this double unit, the bridge is the outby section and the carrier is the inby section, the two being coupled together by means of a rotary turntable and sliding dolly as previously described (see figure 41). At the outby end of the bridge, the cables and hose are provided with couplers for attachment to the bulkhead connectors on the carrier section of the next dual unit. The cables are attached to the outby end of the bridge at the end of the lower straight section below the conveyor drive reducer, as shown in the figure.

Sufficient slack cable is left at this point to allow for rotation of the bridge relative to the carrier at the transfer point. The slack cable is constrained by means of a chain and spring arrangement which prevents it from dragging on the ground, as shown in figure 42. The cable then travels along the sides of the bridge and attaches to the dolly structure through which the bridge slides.

The slack generated by the dolly moving towards the outby end of the bridge is taken up means of a festoon arrangement. The cable is attached at a number of points to spring loaded arms pivoted to blocks sliding in a track

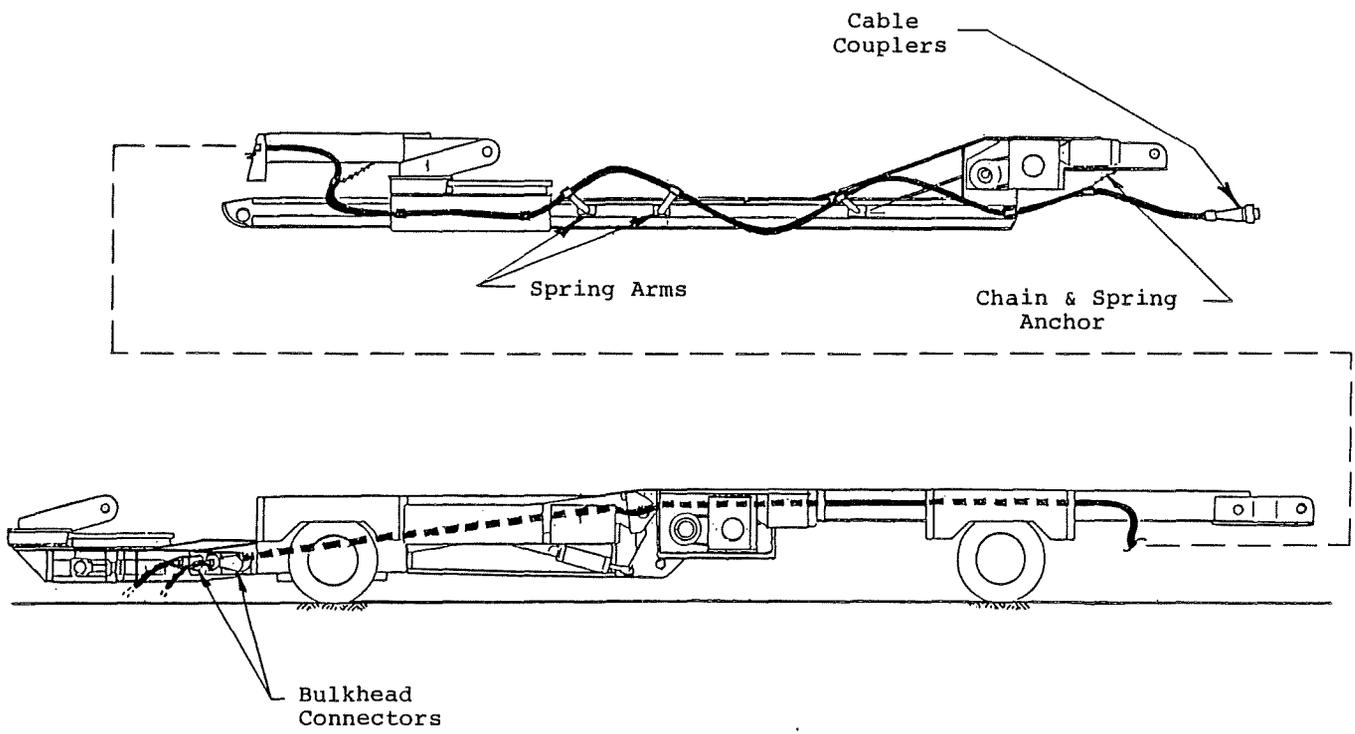


FIGURE 41. - Power cable disposition.

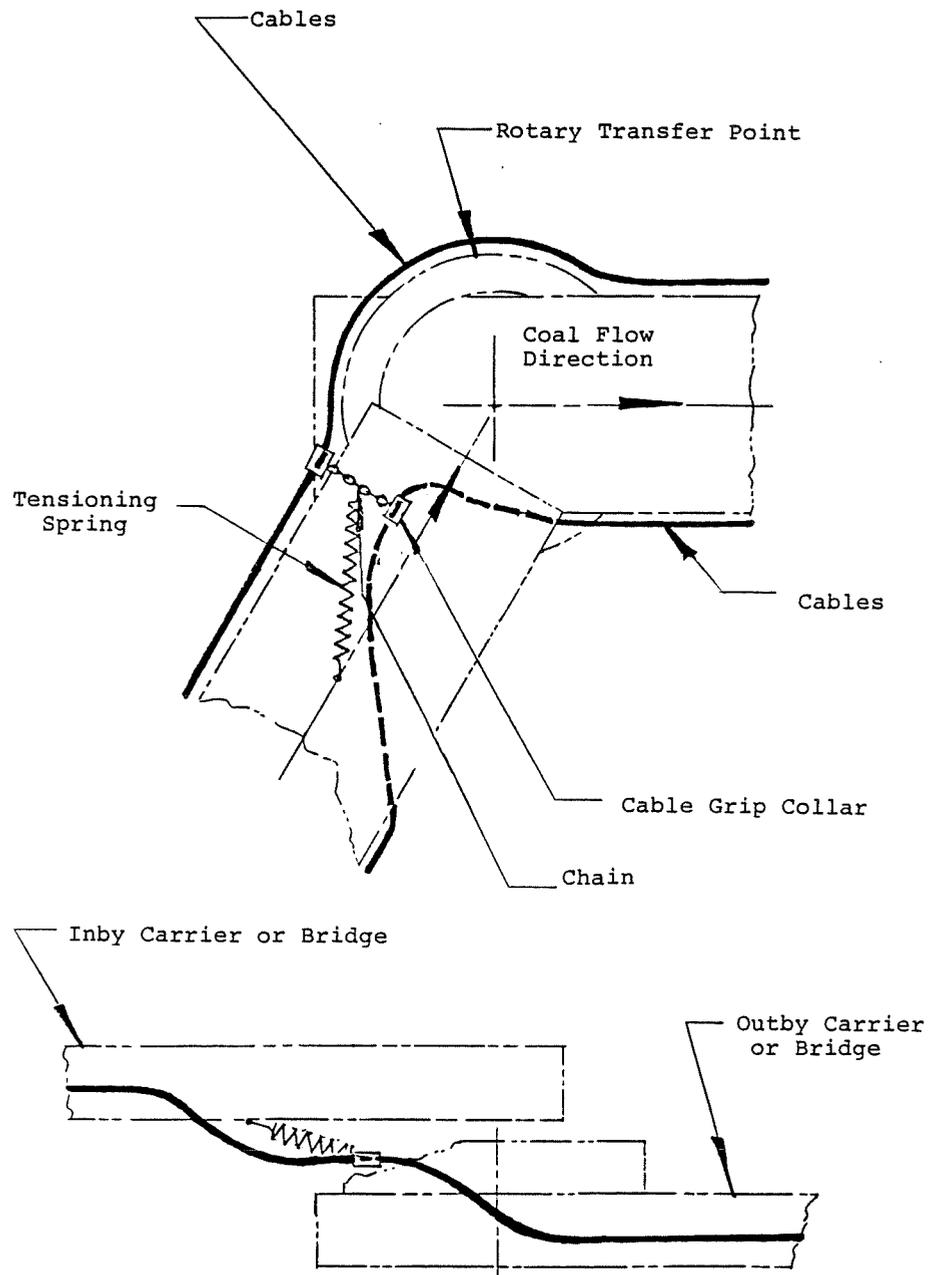


FIGURE 42. - Chain and spring arrangement for handling cables at transfer point.

along the sides of the bridge structure (see figure 43). As the dolly moves outby, the arms swing upwards, folding the cable into a festoon pattern.

Continuing in an inby direction from its point of attachment to the dolly, the cable rises and attaches to the elevated part of the carrier side structure just outby the wheels. It then continues, contained in the recessed sides of the side channels, passing behind the wheel mounting plate, the conveyor drive motor and reducer, the electrical power enclosures and the hydraulic power supply, and the inby wheels and finally enters the explosion-proof enclosures placed beneath the platform supporting the carrier turntable. These enclosures carry the bulkhead connectors for making connection to the next inby unit of the ABCT.

The festooning arrangement alongside of the bridge unit is ample to control the slack produced while the ABCT is in normal operation. However, it may not, by itself, be sufficient to accommodate all the slack cable produced when the bridge is in the fully stored condition beneath the carrier unit. When placing the bridge in this stored state, it may be necessary for the operator to provide some manual assistance to ensure the accommodation of all the loose cable.

3.1.10 Guidance Cable Deployment and the Lead MBC

To facilitate a smooth transition from the fabrication and test phase to the demonstration phase of the program, we fabricated a modified MBC to act as the lead, inby vehicle of the ABCT. The use of this vehicle makes the system a self-contained entity.

The modifications to the standard MBC which converted it to lead vehicle operation are:

- a. Replacement of the inby transfer pivot point with a surge trough
- b. Addition of the guidance cable deployment system
- c. Modification of the guidance system and addition of a manual controller so that initiation of tramping and steering of the front wheels are under the inby operator's control.

These modifications are described below.

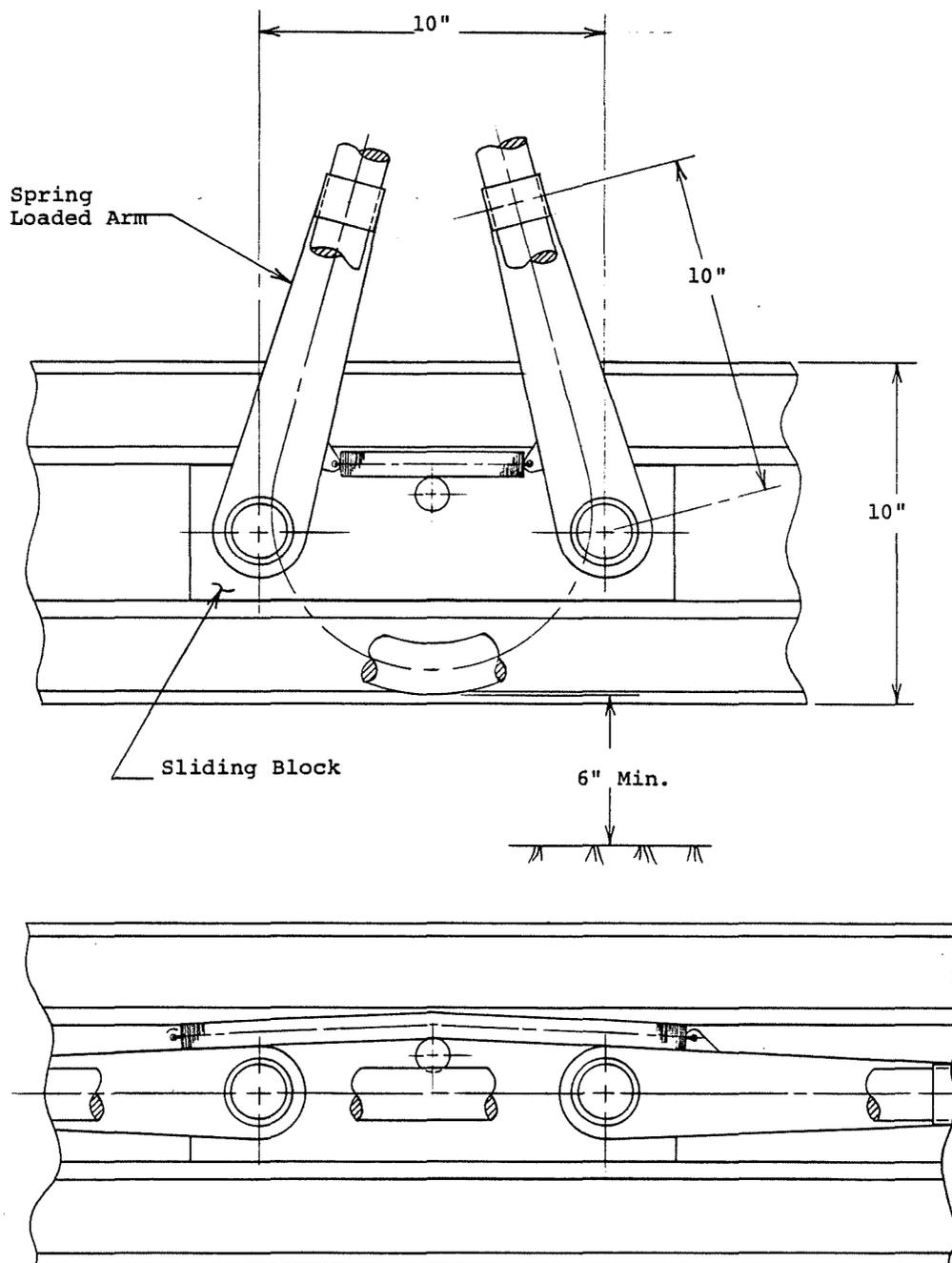


FIGURE 43. - Spring loaded arms.

3.1.10.1 The Surge Trough

The surge trough modification, shown in figure 44, serves two purposes: first, it provides an enlarged target area for the miner tailboom; and, second, provides over a ton of surge capacity at the input of the conveyor system. The trough was added to the standard MBC by simply omitting the rotary track and its support plate, and by adding the flared weldment shown in the figure.

3.1.10.2 Guidance Cable Deployment Gear

When the inby MBC was first built, the guidance cable reel was mounted between the inby pair of wheels on the lead carrier, as shown in figures 44 and 45. The cable was paid out and retrieved by a capstan drive which moved in response to signals from the microprocessor. The cable reel moved in response to signals generated by a switch mounted on the dancer-roll between the capstan and the reel. Preliminary testing of the completed unit exposed the following problems:

- Sensor cable jams at the pancake drive wheel
- Inadequate ground clearance at the proportional valve control sensors
- Wheel override of the sensor cable in tight turns.

The above problems forced a redesign of the deployment gear. Those changes are discussed in section 4.1.1.

The guidance cable is a two conductor, #16 AWG, portable reel cable (Anixter 4E-1602). It is 0.4 in. in diameter, weighs 79 lb/1,000 ft, and can carry 15 A in either conductor. The recommended minimum bend diameter is 3 in.

Two sets of wheel sensor coil assemblies are arranged so that the cable runs between them. The field from the cable is amplified and fed to a Dynex valve which causes the cable deployment reel to run backward or forward depending on whether the cable needs to be deployed or retracted. The direction decision is made by the position of the cable relative to the sensor coils. The cable will be moved toward one assembly when not enough cable is being deployed and toward the other when too much slack is developed.

3.1.10.3 Lead Carrier Guidance System

The lead carrier is controlled manually to initiate tramming and to steer the inby wheel pair. Details of the

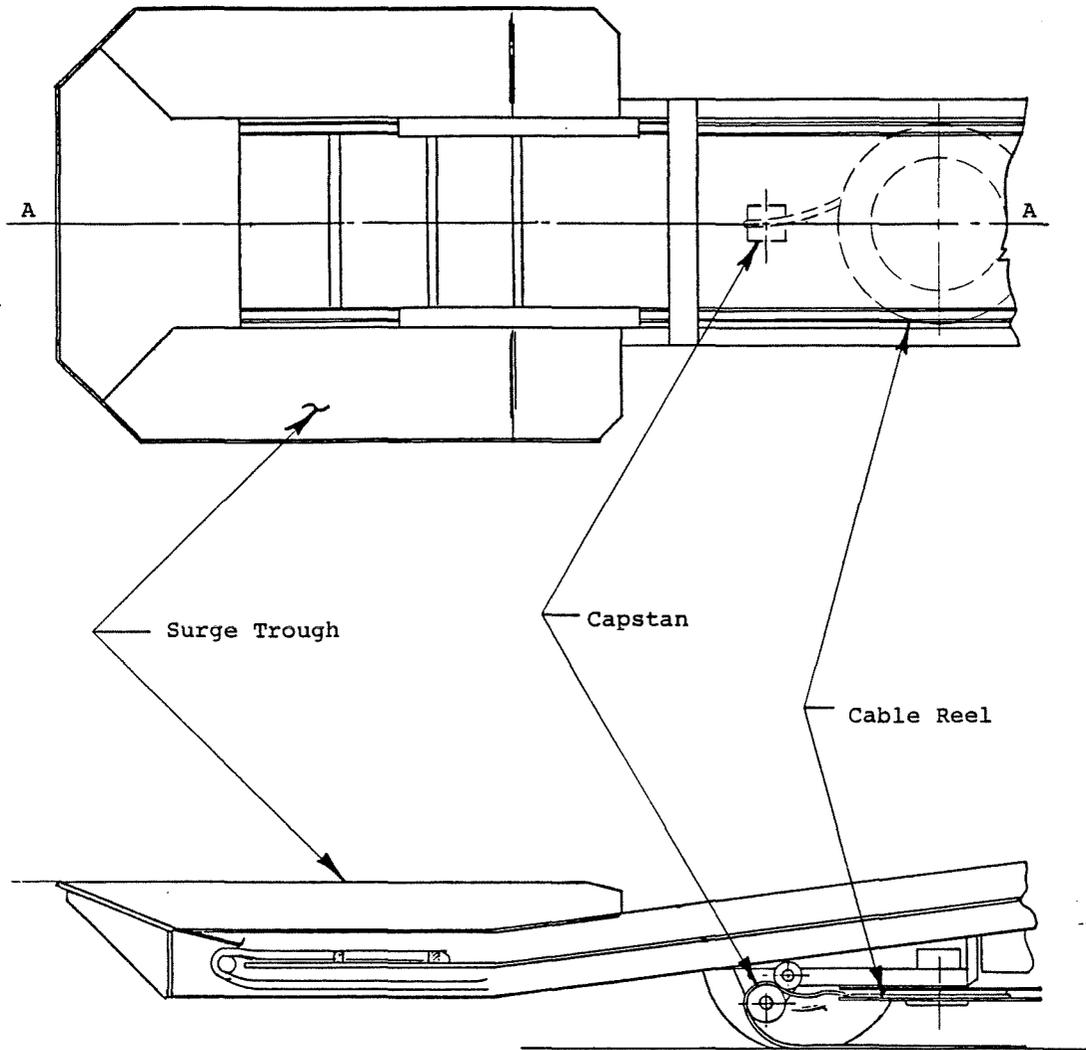


FIGURE 44. - Modification of carrier inboard end to form lead unit.

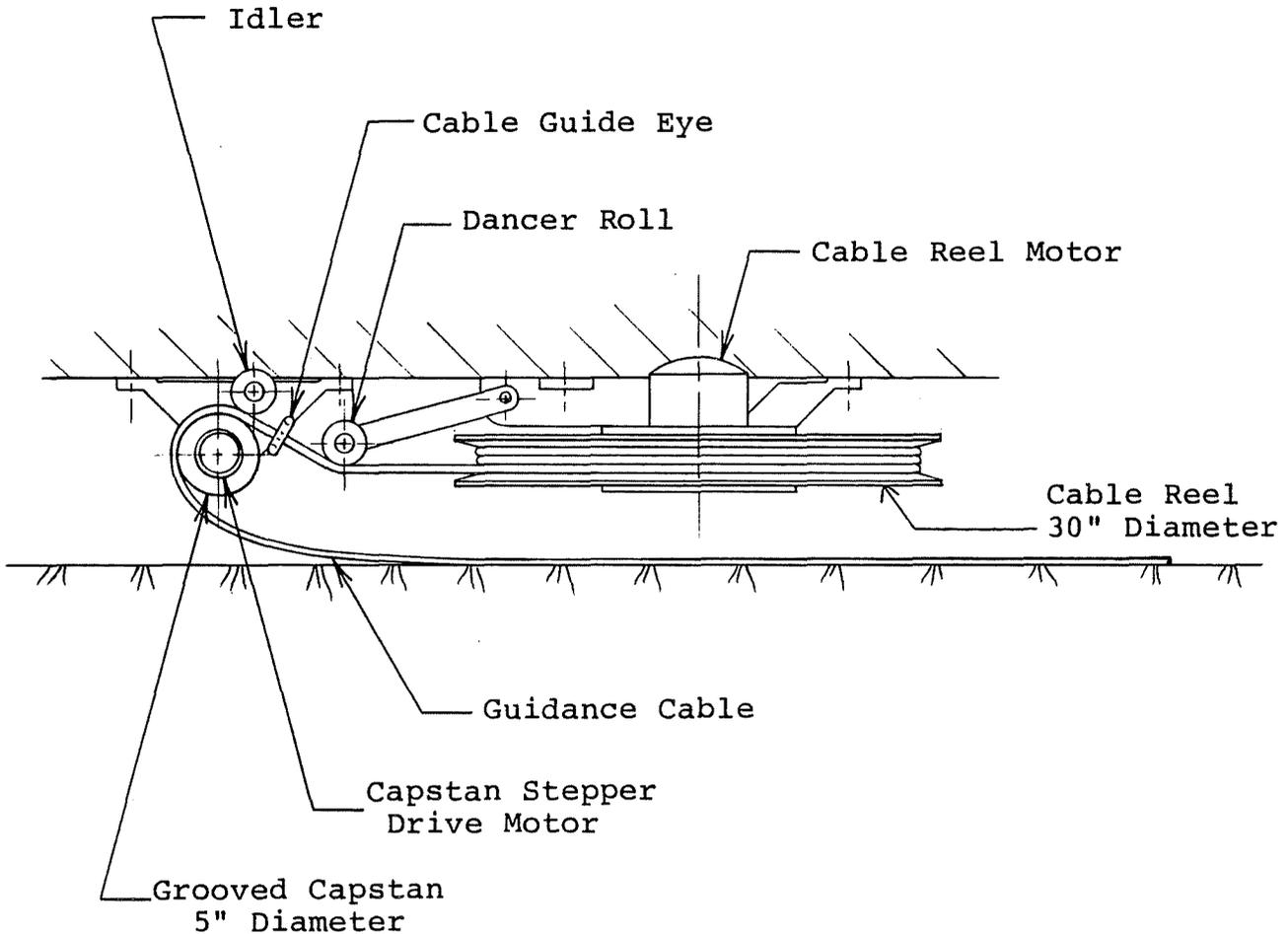


FIGURE 45. - Guidance cable deployment system.

inby operator's control station are shown in figure 46, while an electrical schematic of the controller is shown in figure 47. The inby wheels are steered parallel to each other in response to a voltage generated at the steering potentiometer. While trammig is initiated by the control switch, the velocity of all four wheels remains under automatic control.

3.2 THE GUIDANCE SYSTEM

The basic principle behind guidance of the ABCT is that the inby vehicle pays out an electrical cable onto

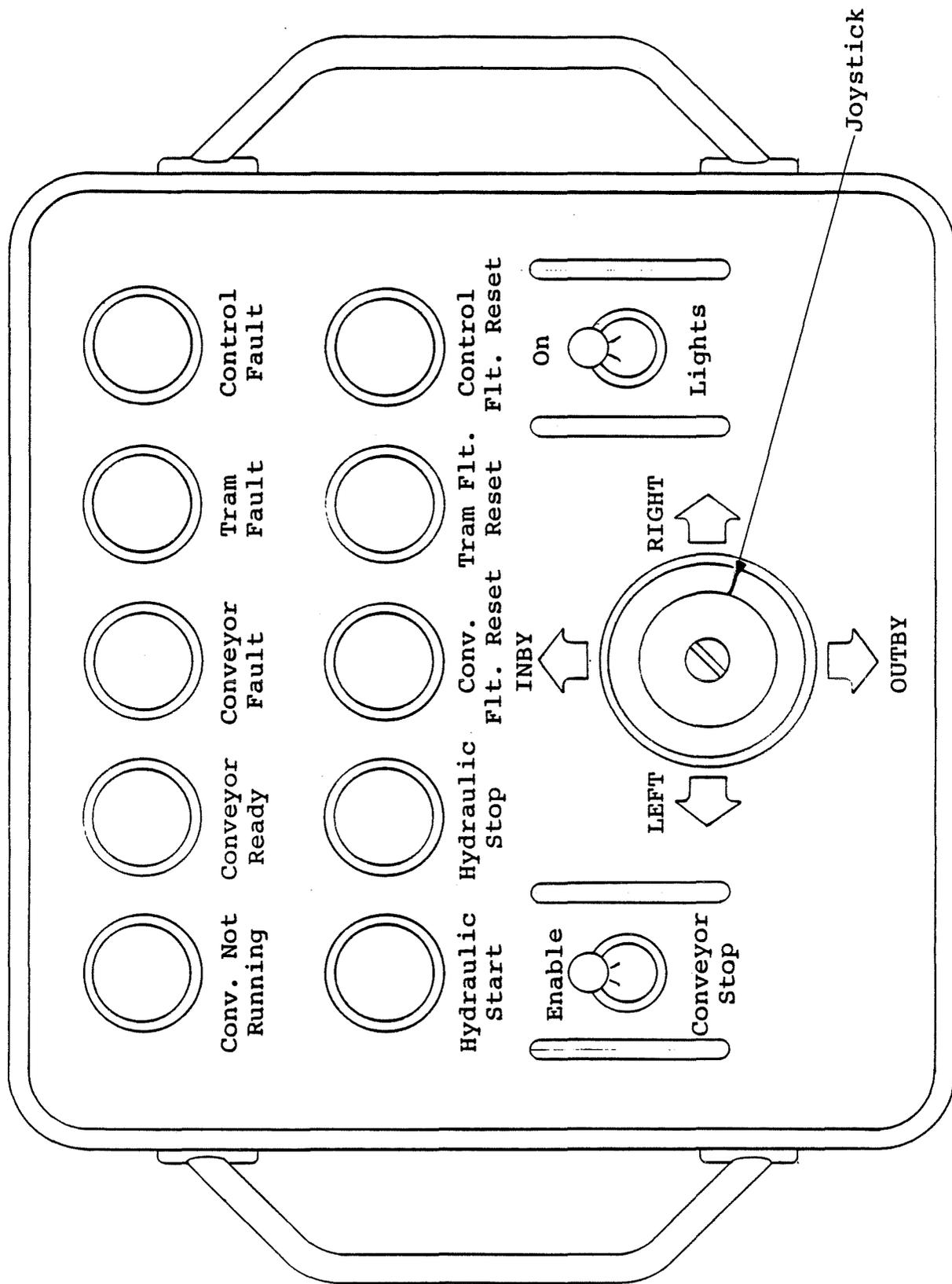


FIGURE 46. - Tram and steering control.

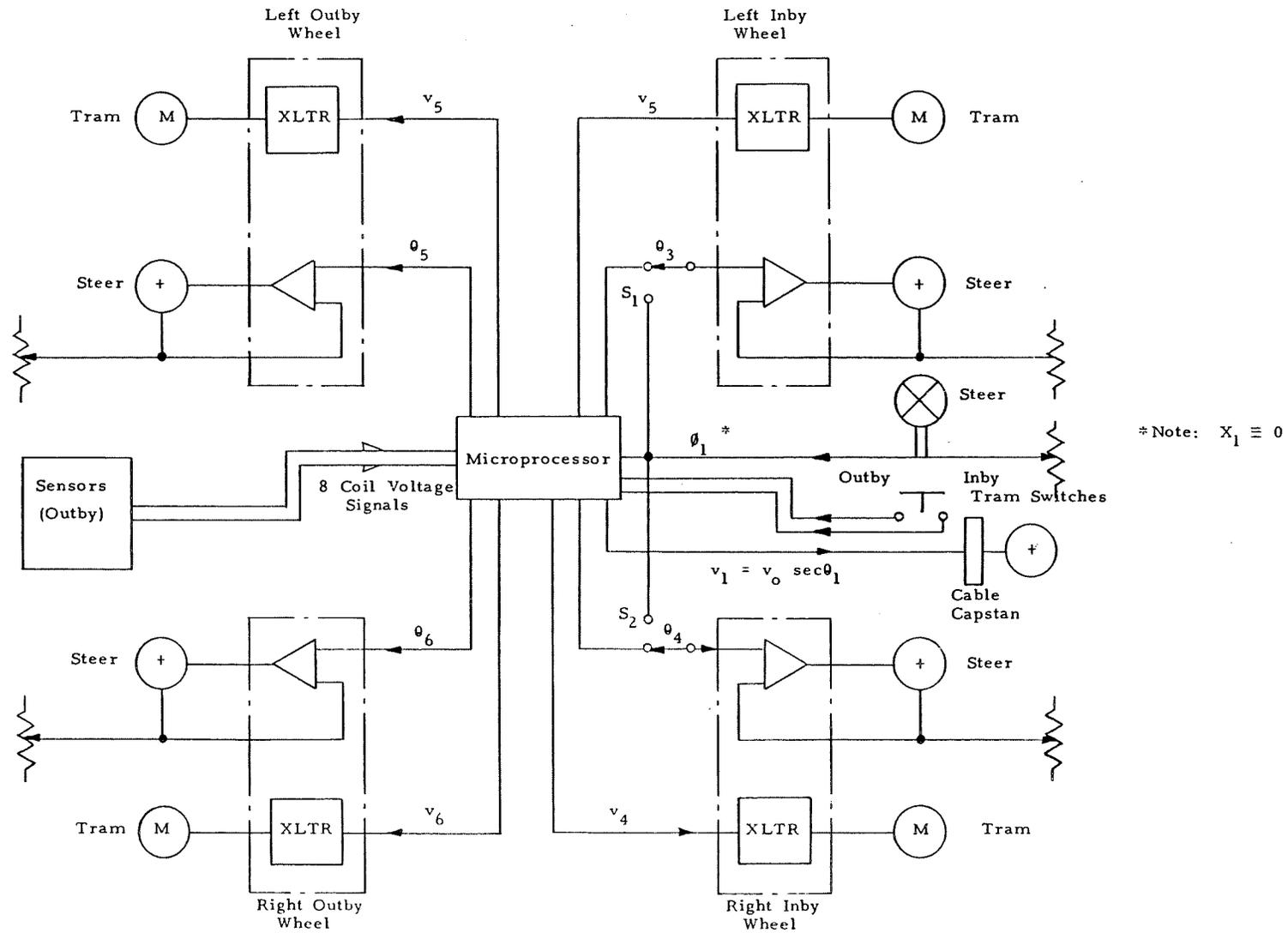


FIGURE 47. - Control schematic - inby carrier.

the floor as it moves during mining or place-changing operations. Each subsequent MBC is equipped to:

- a. Sense the position of the cable with respect to the vehicle
- b. Steer the wheels to follow the cable on both straight runs and turnouts

Specific problems which were addressed by the design of the guidance system are:

- a. The vehicles must be capable of negotiating 90° turns in 18 ft entries. (An MBC is about 35 ft long, while the bridges are about 25 ft in length.)
- b. The path of the vehicles must be simply related to the path of the guidance cable.
- c. Control of the vehicles must be maintained under wet or slippery floor conditions.
- d. The sensors which detect the position of the cable must not be sensitive to the height of the vehicle from the floor so that operation will be possible over a rocky or pitted bottom.
- e. The sensors must be immune to electrical noise associated with the operation of the ABCT and other nearby equipment.
- f. The cable must be easily laid by the inby vehicle, and simply adjusted if necessary.

In order to maintain the most reliable control of each vehicle in the unmanned 500-ft train, a system was designed which independently steers each wheel to the correct angle and turns it at the correct speed for the motion being executed, independent of the load imposed or bottom conditions.

While this concept is very conservative, it is implemented in a straightforward manner through use of micro-processor electronics. An outstanding advantage of this approach is that the control strategy can easily be simplified without the necessity of modifying the system hardware.

A block diagram of the guidance system is shown in figure 48. A description of the overall operation and the detailed design of each element is given below.

3.2.1 Principle of Operation

Each MBC in the conveyor train is a four wheeled vehicle fitted with magnetic sensors and a controller which adjusts the steering angle and speed of each wheel to follow the guidance cable.

The vehicle trams only in response to the motion of the next inby vehicle, and in the same direction. The direction and speed of tramming is determined by use of limit switches on the inby dolly track.

The basic strategy for steering the vehicle is illustrated in figure 49. Eight pairs of sensors are placed in a square array at the intersections of the fore and aft wheel axes with the vehicle centerline. Perpendicular coils (\perp) have an axis perpendicular to the ground and measure the verticle field component. The parallel coils (\parallel) have an axis parallel to the ground and measure the horizontal field component. The voltages produced by the sensors, when passed through the guidance control system shown in figure 48, result in the vehicle being steered at an angle

$$\theta = kx + \phi$$

where

θ = calculated vehicle steering angle

k = steering constant

x = cable displacement at the center of the sensor array

ϕ = angle of the cable with respect to the vehicle

If there is no displacement of the vehicle centerline from the cable ($x = 0$), the wheels are turned parallel to the cable. If there is a displacement, the wheels are further turned to counteract it by an angle proportional to the displacement. Once a steering angle has been chosen for each wheel, velocities are calculated and the wheels are driven such that each rotates without slipping.

The procedure used by the guidance system for controlling the vehicle can be outlined as follows, with reference to figure 48:

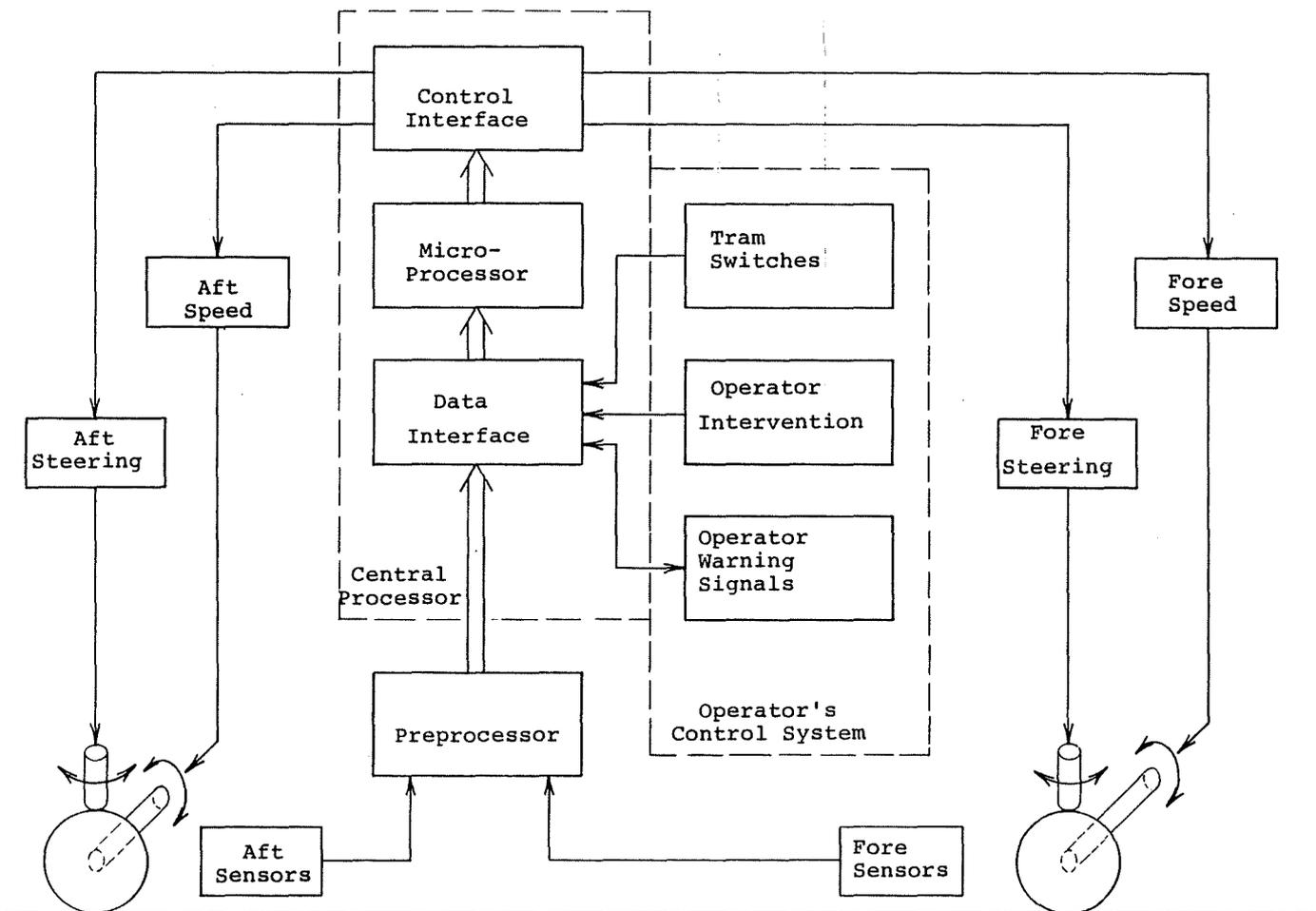
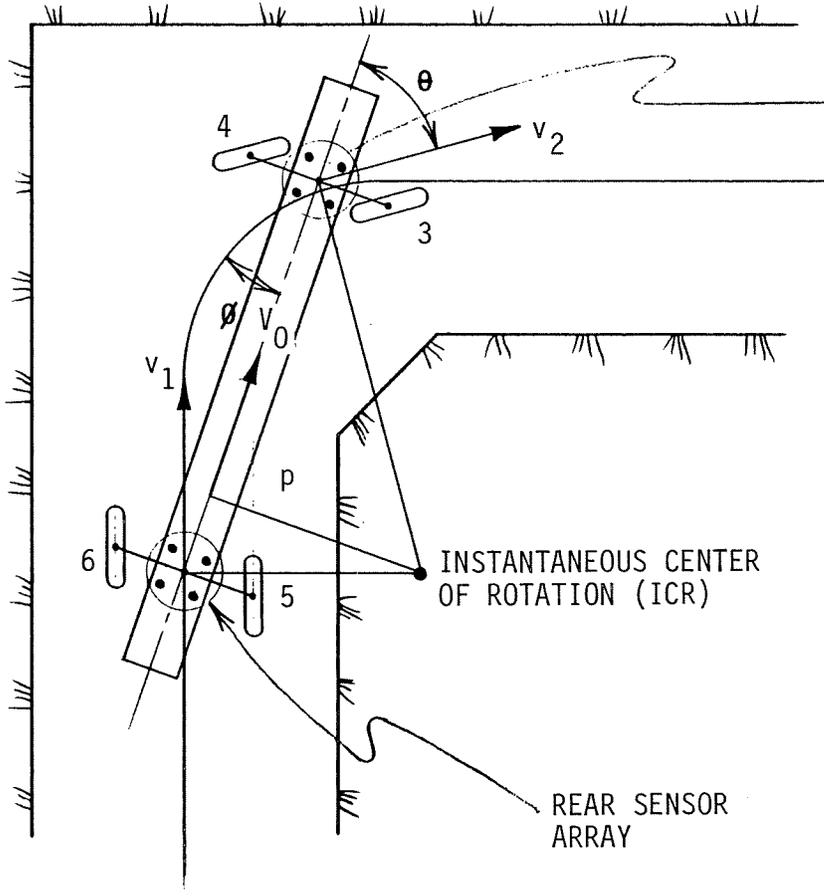
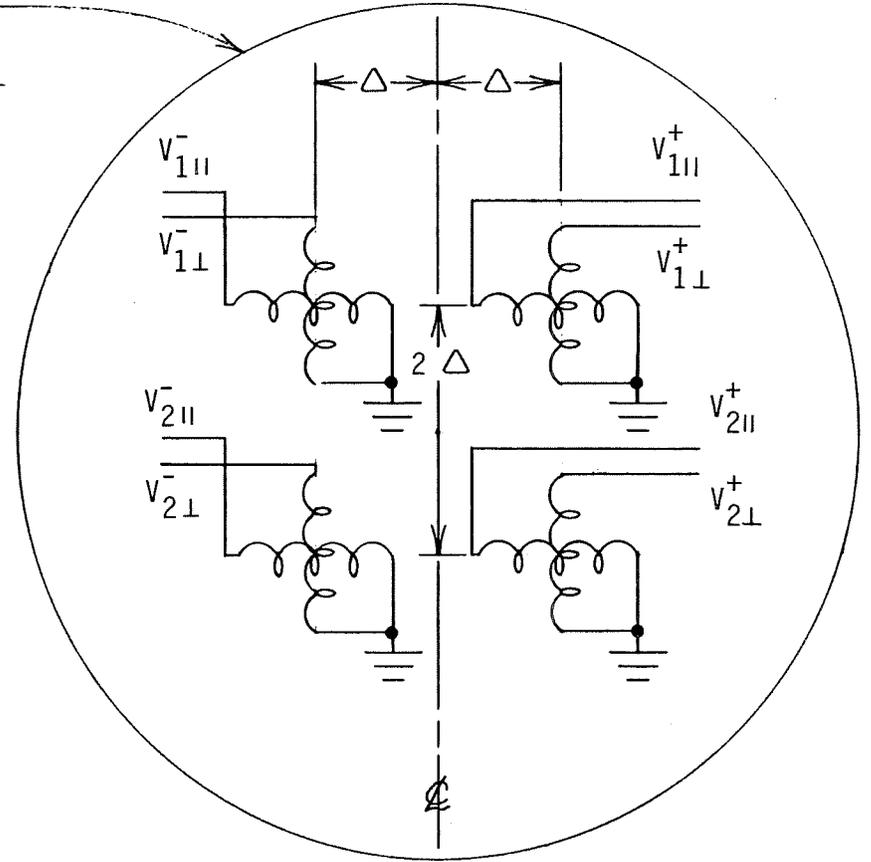


FIGURE 48. - Guidance system block diagram.

FIGURE 49. - Sensor array locations and basic steering strategy.



NOTE: COILS MARKED \perp HAVE THE AXIS PERPENDICULAR TO THE GROUND. COILS MARKED \parallel HAVE THE AXIS PARALLEL (HORIZONTAL) TO THE GROUND. SEE FIGURE 54b.



FRONT SENSOR ARRAY

- a. The voltages for the four fore-sensor-pairs and the four aft-sensor-pairs (16 voltages in all) are obtained in the preprocessor. The preprocessor amplifies the voltages, filters out noise, and converts them to dc signals.
- b. The voltages are sampled and converted to digital form in the data interface (multiplexer).
- c. The microprocessor transfers the digital signals into storage and performs the calculations necessary to determine the offset of the vehicle from the cable and the angle of the vehicle with respect to the cable. From this information, the correct angle and speed of each wheel is calculated and transferred to the control interface.
- d. The control interface converts the speed and angle data to voltage signals suitable for controlling the speed and angle servos for each of the four wheels.

3.2.2 Sensor Design

The displacement of a sensor array, consisting of two sensor assemblies each containing two orthogonal coils located at corresponding positions on opposite sides of the machine, can be measured from a current-carrying cable by measuring the difference in voltage induced in those coils. If four pairs of sensors are used, the angle of the cable, as well as its displacement, can be determined.

Figure 50 shows the configuration of a basic magnetic coil used to track a cable lying on the floor. All automated vehicles in current use employ some version of this sensor.

From formulas developed in textbooks,¹ it can be shown that the two coil voltages are approximately

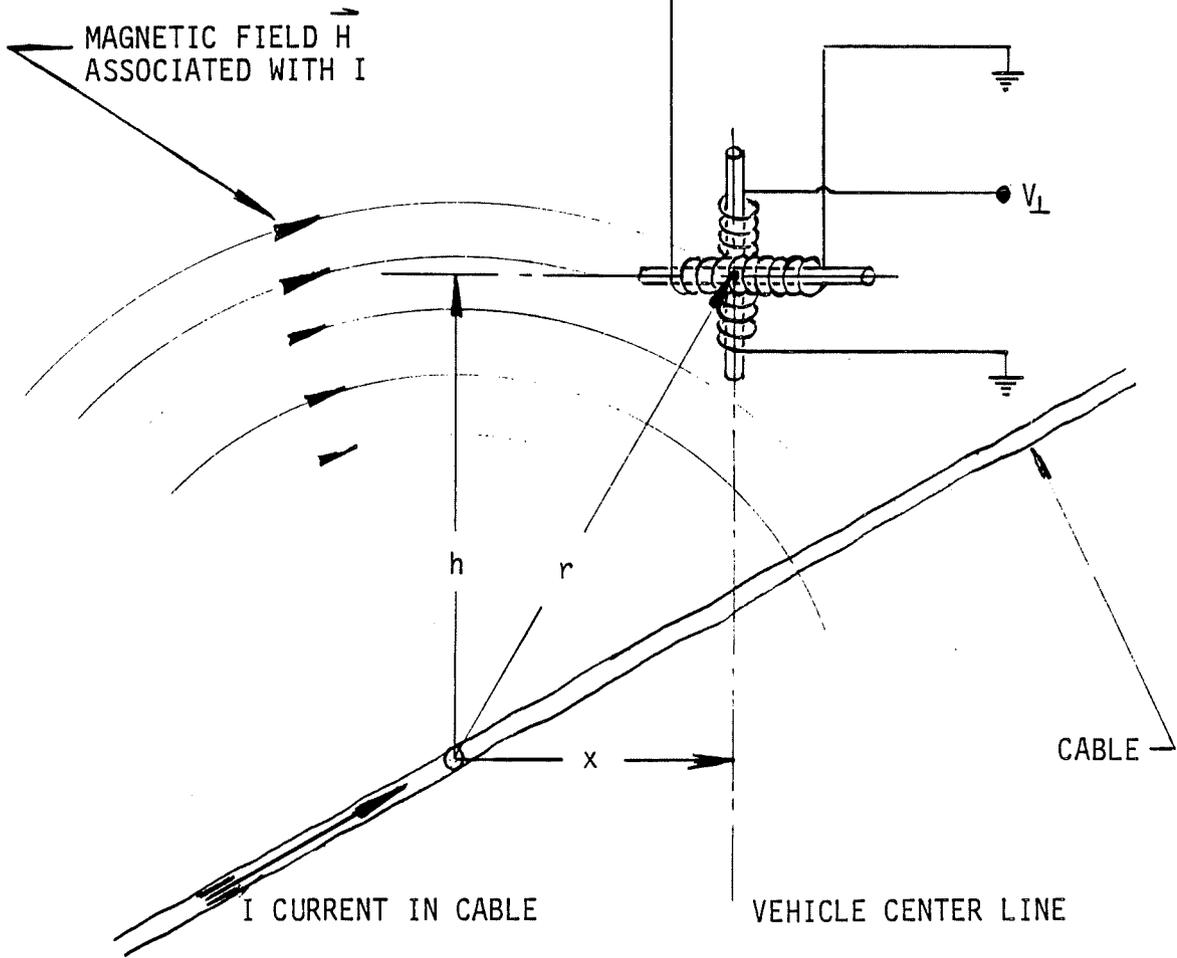
$$V_{\parallel} = NA\mu f I \left[\frac{h}{r^2} \right]$$

$$V_{\perp} = NA\mu f I \left[\frac{x}{r^2} \right]$$

¹See, for example, Electromagnetics, J.D. Kraus, McGraw-Hill, 1953. Chapter IV is relevant.

$V_{||}$ - IS THE VOLTAGE FROM THE COIL PARALLEL TO THE FLOOR

V_{\perp} - IS THE VOLTAGE FROM THE PERPENDICULAR COIL



NOTE: BOTH COILS LIE IN A PLANE PERPENDICULAR TO THE CABLE

FIGURE 50. - Geometry of basic magnetic sensor.

where

V_{\parallel} = voltage from coil parallel to floor

V_{\perp} = voltage from coil perpendicular to floor

N = number of turns on each coil

μ = permeability of iron core

A = cross-sectional area of iron core

f = frequency of cable excitation current

I = amplitude of cable excitation current

x = horizontal displacement of sensor from cable

h = vertical distance of sensors from cable

$$r^2 = x^2 + h^2$$

These fundamental formulas can be rewritten:

$$V_{\parallel} = \frac{NA\mu f I}{h} \left[\frac{1}{1 + x^2/h^2} \right]$$

$$V_{\perp} = \frac{NA\mu f I}{h} \left[\frac{1}{1 + x^2/h^2} \right]$$

in terms of a dimensionless parameters x/h , which we will subsequently call m , and the sensor dependent quantity:

$$\frac{NA\mu f I}{h}$$

In a practical situation,

$N = 800$ turns

$A = 5.07 \text{ cm}^2$ (1 in. diam)

$\mu = 300$ (a good magnetic steel)

$f = 10 \text{ kc}$

$I = 200 \text{ ma}$

$h = 1 \text{ ft} = 0.305 \text{ m}$

This sensor dependent quantity works out to be about 1 V.

Examining the geometry-dependent quantity in brackets, we obtain the plots of voltage versus displacement of the sensor shown in figures 51 and 52.

Most cable-trackers work by making use of something analogous to V_{\perp} for guidance - the linear region gives a voltage proportional to displacement for values of x less than about 1 ft. In principle, this technique can be used at low or high frequency, but at best is strongly dependent upon the vertical height of the sensor, h . A common method of minimizing this dependent is to use a pair of conductors in the guidance cable (like TV antenna wire) to obtain a magnetic field which varies more slowly with distance, and then to operate at high frequencies, where radio effects occur. In this manner, however, the precise geometrical information available from the single conductor is lost, and the signal strength inherently available from a single conductor is compromised by interaction with the second conductor, and susceptibility to noise. An alternative approach is discussed below.

Consider the situation when two pairs of cross sensors are used, as in figure 53.

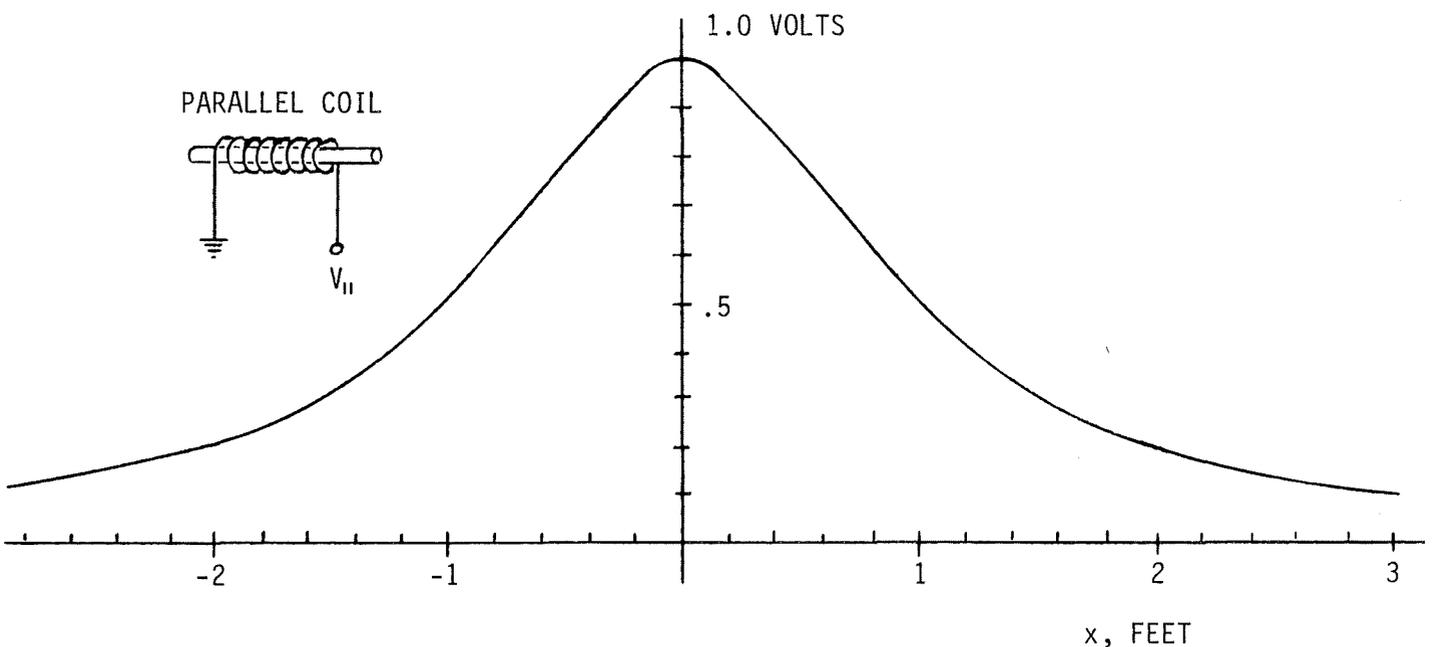


FIGURE 51. - Voltage versus displacement.

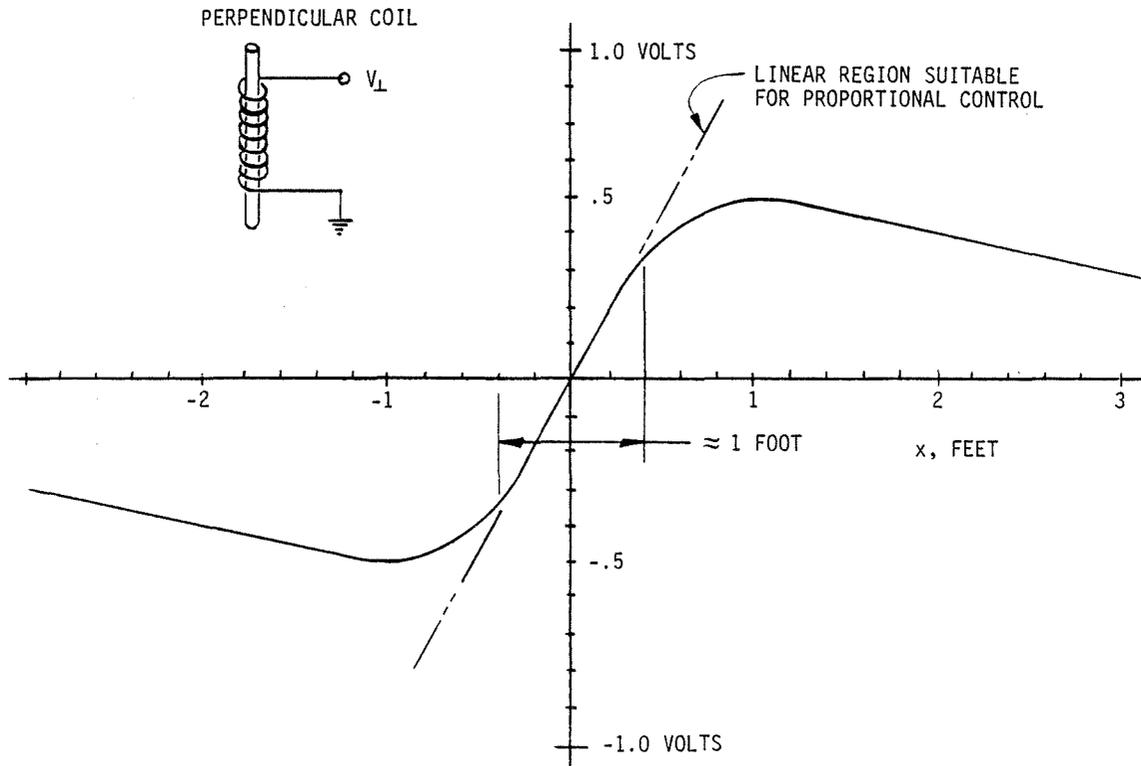


FIGURE 52. - Voltage versus displacement.

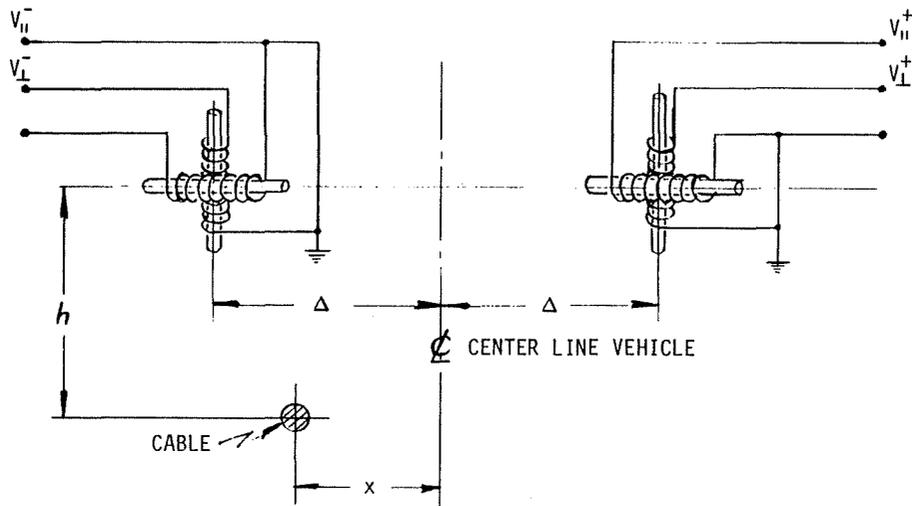


FIGURE 53. - Dual sensor geometry.

Each sensor pair is displaced a distance Δ from the vehicle centerline. Using the same methods as for the single sensor pair, we obtain

$$V_{\perp}^{-} = \frac{NA\mu f I}{h} \left[\frac{(x + \Delta)/h}{1 + (x + \Delta)^2/h^2} \right]$$

$$V_{\parallel}^{-} = \frac{NA\mu f I}{h} \left[\frac{1}{1 + (x + \Delta)^2/h^2} \right]$$

$$V_{\perp}^{+} = \frac{NA\mu f I}{h} \left[\frac{(x - \Delta)/h}{1 + (x - \Delta)^2/h^2} \right]$$

$$V_{\parallel}^{+} = \frac{NA\mu f I}{h} \left[\frac{1}{1 + (x - \Delta)^2/h^2} \right]$$

where the V^{+} 's are obtained from the coils mounted to the right of the center, while the V^{-} 's are from the coils on the left.

We now perform some conceptual signal processing: we divide the voltage V_{\perp} on each side by the voltage V_{\parallel} from that same side, i.e.,

$$R_{+} = \frac{V_{\perp}^{+}}{V_{\parallel}^{+}} = \frac{(x - \Delta)}{h}$$

$$R_{-} = \frac{V_{\perp}^{-}}{V_{\parallel}^{-}} = \frac{(x + \Delta)}{h}$$

Adding the resultant voltages,

$$R_{-} + R_{+} = 2x/h$$

subtracting them gives

$$R_- - R_+ = 2 \Delta/h$$

and dividing again we obtain

$$x = \Delta \left(\frac{R_- + R_+}{R_- - R_+} \right)$$

This shows that x can be obtained by signal processing performed on the four voltages (Δ is, of course a known, constant quantity), and that this value is completely independent of h , the height of the sensor from the floor, and the coil geometry parameters as long as the coils are identical. This ratio method of determining x has several distinct advantages:

- a. A voltage proportional to x is obtained, even if x is large
- b. The voltage is strictly proportional to x even if the floor undulates
- c. Noise, insofar as it is picked up equally by each sensor, will be rejected
- d. The method is insensitive to variations in the guidance cable driver output
- e. The method is insensitive to angles made by the cable with the centerline of the vehicle. Since this is so, the sensors can be firmly mounted on the bottom of the vehicle, and no wheel trucks or linkages are required underneath to turn them as they follow the cable around a corner.

The principal disadvantage of the method is that signal processing will be required to determine the x -voltage. This processing can be performed with a straightforward analog approach.

The first step in the analog determination is to simplify the required relation

$$\begin{aligned}
 x &= \Delta \left(\frac{R_- + R_+}{R_- - R_+} \right) \\
 &= \Delta \left(\frac{v_{\perp}^-/v_{\parallel}^- + v_{\perp}^+/v_{\parallel}^+}{v_{\perp}^-/v_{\parallel}^- + v_{\perp}^+/v_{\parallel}^+} \right) \\
 &= \Delta \left(\frac{v_{\perp}^-/v_{\parallel}^+ + v_{\perp}^+/v_{\parallel}^-}{v_{\perp}^-/v_{\parallel}^+ + v_{\perp}^+/v_{\parallel}^-} \right)
 \end{aligned}$$

The sensor array for the ABCT is schematically shown in figure 54.

It has been shown that the cable displacement, x_1 , x_2 , measured by the pairs numbered 1 and 2 respectively are

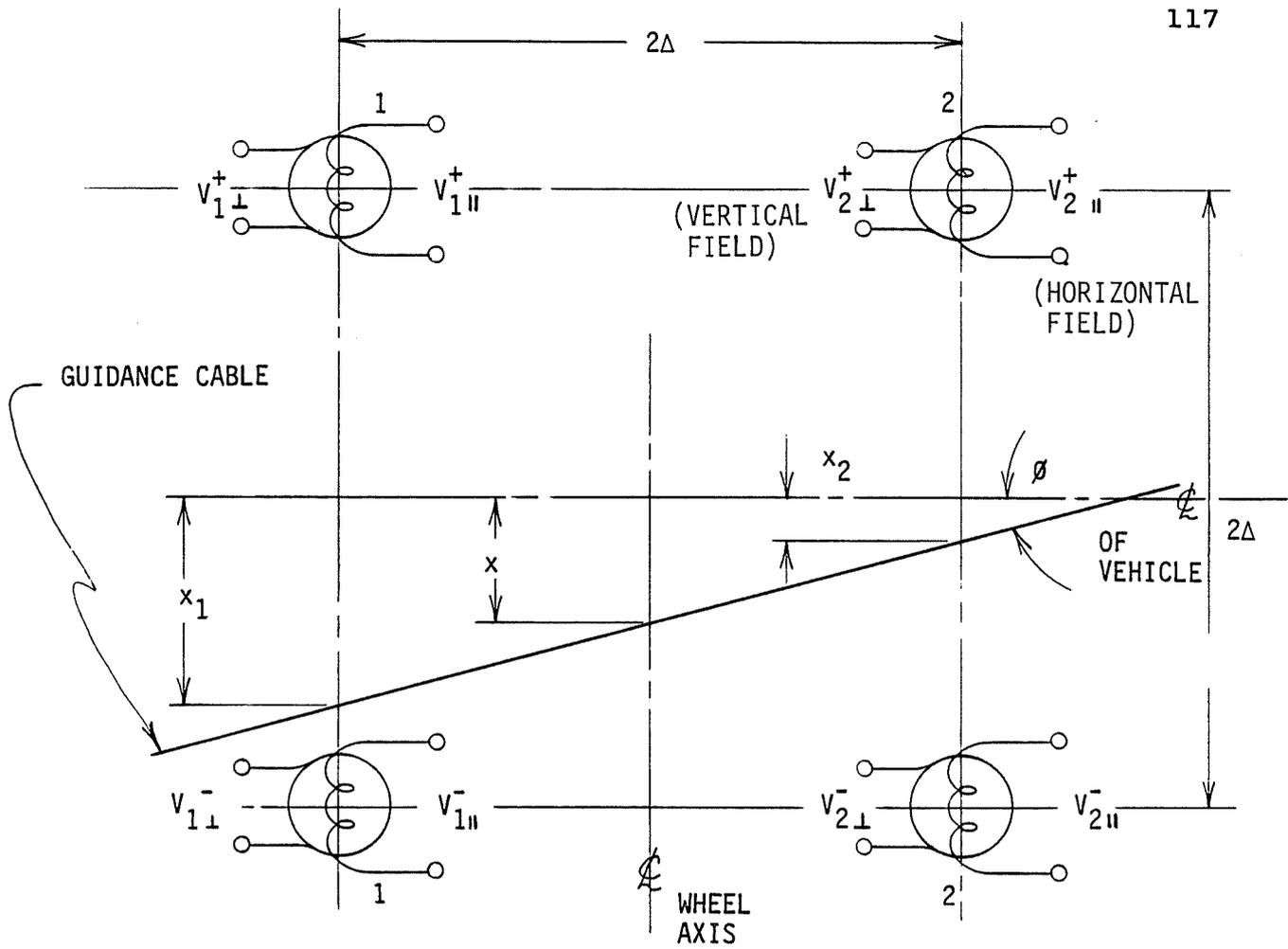
$$x_1 = \Delta \left(\frac{(v_{1\perp})^+ (v_{1\parallel})^- + (v_{1\parallel})^+ (v_{1\perp})^-}{(v_{1\perp})^+ (v_{1\parallel})^- - (v_{1\parallel})^+ (v_{1\perp})^-} \right)$$

and

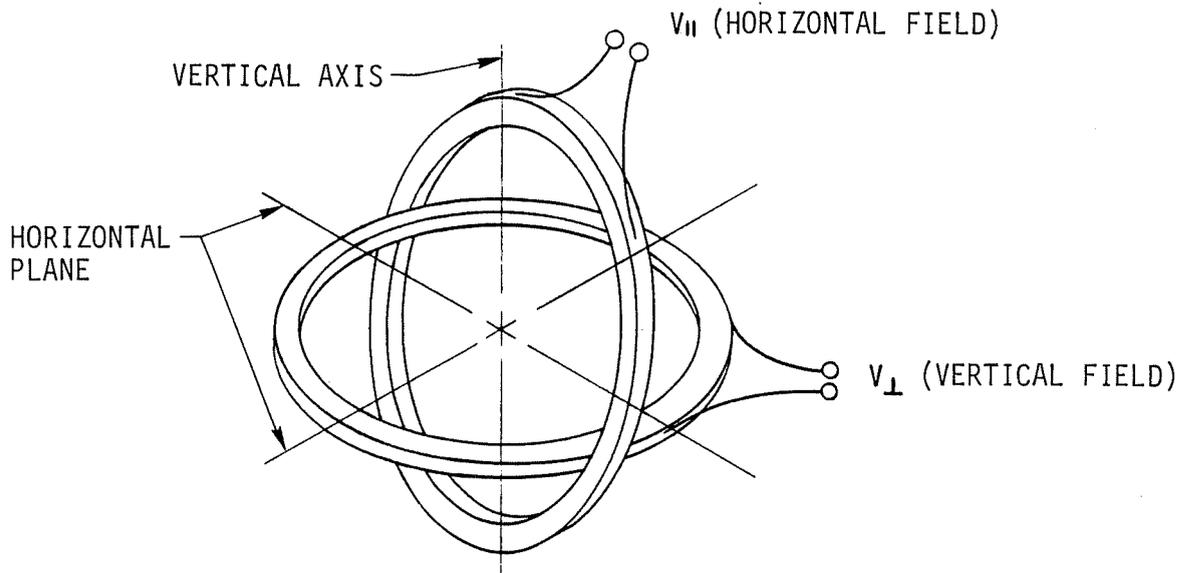
$$x_2 = \Delta \left(\frac{(v_{2\perp})^+ (v_{2\parallel})^- + (v_{2\parallel})^+ (v_{2\perp})^-}{(v_{2\perp})^+ (v_{2\parallel})^- - (v_{2\parallel})^+ (v_{2\perp})^-} \right)$$

These enable calculation of the displacement at the center of the array

$$x = \frac{x_1 + x_2}{2}$$



(a) SENSOR ARRAY



(b) TYPICAL SENSOR PAIR

FIGURE 54. - Sensor array schematic.

and the average angle of the cable with respect to the vehicle

$$\phi = \tan^{-1} \left(\frac{x_1 - x_2}{2\Delta} \right)$$

These values are independent of the height of the sensors from the floor, a fact which is critical to operation in wavy bottom conditions in coal mines.

The mathematical calculations of cable offset and angle can be handled by the central processor; our objective was the practical design of a sensor array which can provide useful voltages from realistic guidance cable currents.

3.2.2.1 The Sensor Coils

The signal voltage generated by each of the sensor coils is proportional to its coil length, frequency of cable excitation, the field produced by the current in the cable, and the number of turns. Since the physical space available for mounting the sensors is limited, a shallow, rectangular design was selected (fig. 55). In order to avoid excessive winding difficulties, a wire gage of #36 AWG was used. The output voltage is given by

$$|V| = |N\ell f I \ln \left(\frac{r_1}{r_2} \right) \cdot 4\pi \times 10^{-7} \text{ V}|$$

where

N = number of turns

ℓ = length of coil (meters)

f = frequency of cable excitation (Hertz)

I = the current in the cable

r_1, r_2 = the distances of the coil sides from the cable (see fig. 56)

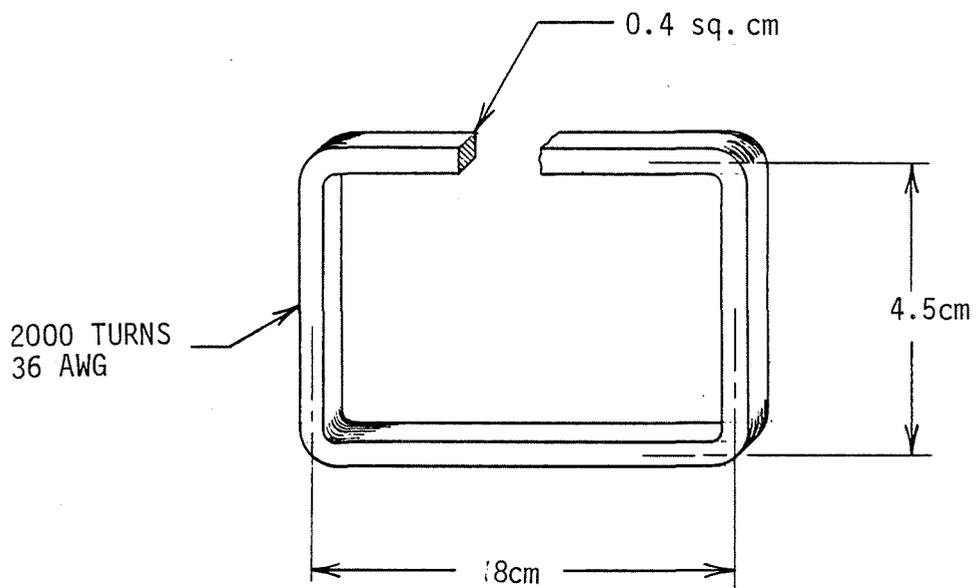


FIGURE 55. - Coil dimensions.

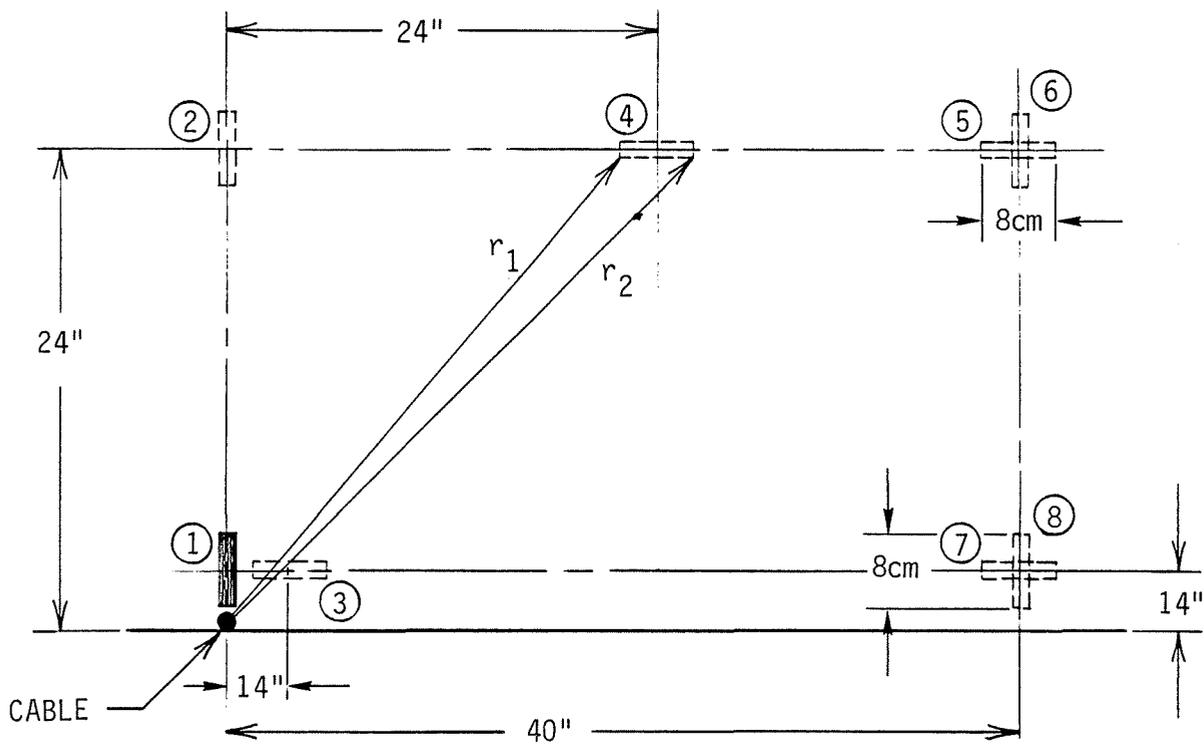


FIGURE 56. - Range of coil positions.

120

In the above equation ℓ is in meters and:

$$f = 1/\text{second}$$

$$I = \text{coulombs/second}$$

$$4\pi \times 10^{-7} = \text{permeability of free space } (\mu) \\ = \text{henry/meter}$$

and

$$e = L \frac{di}{dt}$$

therefore

$$L_{\text{henry}} = \frac{e \, dt}{di}$$

e in volts

t in seconds

i in coulombs/second

$$\text{henry} = \frac{\text{V} \cdot \text{second}^2}{\text{coulomb}}$$

Then, combining terms $\ell f I \mu = \text{volts}$

$$\text{meters} \times \frac{1}{\text{second}} \times \frac{\text{coulombs}}{\text{second}} \times \frac{\text{V} \times \text{second}^2}{\text{coulomb} \times \text{meter}}$$

For a coil of the dimension in figure 55 and a cable current of 0.5 A:

$$N = 2000$$

$$\ell = 0.08 \text{ m}$$

$$f = 10^4/\text{s}$$

$$I = 0.5 \text{ A}$$

Therefore, the output voltage becomes:

$$V = 2000 \times 0.08 \times 4\pi \times 10^4 \times 0.5 \times 10^{-7} \\ \times \ln \frac{r_1}{r_2} \approx \ln \frac{r_1}{r_2} V$$

For the coil positions shown in figure 56, which may be considered to cover the range from extreme maximum and minimum locations, the voltages are:

<u>Location</u>	<u>Voltage</u>
1	0.227 V
2	0.132 V
3	0.113 V
4	0.066 V
5	0.058 V
6	0.035 V
7	0.071 V
8	0.025 V

These voltages are well within the capacity of the pre-processing electronics to provide useful output signals to the data interface.

The design of the sensor package is shown in figure 57. Since work with the prototype guidance system indicated that sensing errors are introduced by surrounding the coil with a metal enclosure, the coils are embedded in tough, rigid, plastic encapsulation (e.g, Epotex 509F). A weathertight terminal enclosure provides for lead and conduit connections.

3.2.2.2 Return Cable

The guidance cable lies along the mine floor below the conveyor and is paid out behind the miner as cutting progresses. The electrical drive generator for the guidance cable is located at the outby end of the conveyor, and a second cable must be provided to return the current from the inby end of the guidance cable to the

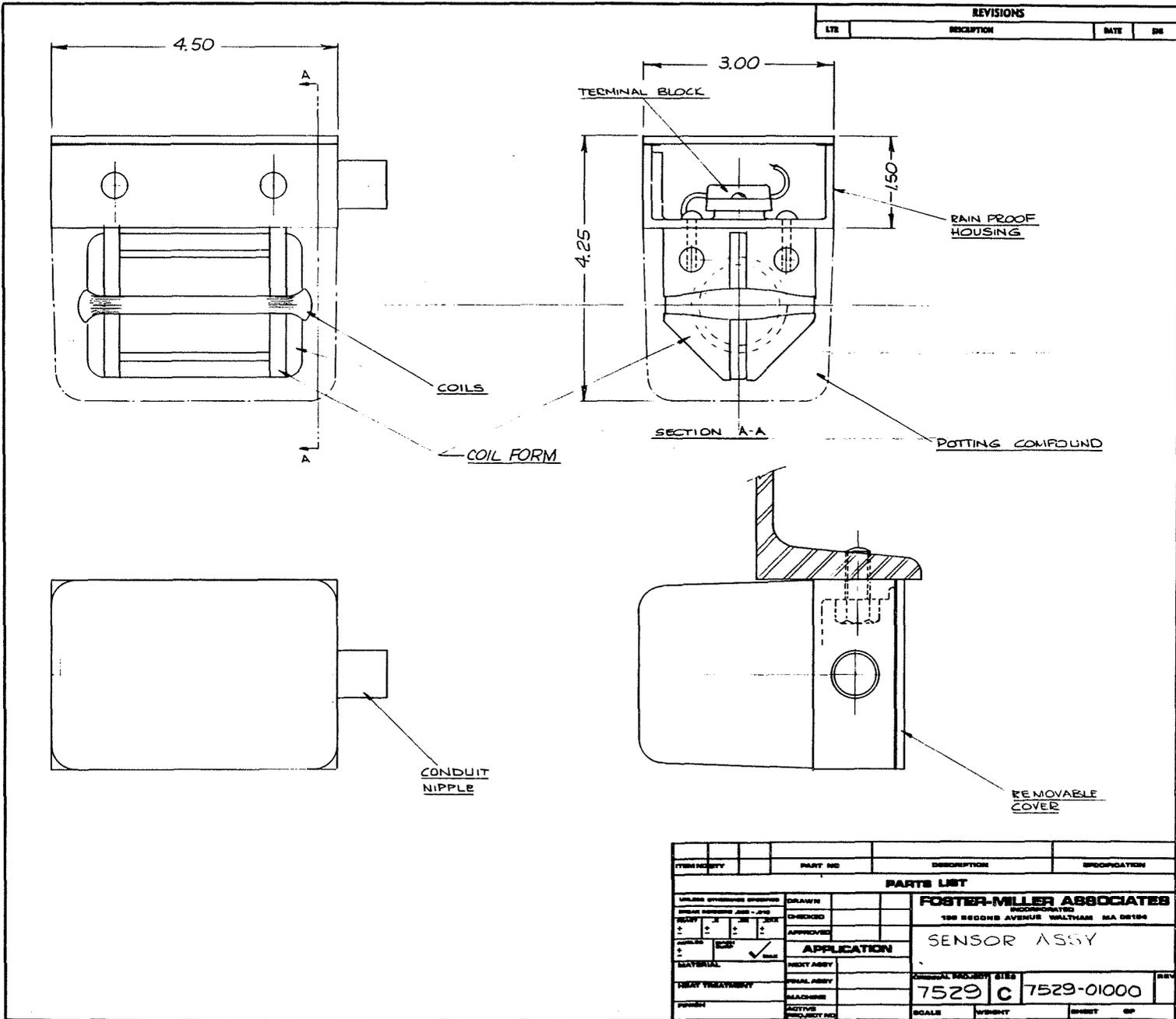


FIGURE 57. - Sensor package.

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generator. It is important to ensure that the magnetic field from this return cable does not interfere with the signals from the main guidance cable.

Shielding of the return cable was tried using a variety of magnetic shielding materials with only limited success. Placement of the return cable to keep it remote from the sensors was also considered. However, it is very desirable to keep the return cable mounted on the conveyor structure to avoid having to move a loose cable when place changing. With this restriction, it is impossible to locate the cable on the structure without generating false signals in the sensors.

Ultimately, we decided to mount the return cable in the plane of the V_{\perp} sensor coils in the center of the array. The effect of false signals generated in the V_{\parallel} coils is theoretically zero, while the voltage generated in the V_{\perp} coils is about 0.134 V for 0.5 A at 10 kHz excitation in the cable. In practice, the known effects of the presence of the return cable are digitally subtracted from the data by the Central Processor.

The deployment of the return cable underneath each MBC is shown in figure 58.

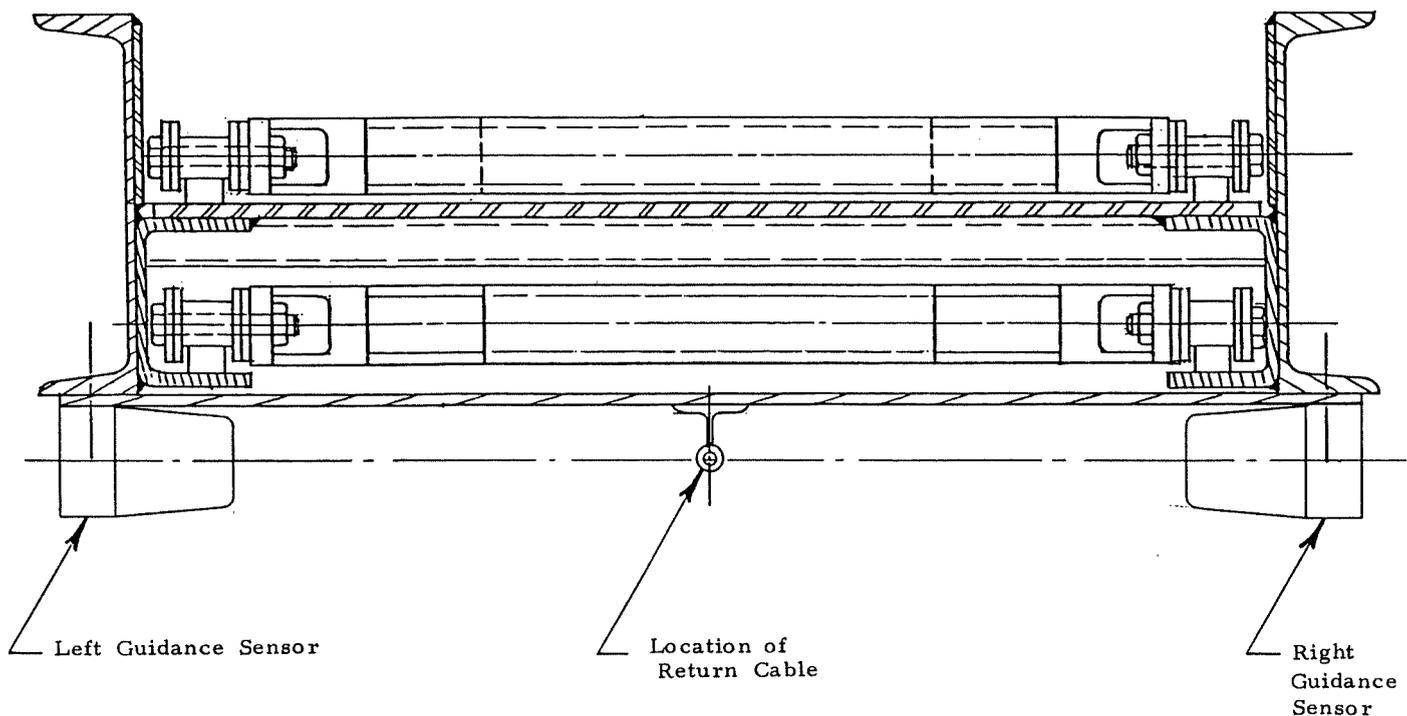


FIGURE 58. - Return cable deployment.

3.2.2.3 Sensor Preprocessing Electronics

Signals from the coils are in the form of ac sine waves at 10 kHz and range from one to several thousand millivolts in amplitude. These signals are amplified, filtered and rectified before being passed on to the control electronics. The phase relationship between signals from the two coils of a sensor pair are also observed and passed on to the controller. (This phase relationship will change by 180° as the sensor pair passes from one side of the guidance cable to the other. It is in this way that the direction of cable offset is determined.) Electronic circuitry for performing these operations is shown in figure 59.

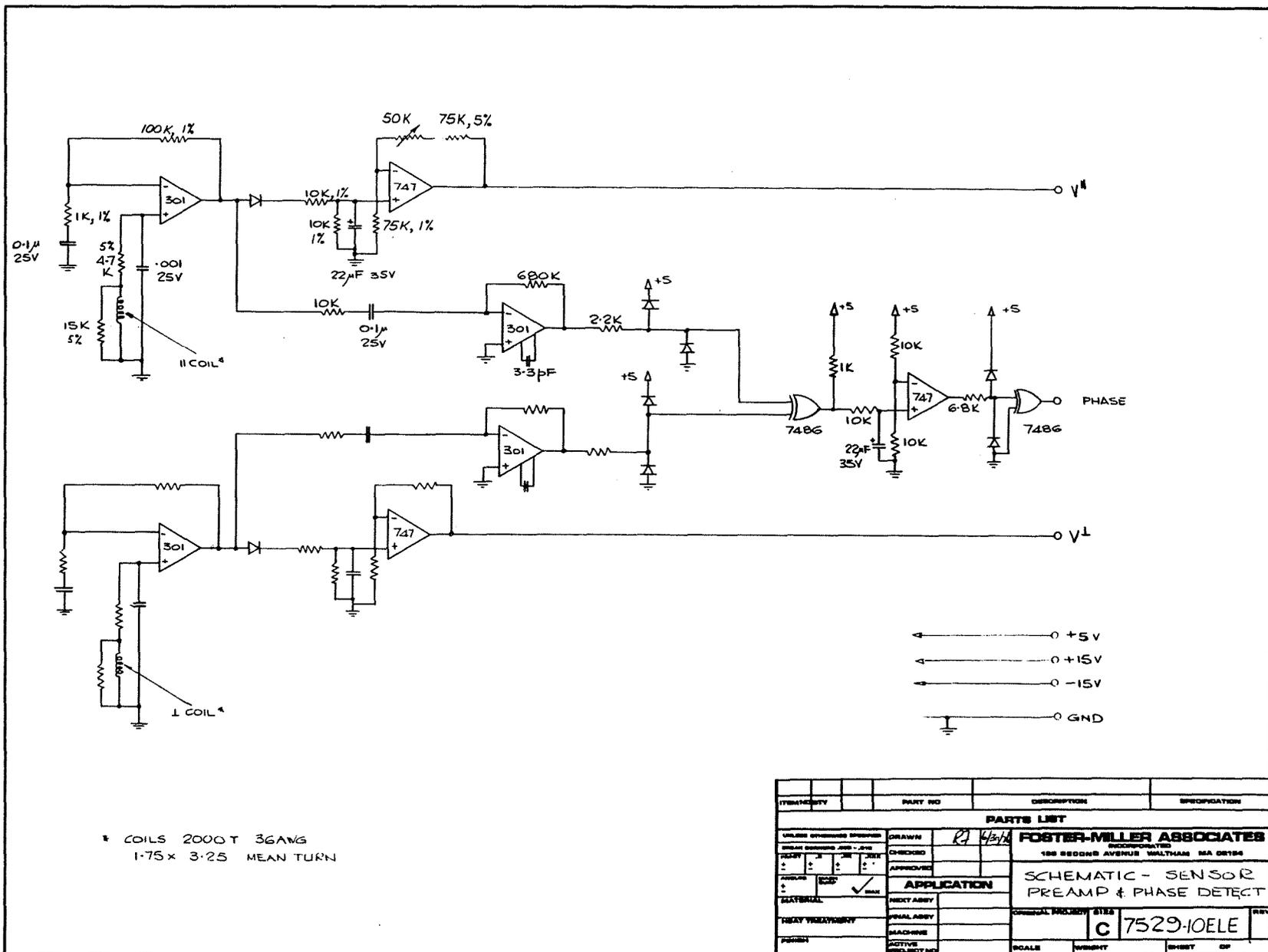
The first stage provides a filter with a peak gain of about 100 at a frequency of 10 kHz. At higher and lower frequencies, the gain falls off, helping to reduce interference from stray fields at other frequencies. A rectifier and smoothing circuit follows which produces a dc voltage equal to the ac peak signal. The smoothing circuit has a time constant of 200 ms; the purpose of this long time constant is to reject signal variations due to vibration of the conveyor structure. The time constant can be adjusted if necessary to accommodate the effects of structural resonances.

The next stage is a buffer whose purpose is to drive the line to the data interface package. This buffer is provided with a gain adjustment to ensure that all sensors of a set have equal sensitivities.

Amplified ac signals from the first stages of a sensor pair are also connected to the inputs of a TTL exclusive-OR gate; if the two ac signals are exactly in phase, the output from this gate will remain low. If they are exactly out of phase, the output will remain high. This stage is followed by a 200 ms time constant filter to eliminate spikes at the zero crossings of the ac signals, and a second TTL gate to provide an output buffer at TTL-compatible levels. This phase signal defines on which side of the cable the sensor pair lies.

The circuitry shown in figure 59 provides for one pair of coils; four sets are required for the array of sensors at each end of the vehicle. The complete set of four circuits is contained in an explosion-proof enclosure together with the tram motor drive circuitry. This enclosure is mounted near the wheel structure and is connected via rigid conduit to the main processing electronics enclosure.

FIGURE 59. - Schematic - sensor preamp and phase detect.



3.2.3 The Control Processor

The control processor takes the 16 sensor voltage inputs and performs calculations necessary to provide voltage outputs to servos which control vehicle motion. In addition, it accepts inputs from the dolly tram switches and makes decisions on when and at what speed to tram. It also provides for interaction with the operator.

An overall block diagram of the control processor is shown in figure 60. The data interface accepts, multiplexes, and digitizes the sensor inputs, and accepts control signals from the operator and the tram switches. Input of all data is under microprocessor control.

The microprocessor, an Intel 8080, performs all arithmetic, logical and input/output functions under program control. The output digital control signals are fed to the control interface, where they are converted to analog, demultiplexed and sent to the servos.

3.2.3.1 The Data Interface

There are 16 channels of sensor data from the preprocessor: 8 from the front sensor array and 8 from the rear sensor array. Each channel of data represents the peak value of the 10 kHz signal from the guidance cable as picked up by the sensor coil. These signals are sent to two chips of analog multiplexer (HI508A) as shown in figure 61. For each multiplexer, there are three address lines and one enable line which are digitally controlled through an output port of the microprocessor. Any particular channel of the analog sensor data can be selected by the microprocessor using the software driver.

When 1 channel is selected, the signal is available at the output line of the multiplexer. It goes through a summing junction of an operational amplifier (LM1458) and, finally, into the analog-to-digital conversion device (AD7570L). A start pulse from the microprocessor is needed to initiate the analog-to-digital conversion process and, in the meantime, the BUSY signal will be low to prevent the processor from accepting the data appearing at the input port. The moment BUSY goes high again, the conversion process is complete and good digital representation of the analog sensor data is presented to the input port of the microprocessor.

The digital signal is represented in the modified two's complement form. The analog-to-digital converter is configured to accept a bipolar (-10 to +10 V) signal with 10-bit resolution. However, the analog sensor input from the preprocessor ranges from 0 to 10 V. Therefore, only

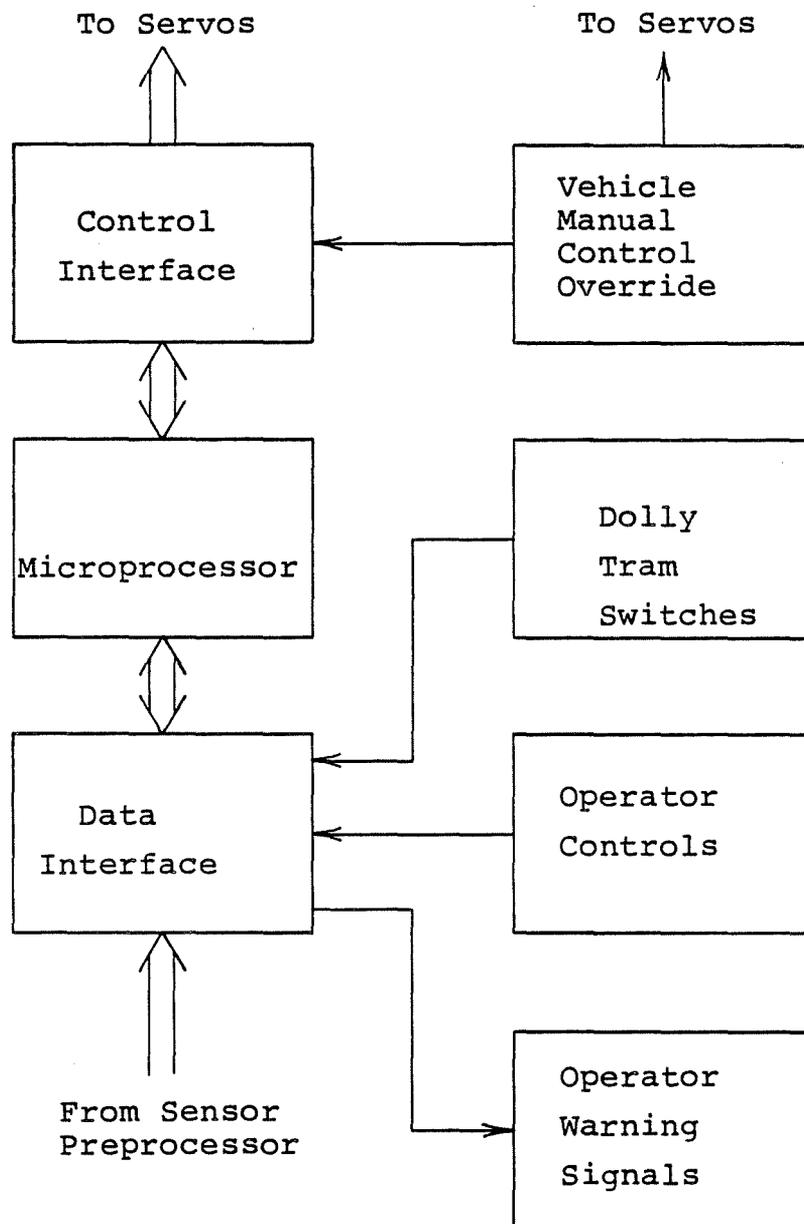


FIGURE 60. - Control processor block diagram.

nine bits are used, which effectively match the 0 to 10 V analog signal into one of the 0 to 511 integer numbers. The microprocessor obtains the digital data in two successive time frames with the low eight bits accessed by enabling the control signal line LBEN and the two most significant bits accessed by enabling the control signal line HBEN.

Signal lines for the two most significant bits are tied to the two least significant bits. This connection is possible because of the tri-state output design of the device. Similarly, the BUSY signal is also tied to the least significant bit and is enabled by the control signal BSEN.

At power-on, the level of all output ports is initialized high and, in order to avoid making all enable lines BSEN, HBEN, and LBEN high, an inversion is provided by 7402 NOR gates. (See fig. 61.)

Other features of the converter include diode protection against latch-up and damage to the chip, and an RC timing network to generate an internal clock for the conversion process: the resistance value is 33 kohms tied between +5 V supply and device pin 24; the capacitance value is 820 pf tied between pin 24 and the analog signal ground.

3.2.3.2 The Microprocessor

A functional block diagram of the microprocessor is shown in figure 62. The functions are:

- a. Data conditioning - The voltage measurements as obtained from the data interface port are not directly usable. They are subjected to certain gain, bias adjustments or sign changes based on factors such as the current amplitude in the return cable, and the geometric orientation or location of the individual sensor on the vehicle.
- b. Control variable calculation - These are the variables used to control the motion of the vehicle. A set of equations derived from the kinematic consideration of the vehicle are used.

The general problem of steering a four-wheel drive vehicle over a cable around a corner is depicted in figure 63. Here, a bridge carrier is shown moving around a corner. The fore and aft velocity vectors are shown as \vec{v}_1 and \vec{v}_2 . The vehicle's motion is \vec{v}_0 . The problem is to determine the correct angle at which to set each

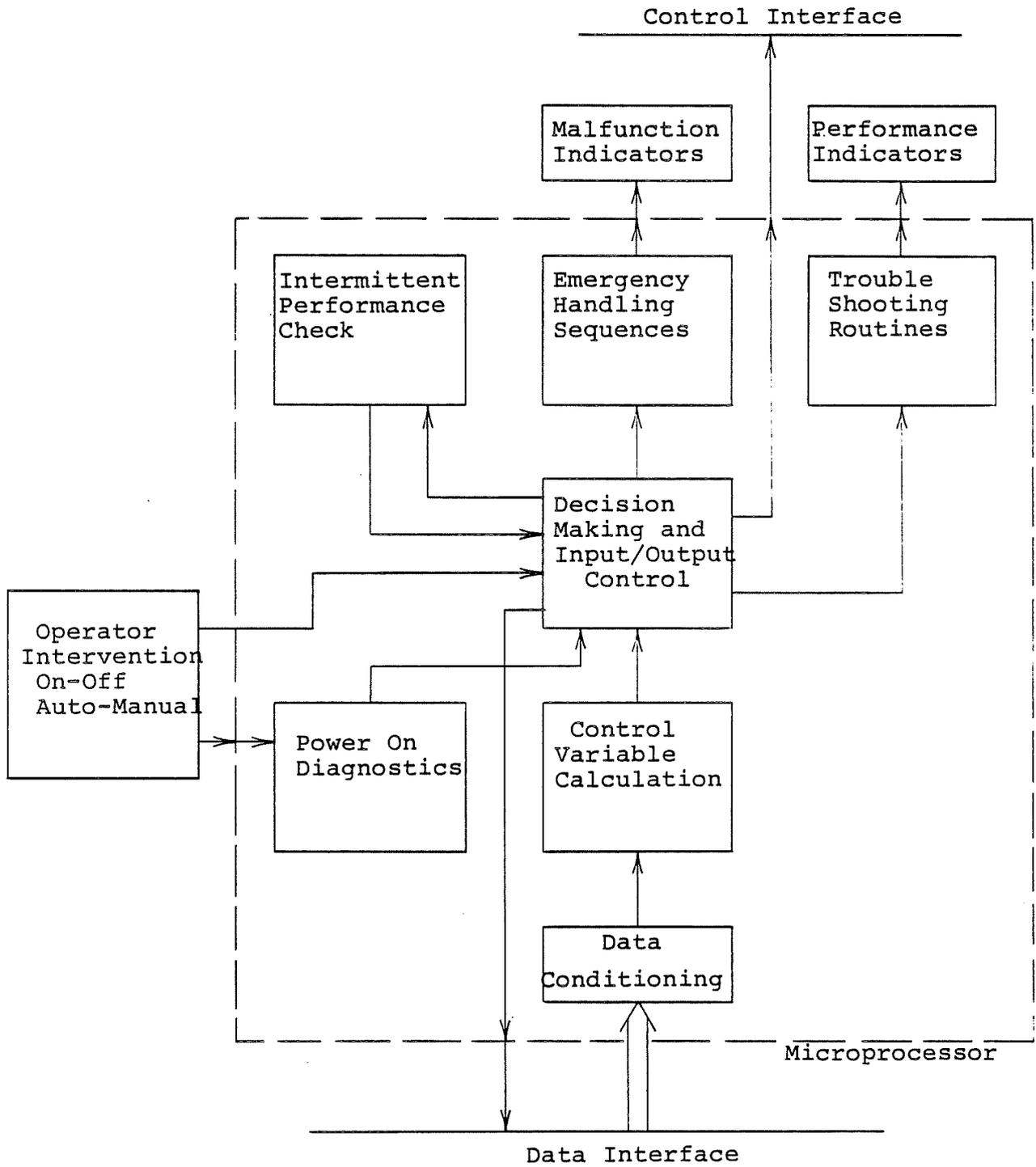


FIGURE 62. - Microprocessor block diagram.

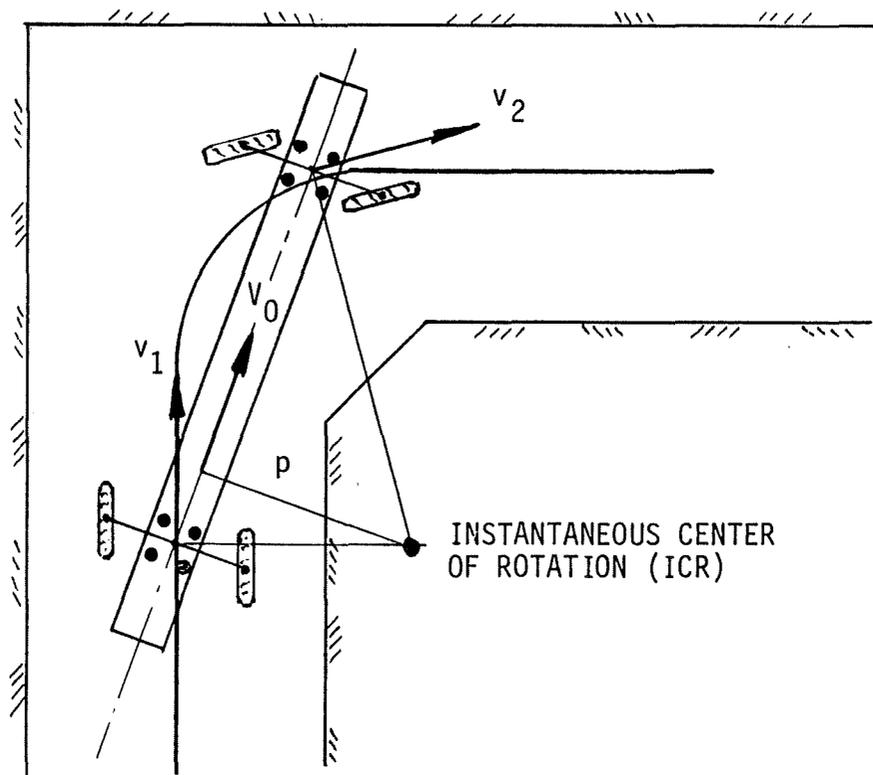


FIGURE 63. - General steering problem.

wheel and at what speed it should be driven, on the basis of our knowledge of its displacement from the cable, X , at each end of the vehicle and the cable angle ϕ .

The solution is as follows:

1. From the steering strategy developed earlier, we know that we want the sensor centers to move at these angles:

$$\theta_1 = kX_1 + \phi_1$$

$$\theta_2 = kX_2 + \phi_2$$

where the kX term will correct for displacements in the direction perpendicular to the vehicle and the θ 's keep the wheels parallel to the cable

2. We determine the instantaneous center of rotation by dropping perpendiculars from \vec{v}_1 and \vec{v}_2

3. A choice of V_0 to match the tramming speed of the miner will then directly determine what v_1 and v_2 must be. Further, from the fact that each wheel swings at instantaneous radii R_3 through R_6 about ICR, we can determine the correct angles θ_3 through θ_6 and the correct rotation speeds v_3 through v_6 . (See fig. 64.)

Calculation of θ_{3-6} and v_{3-6} is now simply performed:

$$l = p \tan \theta_1 + p \tan \theta_2$$

Let

$$q = (\tan \theta_1 + \tan \theta_2), \text{ then}$$

$$l = pq$$

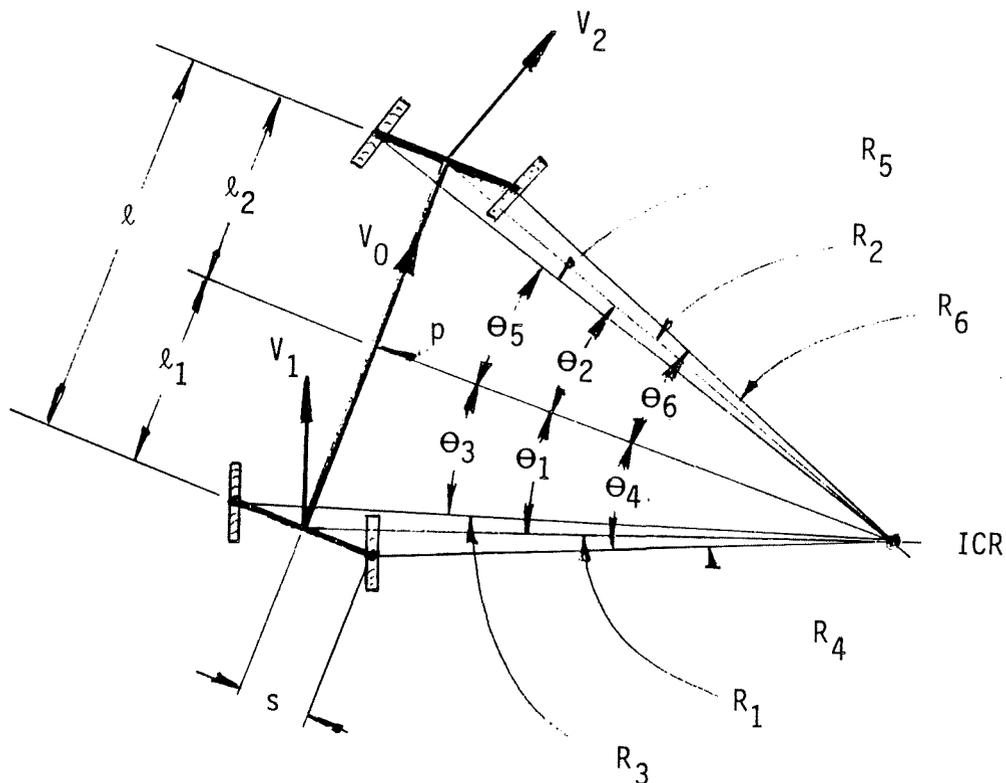


FIGURE 64. - Definition of coordinates for the solution to the general problem.

For a typical case

$$R_3^2 = (p + s)^2 + l_1^2$$

where s is the distance of the wheel hub from the vehicle centerline.

Now, since

$$R_1^2 = p^2 + l_1^2$$

$$R_3^2 = R_1^2 + 2ps + s^2$$

Also

$$R_1 = \frac{p}{\cos \theta_1}, \quad l = pq$$

So

$$R_3^2 = \frac{l^2}{q^2 \cos^2 \theta_1} + \frac{2sl}{q} + s^2$$

Since we are now considering motion about the ICR, we can write

$$\omega = \frac{v_1}{R_1} = \frac{v_2}{R_2} = \frac{v_3}{R_3} = \frac{v_4}{R_4} = \frac{v_5}{R_5} = \frac{v_6}{R_6} = \frac{V_o}{P}$$

Therefore

$$\frac{v_3}{V_o} = \frac{R_3}{p} = \sqrt{\frac{q^2 s^2}{l^2} + \frac{2sq}{l} + \sec^2 \theta_1}$$

The velocities v_{4-6} can be similarly derived.

The angles θ_{3-6} can be determined by noting

$$\tan \theta_1 = l_1/p$$

$$\tan \theta_3 = l_1/p + s$$

$$\tan \theta_4 = l_1/p - s$$

and

$$q = l/p$$

Some algebra gives

$$\cot \theta_3 = (1 + qs/l)\cot \theta_1$$

$$\cot \theta_4 = (1 - qs/l)\cot \theta_1$$

and the other θ 's can be derived in similar fashion.

In summary, the general steering control variables can be derived from the processed sensor inputs, θ_1 and θ_2 , and a knowledge of the desired straight-line tramping speed V_0 , and the formulas are:

1. Wheel velocities:

$$v_3 = V_0 \sqrt{a^2 q^2 + 2 a q + \sec^2 \theta_1}$$

$$v_4 = V_0 \sqrt{a^2 q^2 - 2 a q + \sec^2 \theta_1}$$

$$v_5 = V_0 \sqrt{a^2 q^2 + 2 a q + \sec^2 \theta_2}$$

$$v_6 = V_0 \sqrt{a^2 q^2 - 2 a q + \sec^2 \theta_2}$$

where $a = s/l$, the wheel-based width to length ratio.

2. Wheel angles:

$$\cot \theta_3 = (1 + aq)\cot \theta_1$$

$$\cot \theta_4 = (1 - aq)\cot \theta_1$$

$$\cot \theta_5 = (1 + aq)\cot \theta_2$$

$$\cot \theta_6 = (1 - aq)\cot \theta_2$$

In the above, q is the parameter linking the motions of the front and back wheels:

$$q = \tan \theta_1 + \tan \theta_2$$

- c. Decision-making strategy and input/output control - The computed values of the control variables are checked to prevent certain limits from being exceeded.
- d. Troubleshooting diagnosis - An invaluable capability, the processor can quickly identify faulty elements under its control and also check its own computational accuracy. This feature saves valuable time in real-time debugging and evolution of the control algorithm implementation by signalling operation faults on an indicator panel inside the controller enclosure.
- e. Emergency-handling sequences - During normal operation, the microprocessor performs the tracking function through the position sensor measurements. Should abnormal conditions occur, such as the vehicle moving too far away from the cable, the processor suspends its normal control loop and performs, instead, the necessary emergency sequences. In this example, within a few microseconds of completion of its current instruction, the microprocessor first sets the speed of all four wheels to zero and then triggers the alarm devices to notify the operator.
- f. Intermittent performance check - The status of each parameter within the microprocessor is stored for each iteration of the control loop. When something goes wrong during testing, the data will be available for reference to determine the nature and probable cause of the problem.

The microprocessor currently used on the ABCT consists of a CPU card with EPROM's containing the operating software, an I/O card with four 8-bit input ports and four output ports, and two analog devices RTI 1225 A/D-D/A cards. The latter contain two 8-bit D/A channels and sixteen 10-bit A/D channels.

The CPU card is a Prolog 7805 which uses a 8085A processor chip. The I/O card is a Prolog 7604.

All D/A channels are used to provide analog steering voltages for each wheel. Sixteen A/D channels are used for sensor inputs; one channel for each input.

3.2.3.3 The Control Interface

The output command from the microprocessor actually consists of sequences of operations for routing the eight-bit digital data from its output port to the servo controllers. There are two types of digital-to-analog conversions used; one, bipolar and the other, unipolar (see figures 65 and 66.)

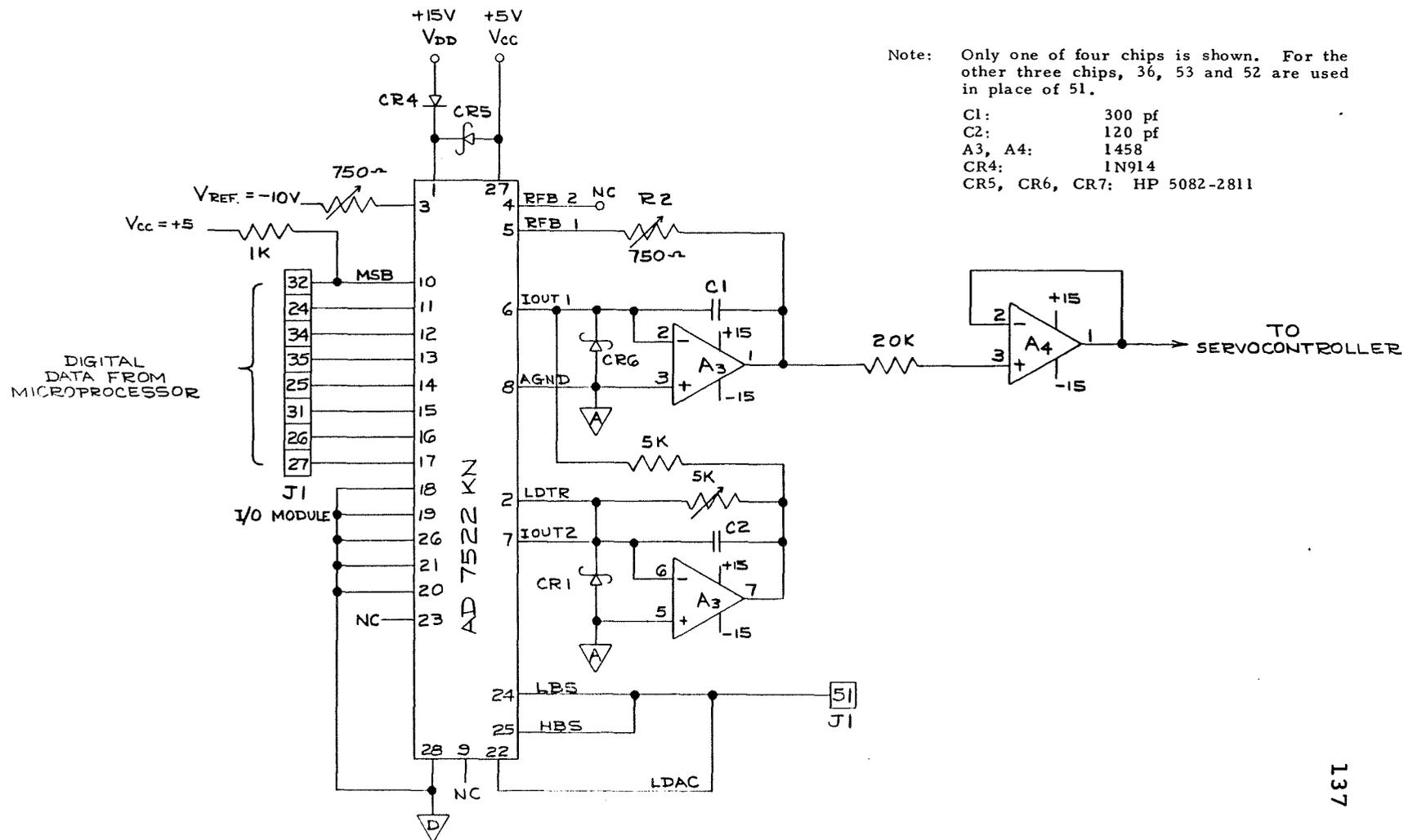
The unipolar digital-to-analog converter is used for the tramping control. The direction of rotation of the wheel is independently determined by two additional digital control lines. The bipolar digital-to-analog converter is used for steering control for either right or left turns. Other than this minor difference, the digital-to-analog conversion processes for both are basically the same.

The computed turning angles or speeds of the four wheels are successively sent out one at a time; the digital data is first presented at one output port by the microprocessor as indicated in the figures. A control signal is then needed to clock the digital data into the internal registers of the digital-to-analog conversion devices (AD7522) and to start the conversion process. The final output analog voltage which appears at one of the output terminals of the operational amplifier (LM1458) passes through a unity-gain isolation amplifier before reaching the servo controller. There are eight digital-to-analog conversion chips used to control the steering and tramping of the four wheels.

3.2.4 The Control Servos

Each of the four wheels on an MBC is provided with both a steering and a tramping servo which move it in response to signals from the control interface. These servos are described in this section.

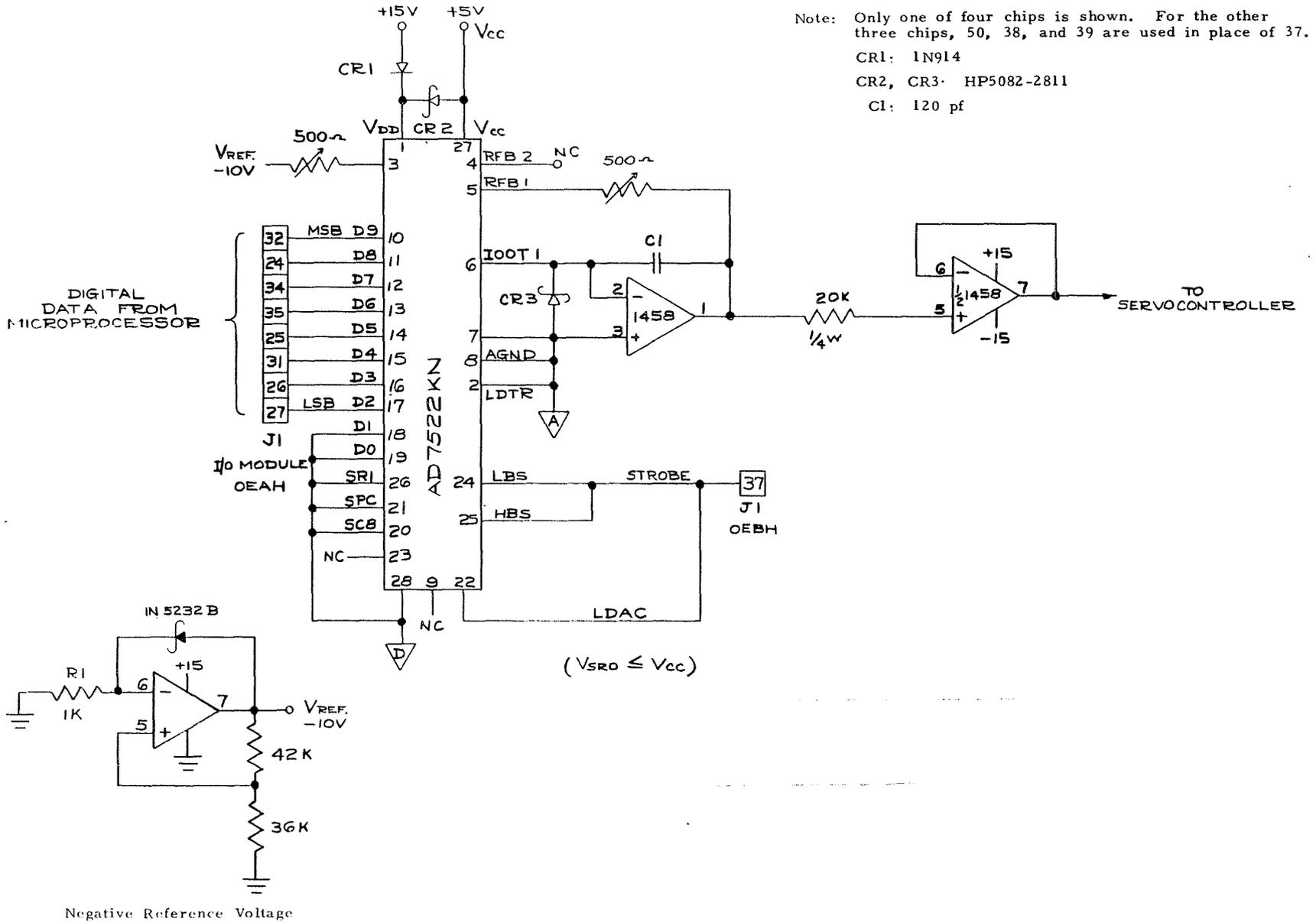
FIGURE 65. - Bipolar output interface for steering control.



Note: Only one of four chips is shown. For the other three chips, 36, 53 and 52 are used in place of 51.

C1: 300 pf
 C2: 120 pf
 A3, A4: 1458
 CR4: 1N914
 CR5, CR6, CR7: HP 5082-2811

FIGURE 66. - Unipolar output interface for
 cramping control.



Note: Only one of four chips is shown. For the other three chips, 50, 38, and 39 are used in place of 37.

3.2.4.1 Steering Control System

The block diagram in figure 67 shows the major parts of the steering feedback control system. Basically, the computed digital result from the microprocessor is first converted into equivalent analog voltages ranging from -10 to +10 V. It is then used as a reference input to the summing junction of an operational amplifier on the Moog 121-105 servo controller circuit board.

The signal subsequently passes through the compensation network and is applied to the valve solenoid of the hydraulic motor. The constant displacement motor (Moog model 25-R10) then drives the wheel steering mechanism through a shaft. This rotational movement then turns a potentiometer which provides a feedback voltage to be summed together with the incoming analog voltage. When the difference becomes zero, the solenoid valve closes and the steering motion stops. The steering voltage from the control interface uniquely determines the equilibrium steering angle of the wheel.

A schematic of the Moog servo controller is shown in figure 68. The compensation network, consisting of R_9 , R_{22} , and C_2 , was used to stabilize the cable tracking action during critical testing of the ABCT.

3.2.4.2 Tram Control System

The block diagram in figure 69 shows the major elements of the tram control system. Signals from the control interface consist of a 0 to 10 V analog speed signal and two digital lines to specify direction. These signals feed a Superior Electric Slo-Syn Translator module, type STM1800CV, equipped with voltage-controlled oscillator (VCO) and acceleration ramp options.

The VCO produces two phase pulse trains which drive the Slo-Syn section of a Washington Scientific electro-hydraulic stepper motor, model HD70-15. The acceleration ramps force the frequency from the VCO to change at a controlled rate to prevent the Slo-Syn from losing pace with the translator.

3.3 THE OPERATOR'S CONTROL SYSTEM

This section discusses the means by which the ABCT interacts with its operators. In particular, it covers:

- a. The panel indicators and control switches
- b. The start-up and shutdown circuits

FIGURE 67. - Steering control system.

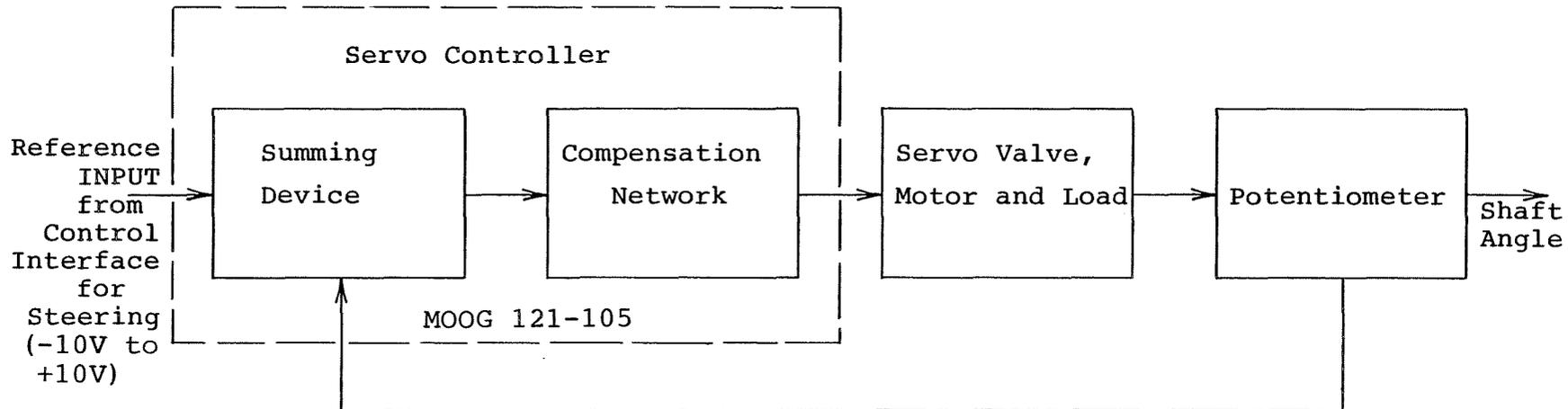


FIGURE 68. - Servo controller.

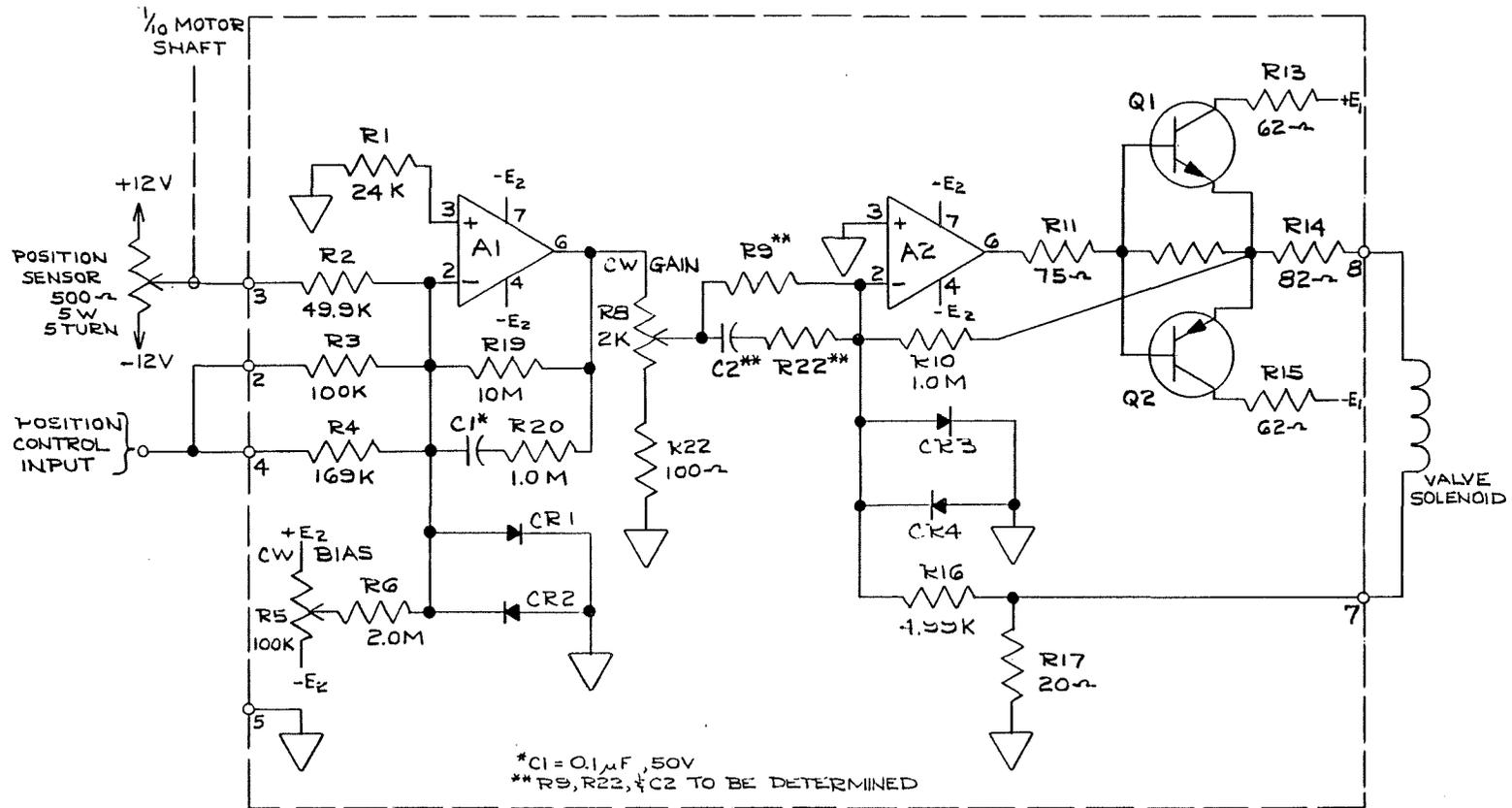
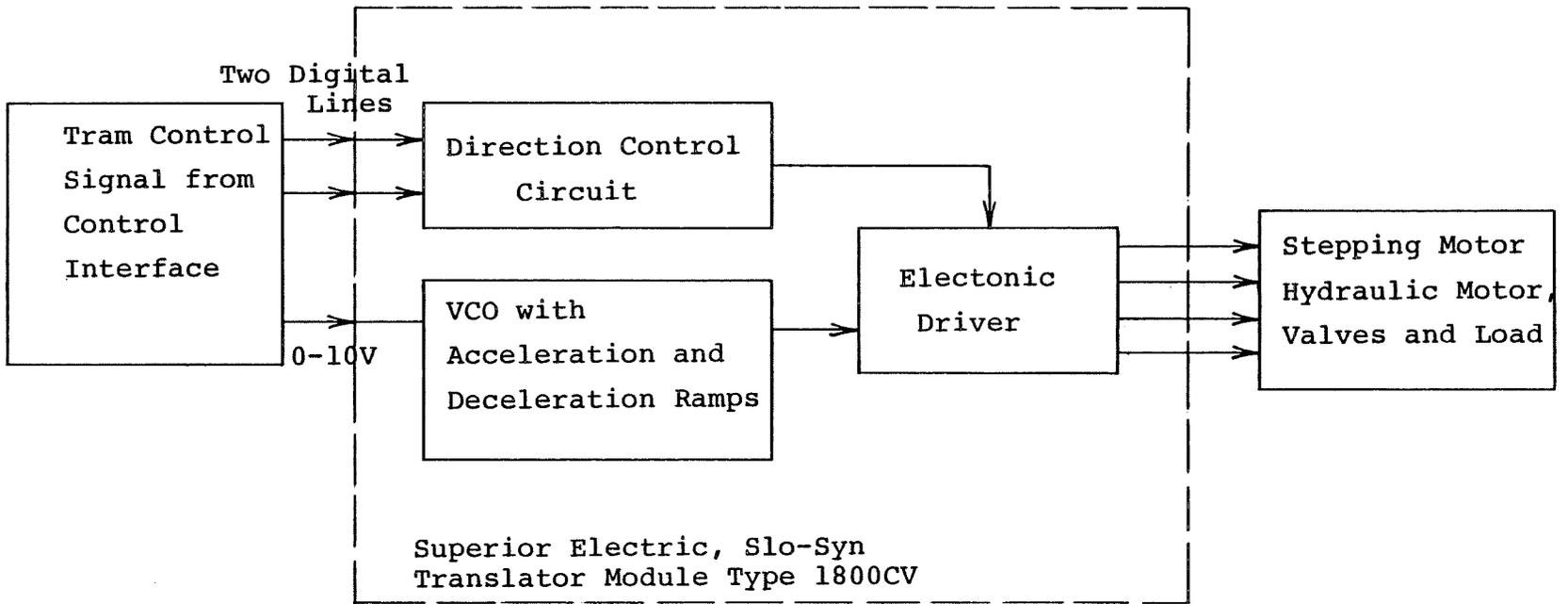


FIGURE 69. - Trammimg control system.



- c. The manual controller, used to tram and steer an MBC independently of the automatic guidance system
- d. The dolly position switches, used to signal the guidance system that a tramping motion is required.

Figure 70 is a schematic of this system.

3.3.1 The Control Panels

The system has two control panels; one each at the inby and the outby ends. In underground operation, the inby operator will be in close communication with the miner operator, while the outby operator will monitor operation of the panel belt and the associated transfer point. A telephone will be provided for communication between the operators, with intermediate stations along the length of the ABCT.

The question of which of these operators should have control over what functions of the ABCT may ultimately be decided on a mine-by-mine basis. It was decided that, for the prototype system, the division of responsibilities would be as follows:

- a. Inby operator
 - 1. Tram and steering control of the lead carrier
 - 2. Start-up of the hydraulic system
 - 3. Normal shutdown of the hydraulic system
 - 4. Reset of the conveyor tramping and guidance system fault latches
- b. Outby operator
 - 1. Start-up of the conveyor motors
 - 2. Normal shutdown of the conveyor motors.

Mine-specific factors may require a different division for efficiency or safety; for this reason, we designed one control panel which implements all controls and indicators. One of these panels is located at the inby and one at the outby operator stations. The unused controls can be disabled and blanked off. Changes can easily be made as required. A drawing of the control panel is shown in figure 71.

FIGURE 70. - Schematic of operator's control system.

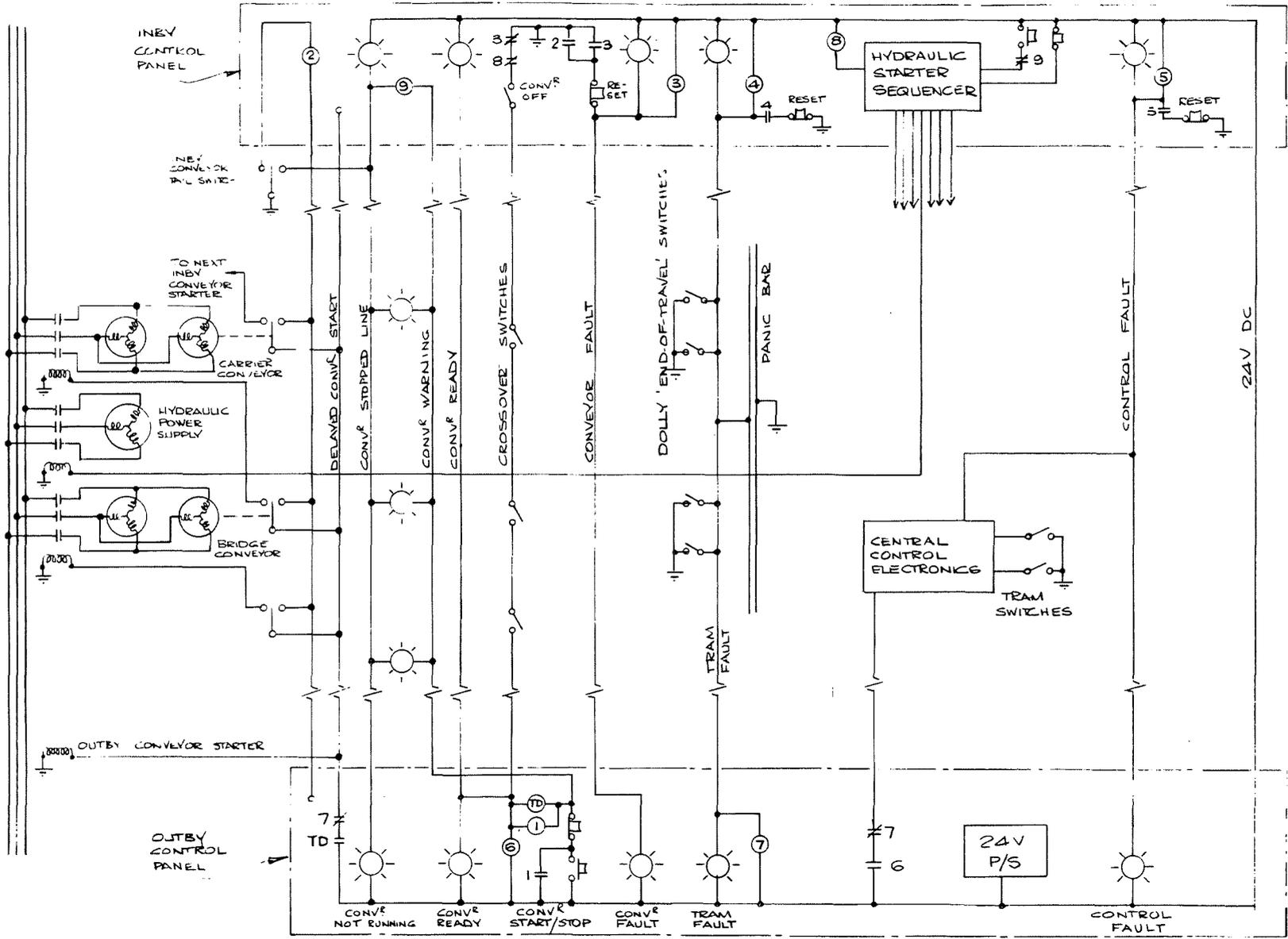
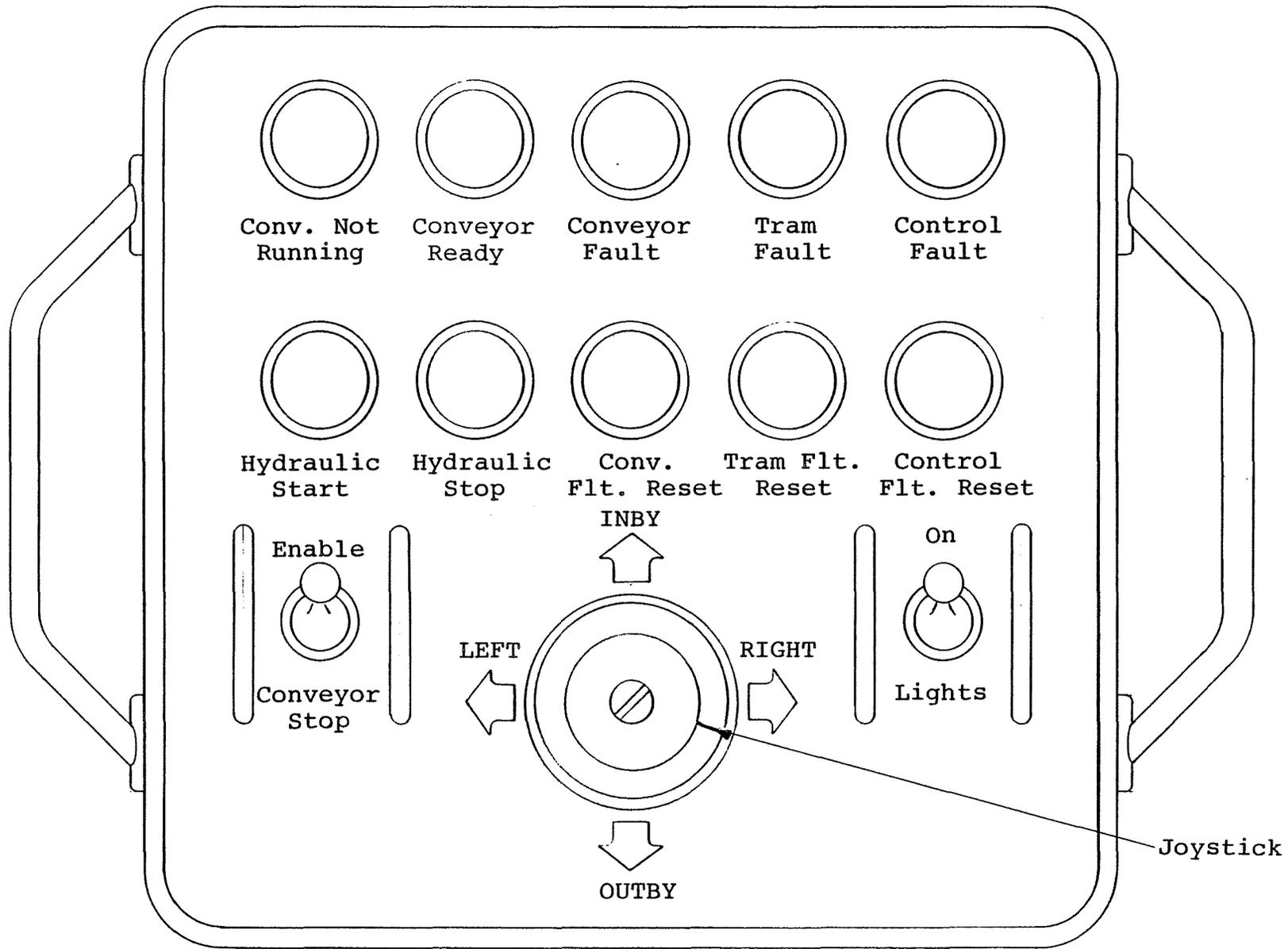


FIGURE 71. - Tram and steering control.



3.3.2 Start-Up and Shutdown

Sequence start-up of the motors throughout the length of the ABCT is essential, for two reasons: first, to limit the peak current demand and allow use of smaller cables than would be necessary if all motors were started simultaneously; and second, in the case of the conveyor drive motors, to ensure that all outby sections of the conveyor are running before the next inby section is started. As far as maximum peak current is concerned during start-up, it makes little difference whether the hydraulic pump motors or the conveyor motors are started first, but the circuit is designed such that if one system is starting, the other cannot be initiated until the sequence of the first is complete. (See fig. 70.)

The hydraulic power supply motors are started by a single push button at the inby operator's control panel. This push button actuates an automatic sequencer which starts the hydraulic power supply motors in order, beginning at the inby end. In order to keep the design of the sequencer simple, it operates on a simple elapsed time basis, each motor being started at a fixed time delay after the previous one. Since the hydraulic motors all start off under a no-load condition, their start-up time is very consistent.

Control of the start-up of the conveyor motors is given to the outby operator, but his control must be enabled by the inby operator. If the inby "Conveyor Enable" switch has been activated, the outby conveyor start switch will start the conveyor motors sequentially, commencing at the outby end. The sequencing here is automatic. Each conveyor motor starter is inhibited until the next outby conveyor is up to speed. This sequence control is generated by the tail shaft speed switch attached to the next outby conveyor. The sequencing delay is inherent in the time taken by a conveyor to come up to speed, close its tail shaft speed switch, and start the next inby conveyor.

Normal shutdown, not in emergency conditions, is accomplished in a similar way; the hydraulic pump motors being stopped from the inby operator's control panel by means of a push button and the conveyor motors by means of a push button located at the outby operator's panel. In the case of shutdown, sequencing is not necessary and all motors stop simultaneously.

3.3.3 Panic Bars and Crossover Switches

Panic bars are installed along the length of both sides of the ABCT. Actuation of any panic bar causes immediate shutdown of all conveyor and hydraulic motors.

Prior to underground testing a series of switches is to be placed at points along the ABCT where it would be convenient for a man to cross from one side of the unit to the other. When one of these crossover switches is opened, it will be impossible to start the conveyors, and tramming will be inhibited at the microprocessor (the hydraulic supplies remain active). If the system is running when a crossover switch is activated, both conveyors and tramming will stop. After the man has crossed over the conveyor, he must close the crossover switch for start-up to occur normally.

3.3.4 Conveyor Jam

Should a conveyor chain breakage or jam occur, the corresponding tail shaft speed switch will be opened. This brings about a shutdown of all inby conveyor sections and a red "Conveyor Not Running" light appears at both the inby and outby operator's control panels. (This light is on at any time when the conveyor is not running.) Under these conditions of conveyor failure, an amber, "Conveyor Fault" light also becomes illuminated on both operator's control panels. This lamp is latched in until a "Conveyor Fault Reset" button is pushed from the inby operator's panel.

3.3.5 Tram Control

The inby end of each bridge unit is mounted in a sliding dolly which permits it, during operation, to slide a distance of 39 in. relative to the next inby carrier unit. Within this 39 in. length is placed, a sequence of four limit switches which provide the tram control for the next outby carrier unit. The arrangement of these tram control switches is shown in figure 66. When the bridge is sitting centrally within its range of movement, that is when the switch actuator is between the two inner switches, B and C, of figure 72, tramming is inhibited and the adjacent inby carrier moves further inby. The dolly will be drawn along the bridge until switch C is activated. This will send a command to the microprocessor in the adjacent outby carrier unit which will: (a) close the dump valve on the hydraulic power supply so that pressure will build up to the full 1,500 psi; and (b) send speed commands to the four wheels of the carrier unit instructing it in which direction and at what speed to tram. The outby carrier unit will then tram inby so as to

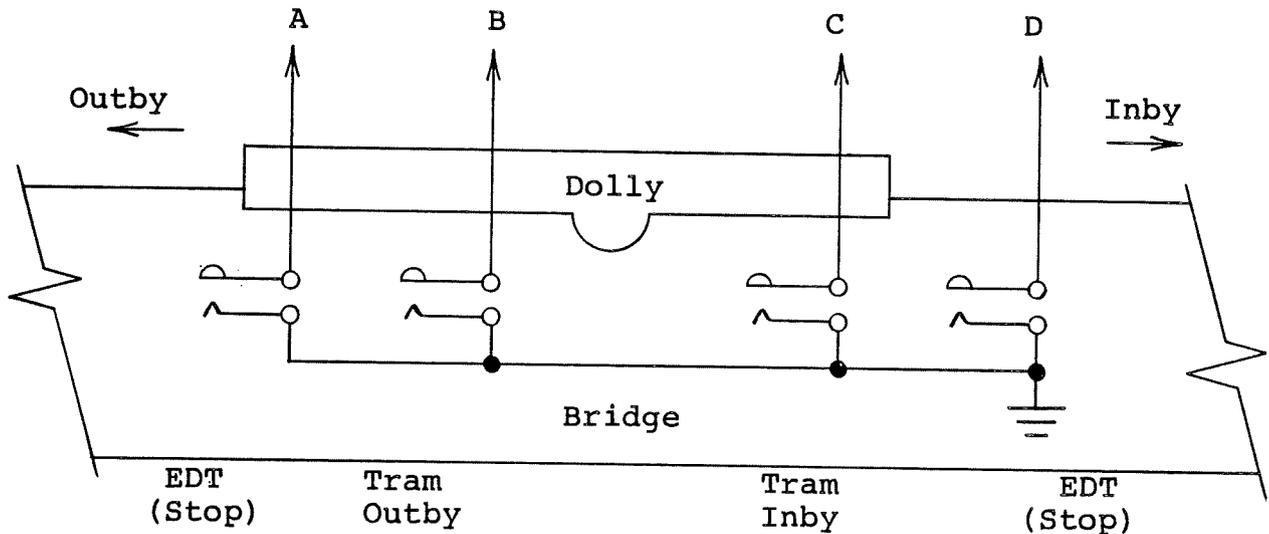


FIGURE 72. - Location of dolly switches.

slide the bridge back toward the central position within the dolly. Similarly, should the inby carrier tram in an outby direction so as to activate switch B, the next outby carrier unit will be instructed to tram in an outby direction, again returning the bridge to the center location.

To prevent erratic motion of carriers, a time delay is incorporated. Once one of the switches has caused a tram or stop operation, that state will be maintained for approximately 1 s before another state change can occur. In addition, once the hydraulic system has been switched into high-pressure condition, it will be maintained in that condition for about 5 s. These two time delays reduce wear and high inertial stress on the tram components.

Should the outby unit be unable to keep up with the inby unit, the bridge will move outside the central range of its travel within the dolly, and will eventually encounter one of the end-of-travel switches A or D. Activation of either of these switches will override the microprocessor tram control circuit and stop all tramping throughout the ABCT. It will also illuminate a flashing red tram fault light at both inby and outby control panels.

3.3.6 Independent Manual Control

It will be necessary on occasion to move the ABCT as a whole, or to move individual bridge-carrier pairs manually, without benefit of a guidance cable. This will happen, for example, when entering a new section, or in the event of a failure in the control system.

A portable control box has been designed for this purpose (see figure 73). To provide control motions, this box requires only that the hydraulic system be operational. It plugs into the carrier electrics, and can be mounted at the approximate center on either side of the carrier structure. It provides two controller handles, one steering the inby wheels and the other steering the outby wheels. Each handle is provided with a button lying under the operator's thumb; depressing one button causes the conveyor to tram in an inby direction, while the other causes tramping outby. A mechanical interlock prevents both buttons from being pressed simultaneously.

The electrical schematic of the manual control unit is shown in figure 74. A multi-pole switch in the central control enclosure is used to disconnect all servo control lines from the microprocessor and reconnect them to the manual control unit, which is plugged into the central control enclosure by means of a multi-pin connector. Inside the unit is a low-voltage, regulated power supply which derives the necessary dc control voltage from the 1,000 V ac supply.

Analog steering and tramping control signals are obtained by means of potentiometers operated by the hand levers and push buttons. These signals are equivalent to those which would normally be generated by the data interface section of the microprocessor. A separate manual switch is used to put the hydraulic circuit in the operational (high pressure) or standby conditions. In the event of total failure of the hydraulics, the planetary reducers driving the wheels may be put into neutral or free-wheel condition and the unit towed into an inactive area using a miner or shuttle car as a tractor.

3.4 HEALTH AND SAFETY REQUIREMENTS

3.4.1 Electrical

All equipment is designed to comply with schedule 2G and illumination requirements appearing in Federal Register, volume 41, no. 64. Individual areas which have received specific consideration are detailed below.

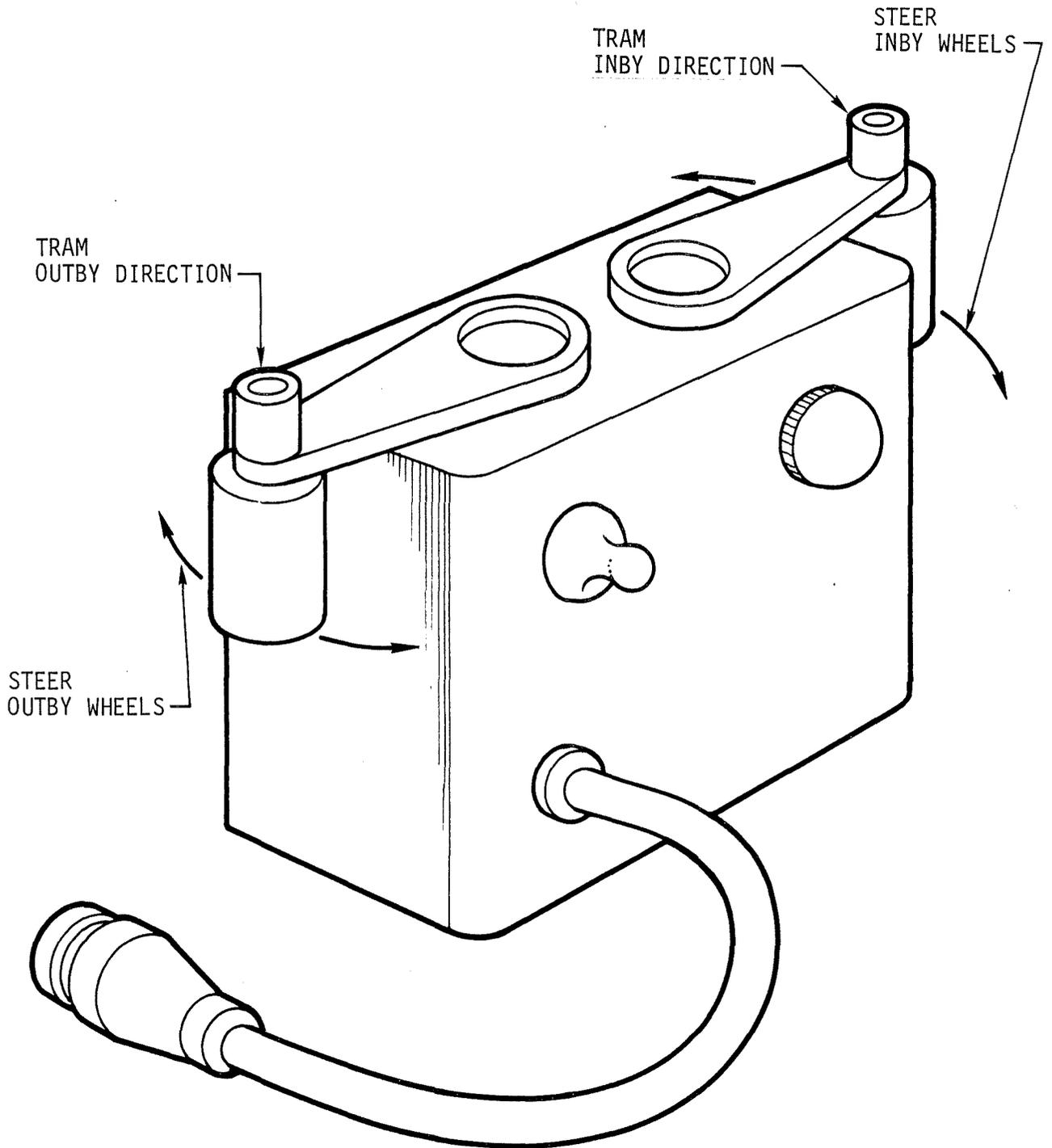


FIGURE 73. - Portable, manual control box.

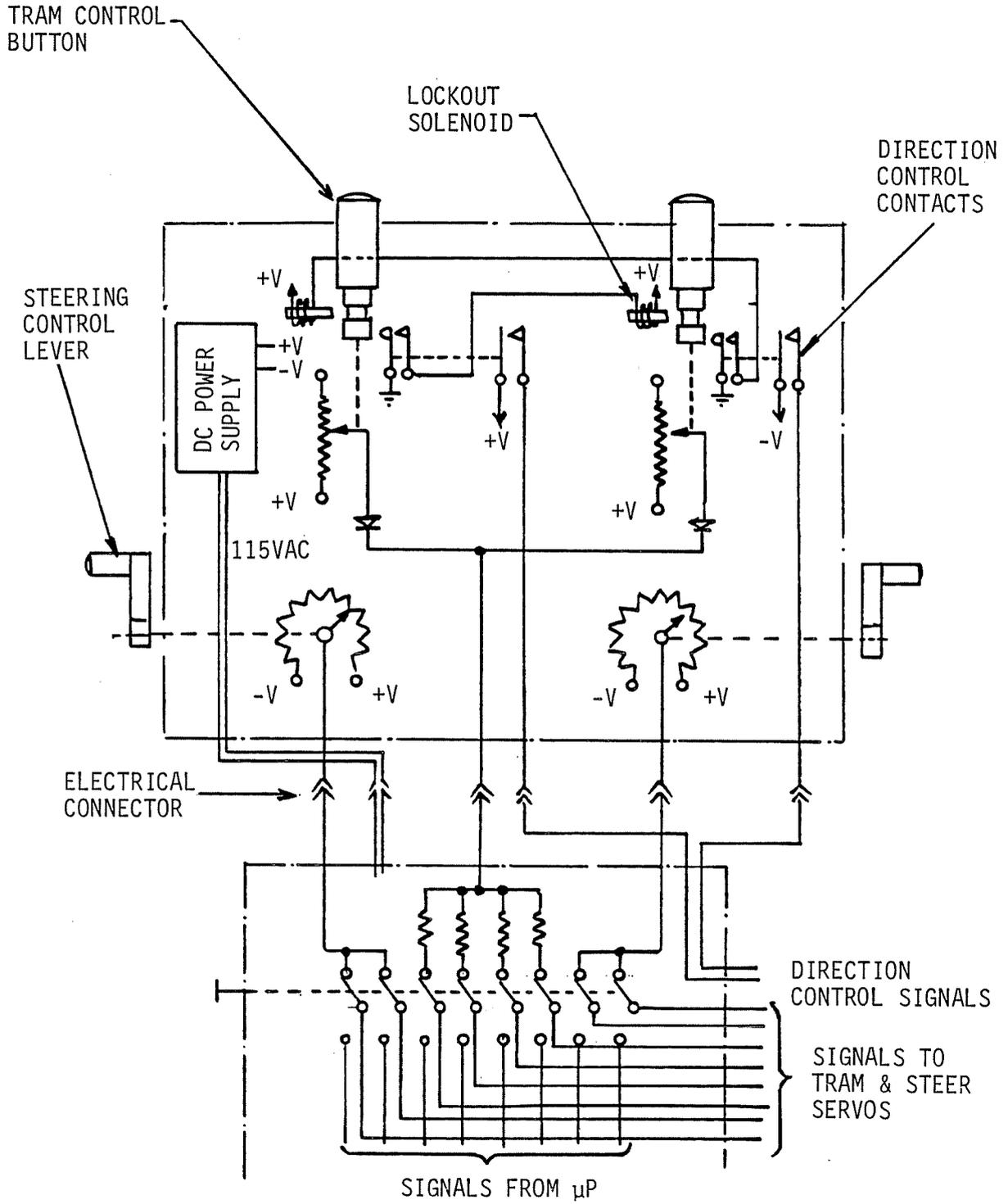


FIGURE 74. - Manual control box schematic.

Wherever possible, commercial equipment is incorporated which has already received approval from the MSHA, and where this is not possible, deviations from such standard practice are minor.

The high-voltage connections between components on the conveyor system are constructed using portable mining cable, U.S. Steel TB2-442. All switch gear, starters, and controls are mounted in steel explosion-proof enclosures made by Long-Airdox Corporation. The enclosures are drawn from their designs which have already been certified by MSHA.

Approved, mine-rated motors for the conveyor drive and hydraulic pump drive were supplied by Reliance Electric Corporation.

Tramming motion of the carrier is initiated by limit switches attached to the dolly riding along the bridge. These limit switches are proximity sensors manufactured by R.B. Dennison Corporation; they are certified as intrinsically safe by MSHA.

A speed switch connected to the tail shaft of each conveyor, ensures correct sequential starting of the conveyor sections. It is the Hubbel Industrial Controls Division model 2200, type PR, approved by MSHA.

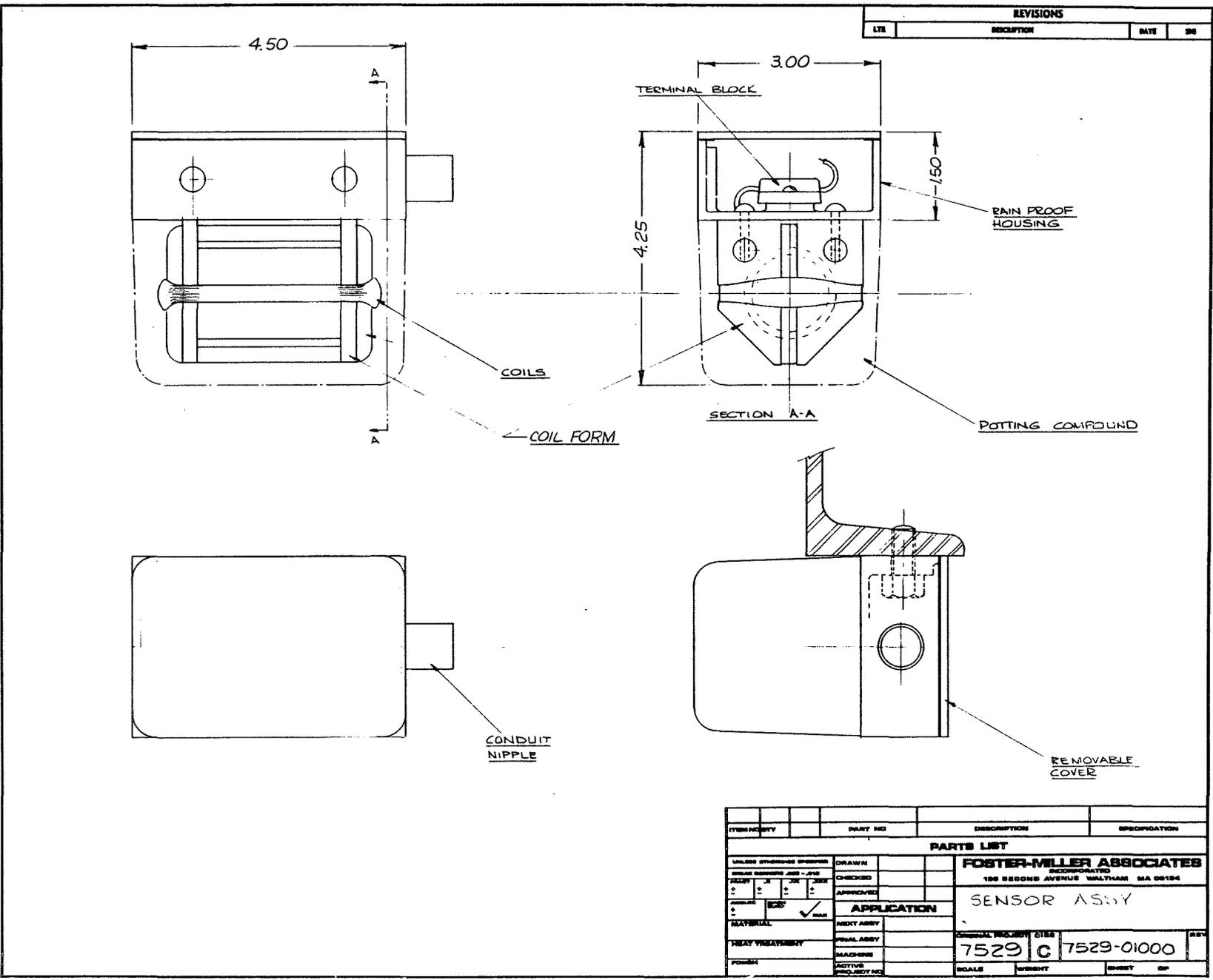
3.4.1.1 Guidance Sensors

In the sensor preprocessor schematic (fig. 75), the sensor coil is connected to the input of an operational amplifier via a 4.7K resistor. In view of the low potential power level at which the sensor operates, it is intended that this component be certified as intrinsically safe prior to underground use.

Since enclosing this sensor in a metal case has serious adverse effects upon its performance, we elected to encapsulate the coils in a hard, rugged plastic of substantial proportions (see fig. 76). The plastic is an epoxy formulation, Epo-Tek no. 509F. Connections to the coil are made in a small weather-tight enclosure attached to the back of the encapsulated assembly.

Assuming that intrinsically safe certification is obtainable, no difficulty is anticipated with this unit. The circuitry for processing the signals from the sensors before passing them on to the microprocessor is enclosed in an explosion-proof housing placed near the sensor array.

FIGURE 76. - Sensor package.



REVISIONS			
LTR	DESCRIPTION	DATE	BY

ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
PARTS LIST			
<small>UNLESS OTHERWISE SPECIFIED</small> <small>UNLESS OTHERWISE SPECIFIED</small>		FOSTER-MILLER ASSOCIATES <small>INCORPORATED</small> <small>188 BECONC AVENUE WALTHAM MA 02154</small>	
<small>DRAWN</small> <small>CHECKED</small> <small>APPROVED</small> <small>DATE</small>	<small>DATE</small> <small>BY</small> <small>BY</small>	SENSOR ASSY	
<small>APPROVED</small> <small>DATE</small>	<small>APPROVED</small> <small>DATE</small>	<small>ORIGINAL NUMBER</small> 7529 C	<small>REV</small> 7529-01000
<small>MATERIAL</small> <small>TREAT TREATMENT</small> <small>FINISH</small>	<small>NEXT ASSY</small> <small>PREL ASSY</small> <small>MACHINE</small> <small>ACTIVE PROJ. NO.</small>	<small>SCALE</small> <small>WEIGHT</small> <small>SHEET</small>	<small>OF</small>

3.4.1.2 Panic Bars and Crossover Switches

Panic bars are installed on both sides of the ABCT, on both MBC and bridge units. In addition, a crossover switch is placed on each carrier unit just ahead of the inby wheel assemblies. At this point, the conveyor structure is low; a relatively unimpeded crossover point is available. Once the panic bar or crossover switch has been activated, the conveyor and tram functions will stop throughout the entire ABCT. It is not possible to reactivate either function until the crossover switch on the affected carrier unit has been placed in a reset position, at which time the operator at the inby end may restart the conveyor and the hydraulic drive motors.

3.4.2 Fire and Dust Control

Fire resistant fluids are used throughout the hydraulic system.

Dust control water sprays are supplied at each transfer point between successive bridges and carriers. Water for the dust control sprays is supplied by a low-pressure hose running the length of the ABCT. This hose also supplies water for dust control sprays at the miner itself.

3.4.3 Noise

The ABCT has been designed wherever possible to minimize noise generation. In addition, provision has been made for investigating several techniques for reducing noise transmission to the surrounding environment. In particular, these consist of:

- a. Using composite materials for the belly pan to eliminate noise from the return strand of the conveyor train and flights
- b. Enclosing the hydraulic pump and its associated motor and valving in a soundproof enclosure
- c. Using sound-deadening materials, such as polyurethane and high-density polyethylene, for lining the conveyor pan itself.

4. CRITICAL TESTING

The previous section detailed the design from which two double-unit sections of the ABCT were fabricated by Long-Airdox of Oak Hill, WV. Upon completion of the units, preliminary testing exposed certain deficiencies which were corrected prior to shipment of the equipment to the Mining Equipment Test Facility (METF) in Bruceton, PA. In Bruceton, the system underwent more extensive testing between November 1979 and September 1980.

This section describes the testing program in two sections:

- a. Section 4.1 covers preliminary tests at the manufacturer's facility and subsequent modifications to the units
- b. Section 4.2 details the surface tests conducted at the METF.

4.1 PRELIMINARY TESTING AND MODIFICATIONS

Testing at the Long-Airdox facility was quite limited (approximately 2 weeks), due in part to the short test area, but it exposed several features needing redesign prior to any meaningful tests in Bruceton. They included:

- a. Cable Deployment System Redesign
- b. Add Coal Deflectors
- c. Add Oil Coolers and Hoses.

These modifications and additions are discussed in the following subsections.

4.1.1 Cable Deployment System Redesign

Operation of the cable deployment system is crucial if the machine is to be operated in the automatic mode. The original design suffered from cable jams within the pancake drive. A new design was conceived and implemented to alleviate this problem.

4.1.1.1 Pancake Drive Redesign

The original design consisted of a large wheel and three smaller spring-loaded wheels which forced the cable against the periphery of the large wheel. The large wheel was driven by a hydraulic motor through a chain drive. This system is schematically shown in figure 77.

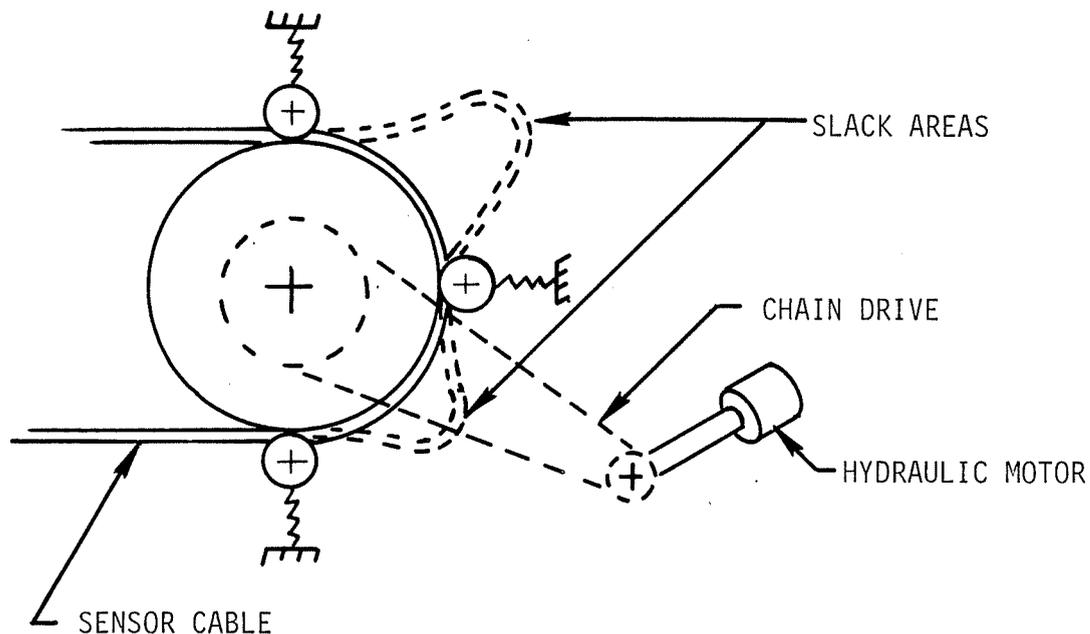


FIGURE 77. - Original pancake design.

Examination of the figure shows slack that developed between the small wheels. This condition resulted in sensor cable jams.

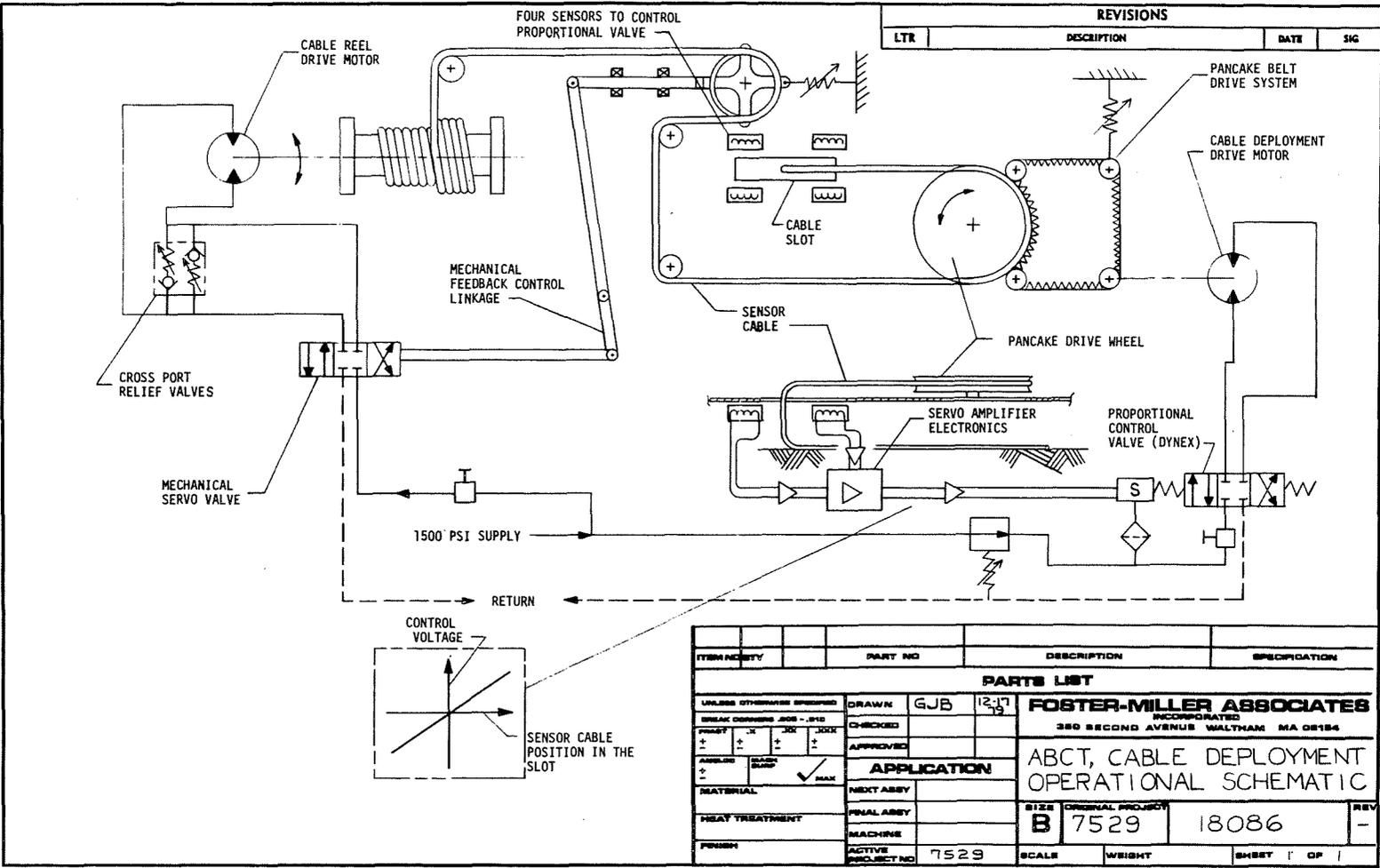
To overcome this problem, a new concept was designed, built, and installed. Figure 78 is the operational schematic of the new design. The three small wheels have been replaced with a timing belt which maintains a constant pressure against the large wheel over approximately 180° . The large wheel drive was also changed from a chain to a direct belt drive.

With this design the cable has less chance of jamming, and the friction necessary to drive the cable is increased because of the continuous wrap of the timing belt. With the larger wrap area, the design is much more tolerant of dirt than was the original design. This design also allows an oversized cable splice to pass through the system. This was not the case previously.

4.1.1.2 Cable Deployment Sensor Redesign

The original design (as described in section 3.1.10.2) used four large sensors to detect the cable position and shape as it exited the pancake drive system. The sensors were identical to those used to locate the cable near the

FIGURE 78. - Operational schematic of new design.



drive wheels of the carrier. Although the sensors worked well electrically, their size prohibited continued use for this application. There was only 2 in. of clearance between the bottom of the sensor and the ground, and this was only true where the ground was flat. It was obvious that these sensors would not survive severe floor conditions.

To alleviate the clearance problem, much smaller sensors were designed and built. The design utilized the same principle as in the large sensor design. However, the small sensors have only one coil each and provide 4 in. of ground clearance. Additionally, the new design is protected by a rugged steel cage. Figure 79 shows the sensors and protective cage.

4.1.1.3 Pancake Drive Relocation

The original machine design had the pancake drive located between the inby pair of wheels and on the longitudinal centerline of the inby carrier. This worked well when the machine trammed in a straight line or when gentle curves were attempted.

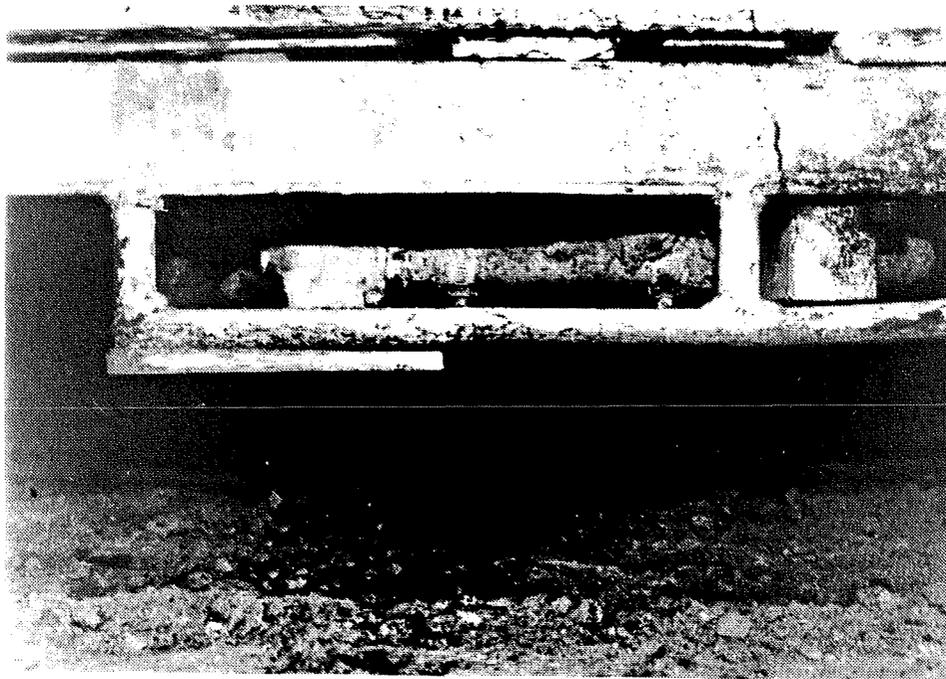


FIGURE 79. - Small sensors and protective cage.

However, when there were large cable offsets that were a result of making tight turns, the wheels would occasionally ride over the sensor cable before the pancake had a chance to pick it up.

To correct this problem, the pancake drive system was relocated 18 in. outby from the centerline of the inby wheels. This position allowed the system to pick up the cable before the wheels could run over it. Both positions are shown in figure 80.

4.1.2 Add Coal Deflectors

The first coal haulage tests at the Long-Airdox facility showed the need to add coal deflectors in two locations.

Some spillage occurred at the sides of the bridge where it begins the upward sloped ramp towards the outby end. Figure 81 shows the pivoted coal deflector on the bridge.

The pivot was necessary to allow the bridge to be stored completely under the carrier. If the inby end of the deflector did not fold back, it would hit the dolly during the storage operation.

The second area that required deflectors was just outby where the coal entered carrier no. 2. One piece of steel 6 in. high was added to each side. The pieces run between the yoke and the main side boards of the carrier. Figure 82 shows this configuration.

The addition of these deflectors eliminated much of the spillage problems.

4.1.3 Add Oil Coolers and Hoses

Another problem discovered at Oak Hill was that the oil reservoir on the carriers was not of sufficient size to provide adequate cooling of the oil. Calculations had shown that 70 gal of oil should be adequate to keep the oil temperature below 160°F. However, upon running preliminary tramming tests, the oil temperature was checked and found to be over 200°F.

To solve the problem a Modine liquid-to-liquid shell-and-tube type heat exchanger was added to each of the two carriers. Figure 83 shows a heat exchanger mounted to a plate on the underside of the oil filter.

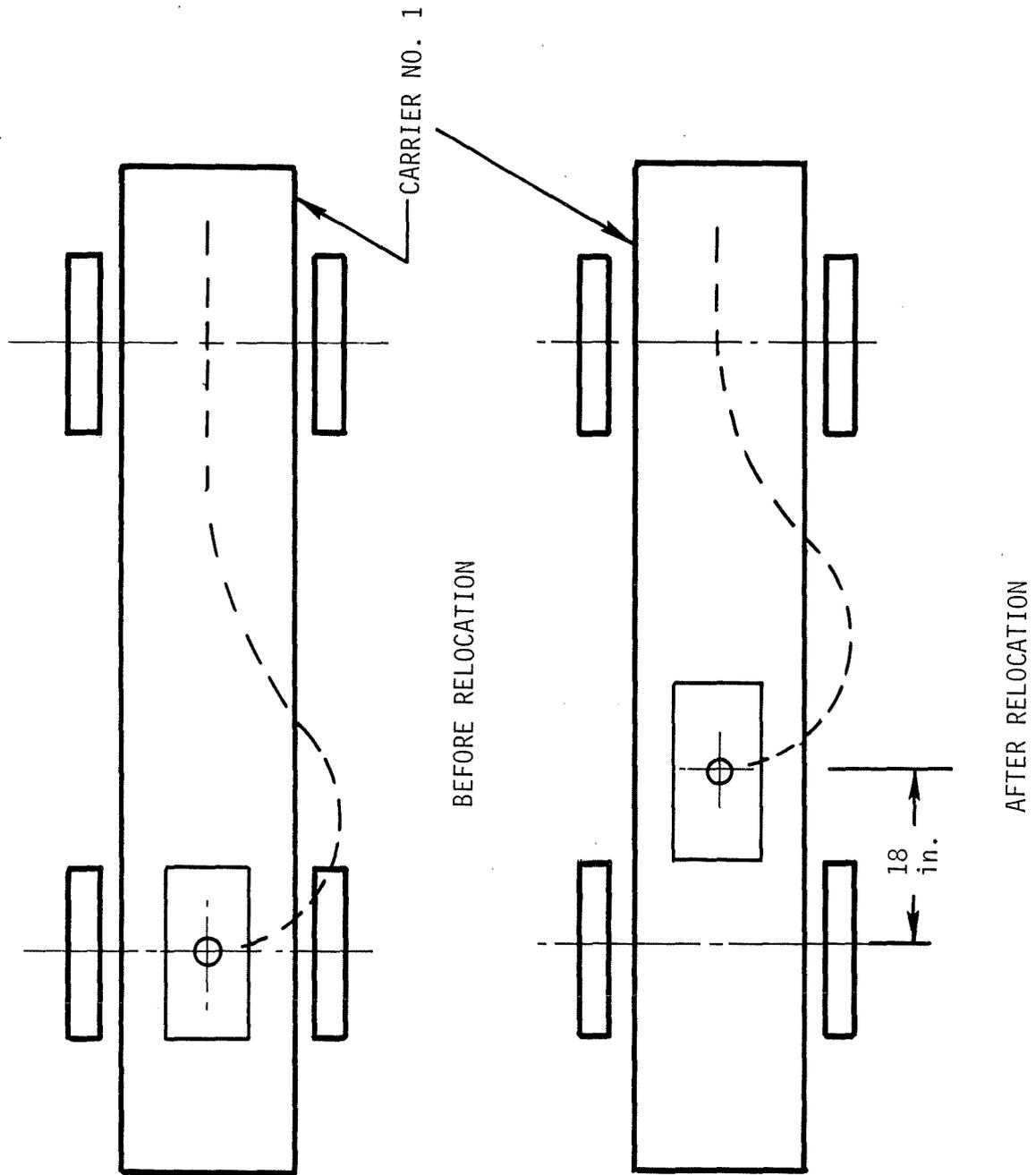


FIGURE 80. Relocation of pancake drive system.

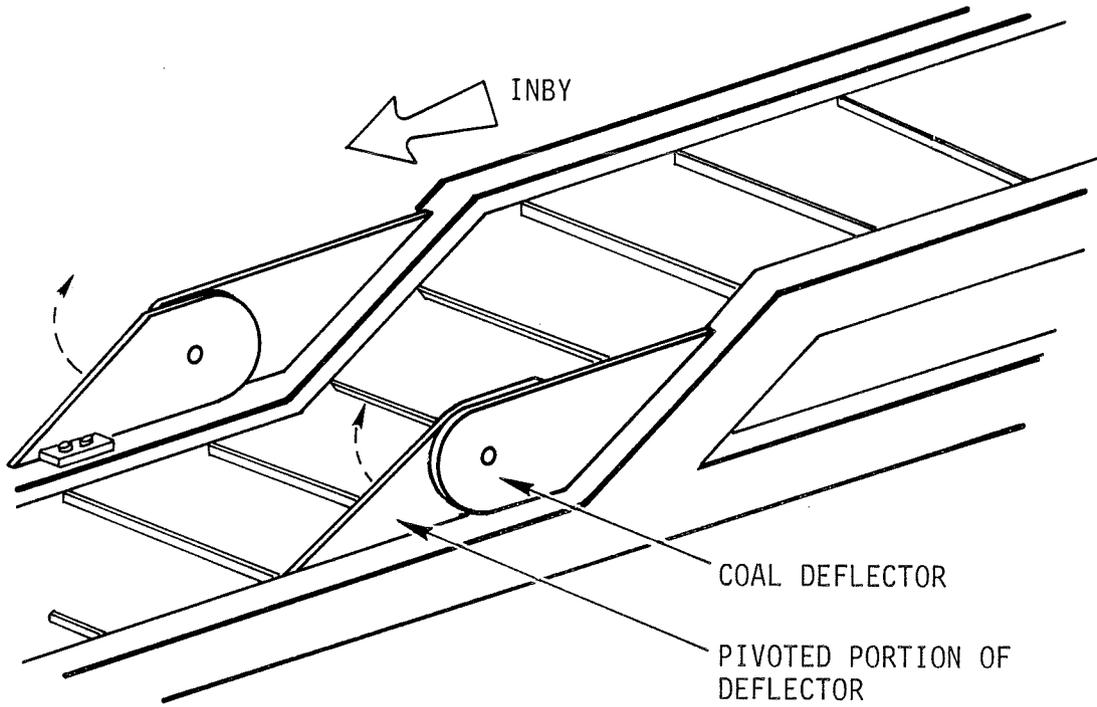


FIGURE 81. - Coal deflector on bridge.

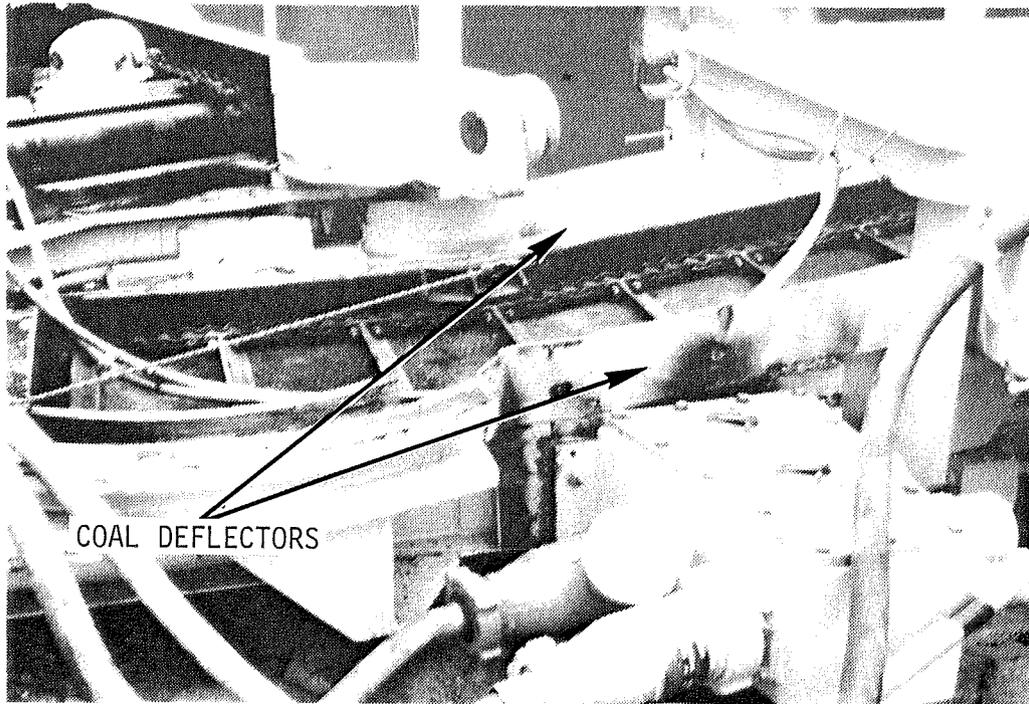


FIGURE 82. - Coal deflectors on carrier no. 2.

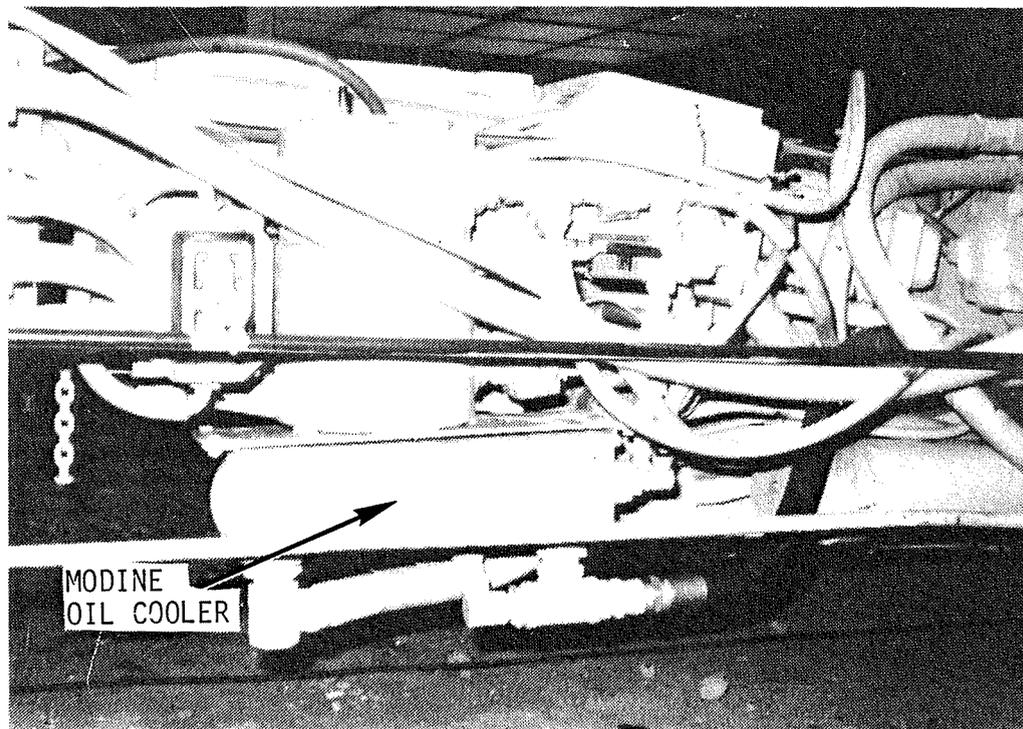


FIGURE 83. - Oil cooler on carrier.

Once hoses were run to the cooler, the system was run and the temperature of the oil was checked. Depending upon the ambient air temperature, the oil ran between 135°F and 145°F. During these tests, ambient temperatures ranged from 10° to 50°F. Underground temperatures are expected to average between 55° and 65°F.

The oil cooler was fed with cold water from a 150 lb/in.² source that was 300 ft away. A 5/8-in.-diam hose was used for both the supply and drain side. Measurements of coolant flow when the machine was running and up to temperature was 8 gal/min. When haulage tests were being performed the water from the output side was used for supplying the water sprays.

4.2 SURFACE TESTS

The surface tests consisted of five tasks. They were:

1. Maneuver within the METF for 40 h on the existing floor surface (see figure 84 for test facility layout)
2. Repeat the above for 30 h on moderately rough floor surface

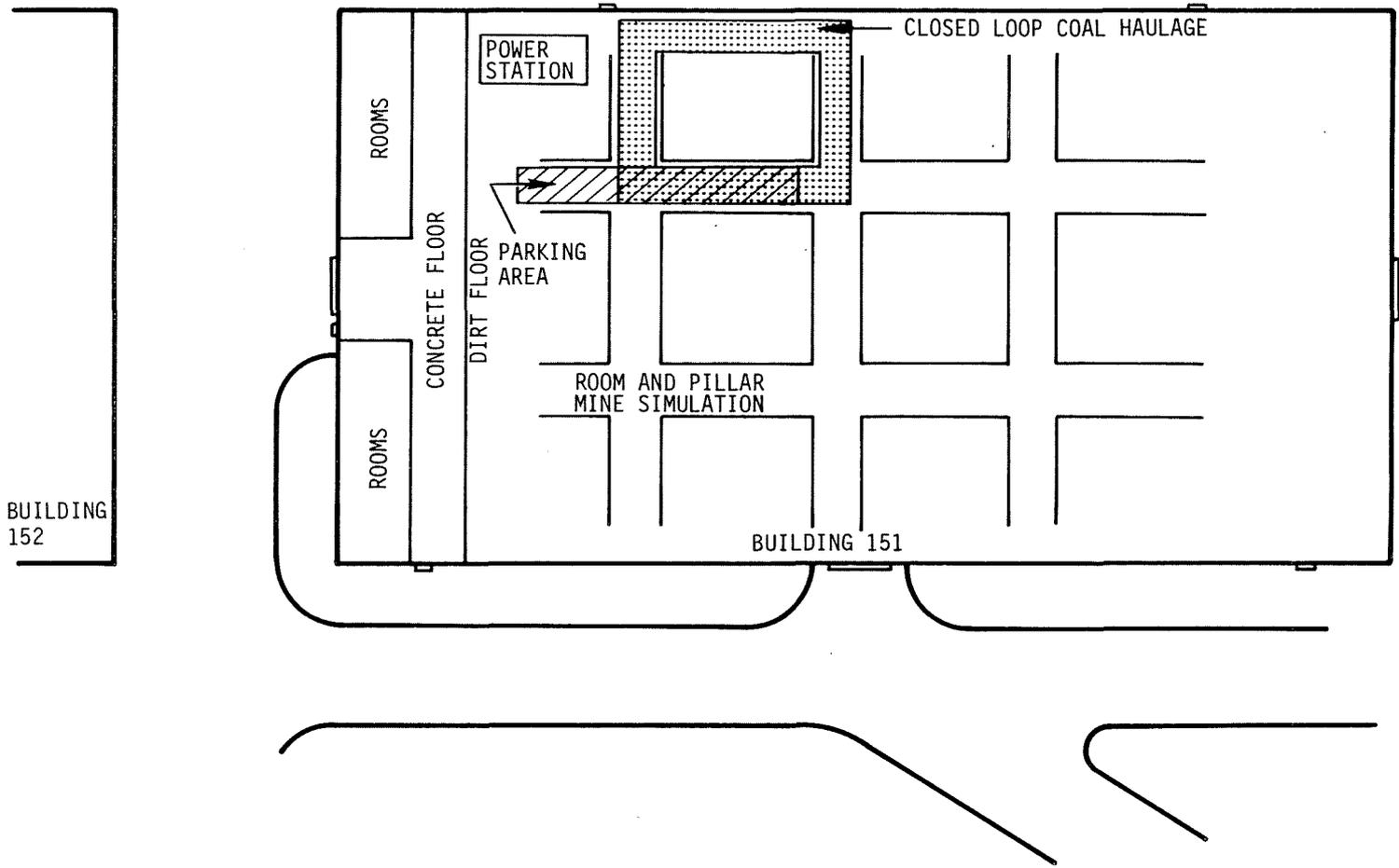


FIGURE 84. - Layout of test area at the METF.

3. Again repeat step No. 1 for 30 h on very rough floor surface with some obstacles placed in the tramming path
4. Perform haulage and surge haulage with ROM coal
5. Perform braking tests on grades near Building 151 to determine braking capability.

These five tasks will be discussed in detail in the following subsections.

4.2.1 Testing over the Existing Floor

The objective of this test was to debug the four-element system, to gain operating experience required for tramming through the room and pillar gallery, to observe the maneuverability of the machine and its components and to try operating at various speeds. In order to appreciate how these objectives were attained, the testing activities will be presented in a chronologic fashion.

In early phases of testing there was much debugging, and running time during any particular period was generally short. As the tests progressed the time between failures decreased dramatically, and the machine could operate flawlessly for hours at a time.

Since the only tramming accomplished up to this point had been at Long-Airdox's Oak Hill, WV facility, the process of learning how to steer the units within the confines of the METF had to be mastered. Also observations of how the various machine elements would react with respect to each other were made. The area where the system was tested at Long-Airdox was quite short (approximately 200 ft) and, therefore, an operator could not get into too much trouble. The elements were assembled in their fully extended position, but when the ABCT was shipped to Bruceton the bridges were stowed under the carriers. Testing personnel soon learned that the correct way to get the bridge out from under the carrier was to pull it out by using an outby carrier rather than by tramming the inby carrier forward. The initial attempt caused the bridge to slew sideways. As it did so, it came into contact with a stepper motor on the left outby wheel of carrier no. 1, and as a result the mounting base of that motor cracked. When trying to correct the situation the operator overcompensated and the bridge collided with the outby wheel sensor on the other side of the carrier. That experience was enough to dictate the proper way of unstowing the system.

Upon arrival at the METF the machine was started and run for a very short period for debug purposes, but once testing began in earnest several additional problems were encountered. The end fittings on some of the hoses that were assembled at Long-Airdox began to get loose and had to be replaced. Additionally it was obvious that hoses around the wheel units would be very vulnerable to damage and that they should be rerouted. This is shown in figures 85 and 88.

The tests began by tramping the system up and down the straight entry in which the ABCT had been parked. This was the first time that the machine had run longer than 15 min at any one stretch and once the operators began to get the feel of operation they made a right turn into the second cross cut. This operation was repeated several times. Each time the steering angle was changed slightly to try to optimize the vehicle position. The most favorable condition was obtained by beginning to take a right turn about 10 ft prior to the rib intersection and then to follow a course that kept the inby carrier in the center of this entry. This is shown in figure 87.

In order to tram through the cross cut and up the adjacent entry to the far end of the building, test personnel trammed up the usual entry, took a right turn

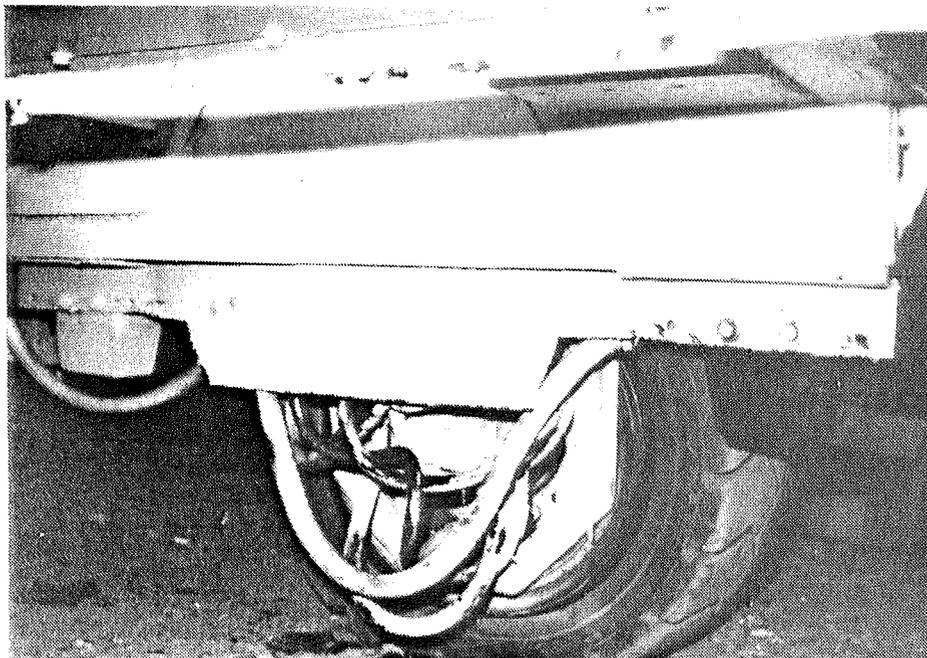


FIGURE 85. - Original wheel unit hose configuration.



FIGURE 86. - Revised wheel unit hose configuration.

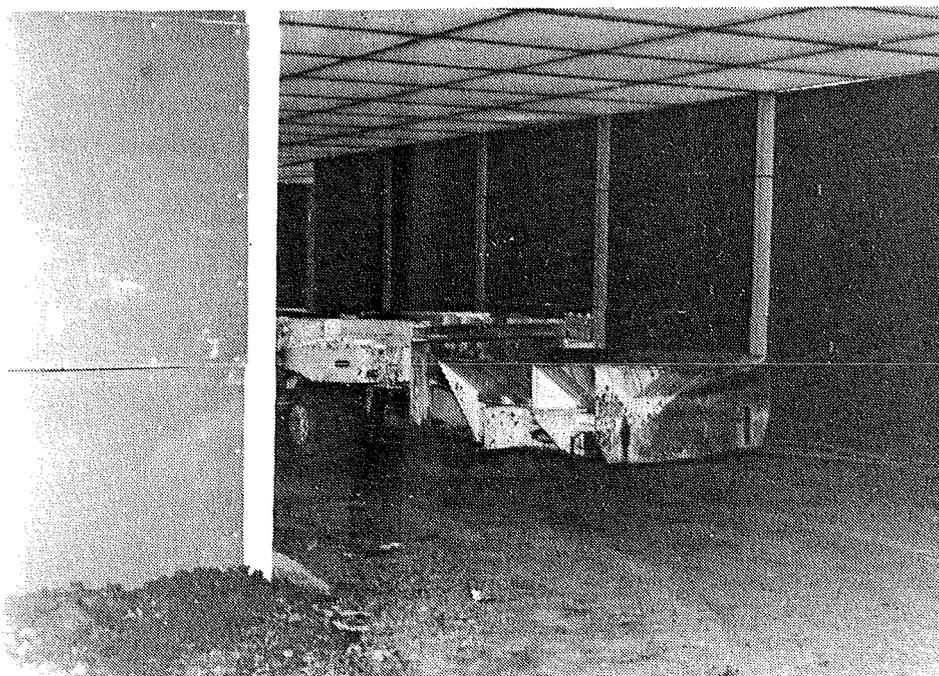


FIGURE 87. - ABCT steering into cross cut.

into the cross cut, and then turned left up the next entry. As the inby carrier turned into the entry, the system was in an "S" shaped configuration (see figure 88).

This configuration placed a considerable amount of stress on the dolly located at the outby end of carrier no. 1. As a result the yokes which hold the bridge centering wheels broke. This design was questioned during preliminary testing at Long-Airdox. There was some concern as to whether the springs which load the centering wheels would have enough play. A decision was made to attempt the Bruceton testing with the current design and then to redesign if necessary.

The dolly on the spare bridge was stripped of these parts, and once they were installed in the damaged dolly the testing continued. Figure 89 shows the original design and the fracture points.

Subsequent to these actions a redesign of the area was completed. The changes are shown in figure 90. Note the increased spring length and the adjustment feature which allows the side forces to be tuned. The new parts were ordered and when they arrived in Bruceton the dollies were retrofitted. The new design was a success and no more problems associated with the side play were encountered.

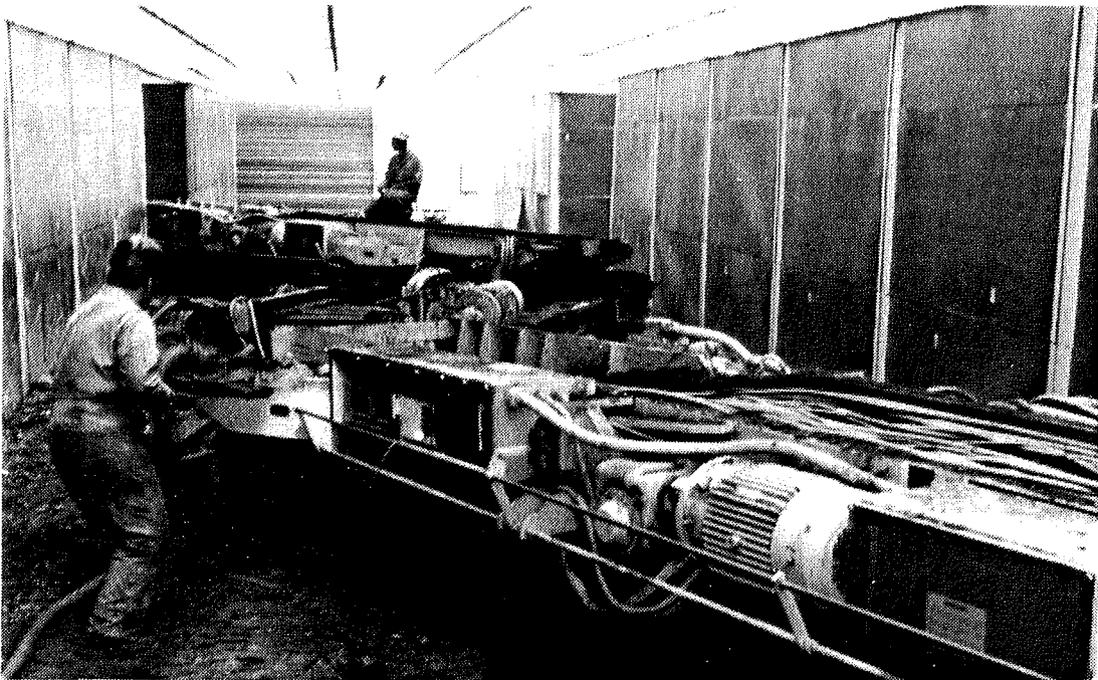


FIGURE 88. - ABCT in place changing configuration.

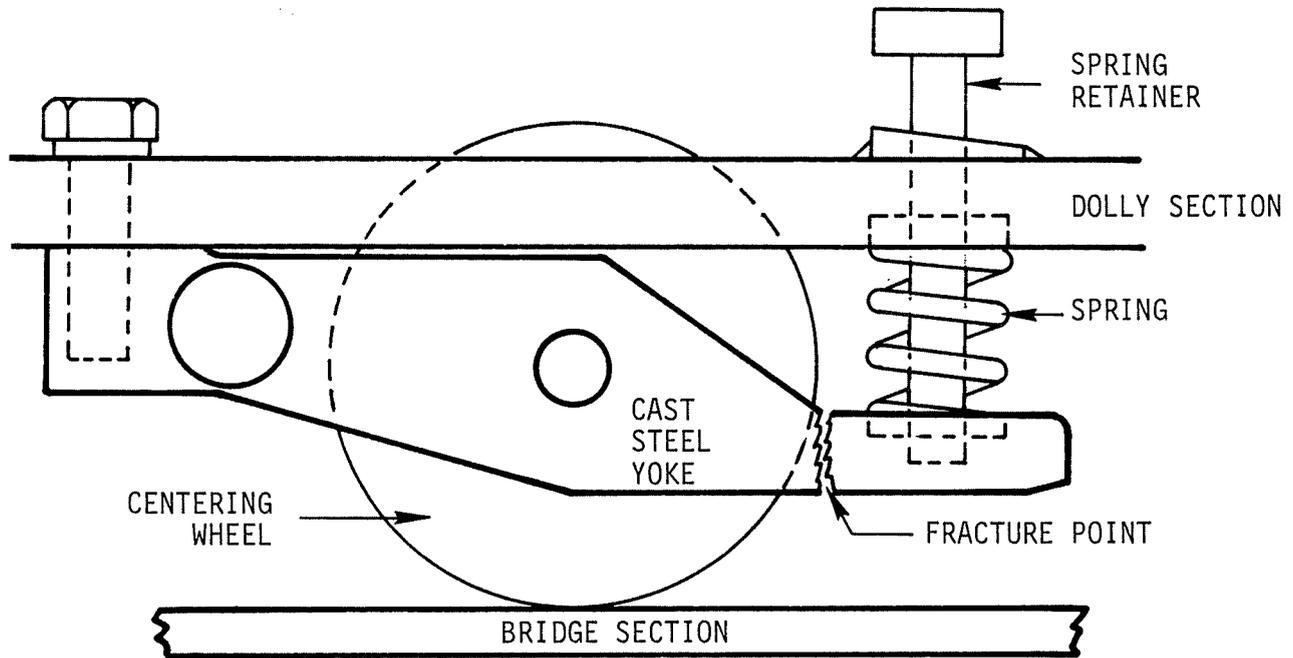


FIGURE 89. - Original design of wheel centering device and fracture point.

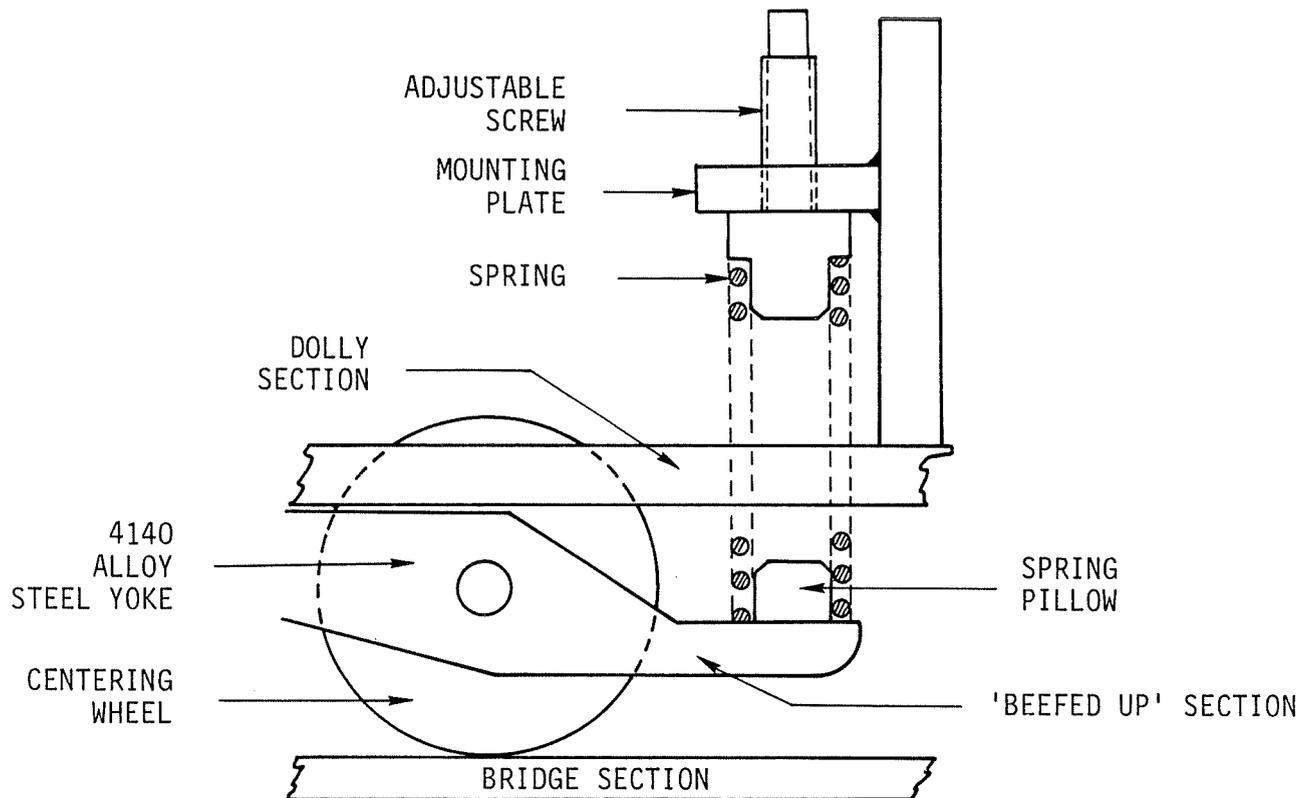


FIGURE 90. - Redesign of wheel centering device.

Up until this point, all of the tests were run at 24 ft/min. The machine was then adjusted so that it could be run in the manual mode at speeds of 32 and 40 ft/min. In general these tests were performed satisfactorily. Two exceptions were:

- a. Occasional wheel hangup when running at 40 ft/min
- b. Some cable handling problems.

Cable clamps and strain reliefs were added to correct the last problem, but further investigation revealed that, at the highest tram speed, hydraulic starvation was causing the wheel to "stall." It is anticipated that during underground testing the ABCT will have to tram at much higher speeds in order to avoid having a mining sequence that is limited by the inability of the system to keep up with the miner tram speeds. Sources at Consol have indicated that a fast forward tram should be at least 50 ft/min.

After testing at 32 and 40 ft/min, the machine was reset to automatic mode and the tramming tests continued at 24 ft/min.

4.2.1.1 Modification Required for Next Tramming Test

As running time accumulated on the existing floor surface it became obvious that certain refinements could be made to increase tramming over rough floor conditions. These modifications are discussed in the following four sections.

Increase Dolly Ground Clearance

There were two areas on the machine that were clearing the ground by only a few inches. They were the cable deployment system and the dolly at the outby end of carrier no. 1. The cable deployment system is low by necessity, but the dolly had a nominal clearance of only 3 in., and when tramming over the existing, relatively smooth surface of the METF it would occasionally bottom out on small rocks and humps. When this happened the guidance cable got pinched between the floor and the bottom of the dolly. It was obvious that this condition would only worsen when the ground conditions deteriorated.

To rectify the problem, special 1-in. thick spacers were made and subsequently installed at the appropriate points on the inby carrier which is hinged in the middle. This is shown in figure 91.

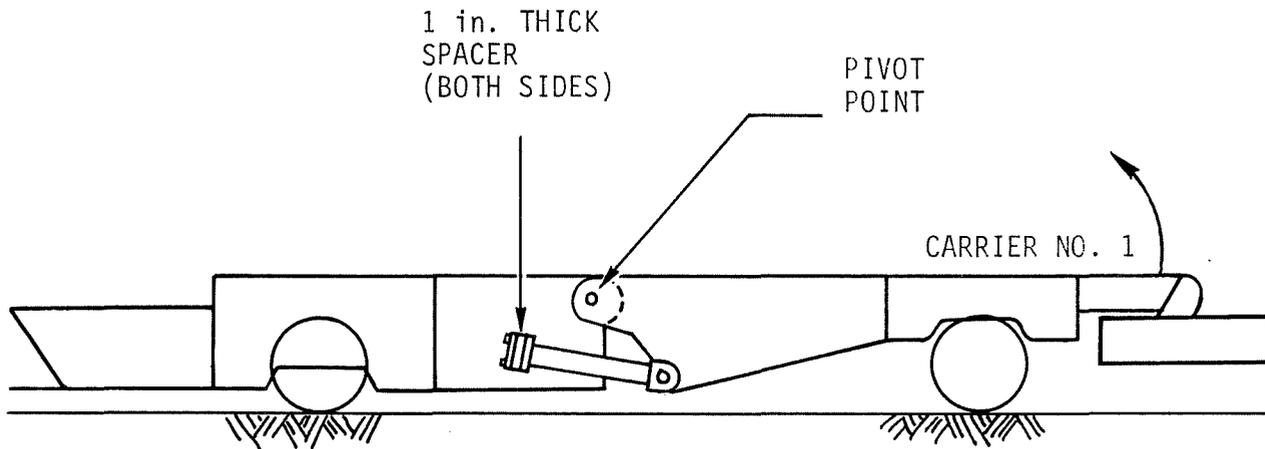


FIGURE 91. - Installation of spacers on carrier no. 1.

This change raised both ends of the carrier thus increasing the ground clearance of the dolly from a nominal 3 in. to just under 6 in.

Improved Cable Handling

The main power cable enters ABCT at the power junction box located on the inby end of carrier no. 2. When executing a left turn the cable became pinched between the box and carrier no. 1. This condition is illustrated in figure 92.

To ease this problem the power junction box was moved 5 in. outby.

In the original design the cable clamps on the outby end of the carriers were welded in place and that condition combined with relatively stiff cables kept the cables from swinging in a stress-free arc as the carrier turned one way or another. To ease this condition, the cable clamps were modified to let them swing in a horizontal plane. The cable service loops were also refined near the transfer points, resulting in much improved power cable handling at the transfer points.

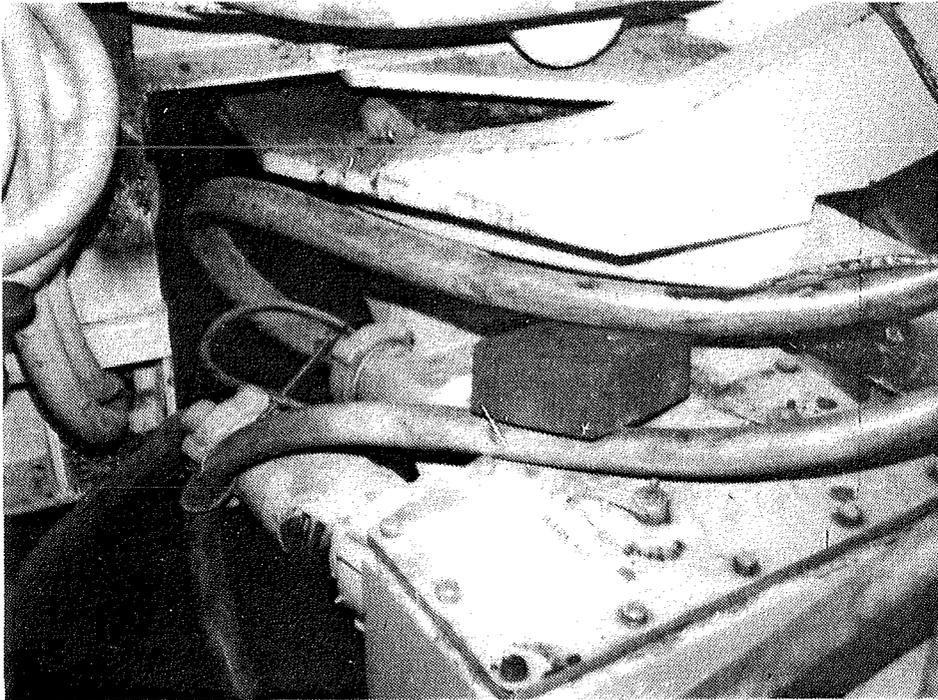


FIGURE 92. - Power cable in pinched condition.

Foam Filled Tires

The tires used in testing contained innertubes which were to be kept inflated to 90 lb/in.². Several times during the testing we had unexplained flat tires which caused us to lose 2 to 3 days at a time. An investigation revealed that once the tube pressure drops below 90 lb/in.² the tire and tube begin to squirm on the rim. Disassembly revealed imperfections in the liners surrounding the inner tubes. Several of the liners had small splits in the rubber while another had a small mark in the liner which allowed the inner tube to expand outward. The combination of tire squirm and the imperfections caused the inner tubes to become punctured.

To remedy the problem, all of the tires were dismounted and sent out to be foam filled and cured. Once they were returned and put back onto the carriers the tire problems disappeared.

Cable Deployment System Diagnostics

Testing up until this point had been hampered by intermittent operation of the cable deployment system. Much of the early problem was caused by dirty filters and

faulty Dynex valves. However, there had been some problems that were caused by faulty electronic signals.

To aid in debugging cable deployment problems a simple diagnostic system that utilizes red and green LED's were added within the control electronics enclosure. By determining which light is on, or if both lights are on, or if neither light is on one may determine:

- a. Whether the output signal from the amplifier boards are above the minimum threshold level
- b. Whether the wheels are being programmed to change their direction or whether they are in a neutral position
- c. Whether the system has been commanded to tram in either direction or is in a neutral condition and thus determining the state of the cable deployment system.

4.2.1.2 Conclusions from Initial Trammng Tests

Initial testing of ABCT within the MSTF provided answers to questions of maneuverability and to the amount of operator experience required to steer the system throughout the room and pillar gallery.

The tests showed that little operator experience is required to operate the system. Several people operated the machine, and after about an hour's worth of experience, each began to feel comfortable with the controls.

The automatically controlled components performed as expected although, as described earlier in this section, debugging constituted a large percentage of time at the beginning of the test period.

Several design improvements were incorporated to increase the survivability of the machine. They included:

- a. Rerouting of some hydraulic hoses
- b. Redesign and subsequent refitting of the bridge centering device
- c. Increasing the dolly ground clearance by several inches
- d. Repositioning of the power junction box

- e. Improved cable handling
- f. Addition of cable deployment system diagnostics.

The testing and conversations with industry officials indicated two areas of need for further work. These were:

- a. Identifying causes of wheel hangup problems at higher tram speeds
- b. Increasing fast forward tram to at least 50 ft/min.

4.2.2 Maneuvers on Moderately Rough Floor of the METF

In this subsection we will describe the surface preparation for this test effort and the ensuing 30-h test.

4.2.2.1 Preparation for Testing

With the initial tramming tests completed, preparation for testing over moderately rough floor conditions began. When this series of tests were conceived it was believed that the existing dirt floor could be tilled to produce the desired floor conditions. However, further investigation revealed that when the METF was constructed, wires were buried in the floor. This fact combined with the relatively limited headroom in the "entries" eliminated the use of a backhoe to till the floor.

To overcome the problem we arranged to obtain 200 tons of gob from the Mathies Mine in Library, PA. This amount of material provided an average depth of 6 in. in the area indicated in figure 93.

A scoop was used for spreading the gob. Before it could be used FMI personnel had to change out the batteries and repair the brakes. Once this was accomplished the gob was spread as planned.

4.2.2.2 Testing over Moderately Rough Floor

Once preparations had been completed, two units of the train were moved onto the gob in entry No. 1. The parked position of the train with respect to the gob covered area is shown in figure 94.

Carrier no. 2 and the bridge backed up onto the gob with no problems, but as the dolly on the outby end of carrier no. 1 backed over the material it squeezed and subsequently dragged the guidance cable between it and the gob. This is shown schematically in figure 95.

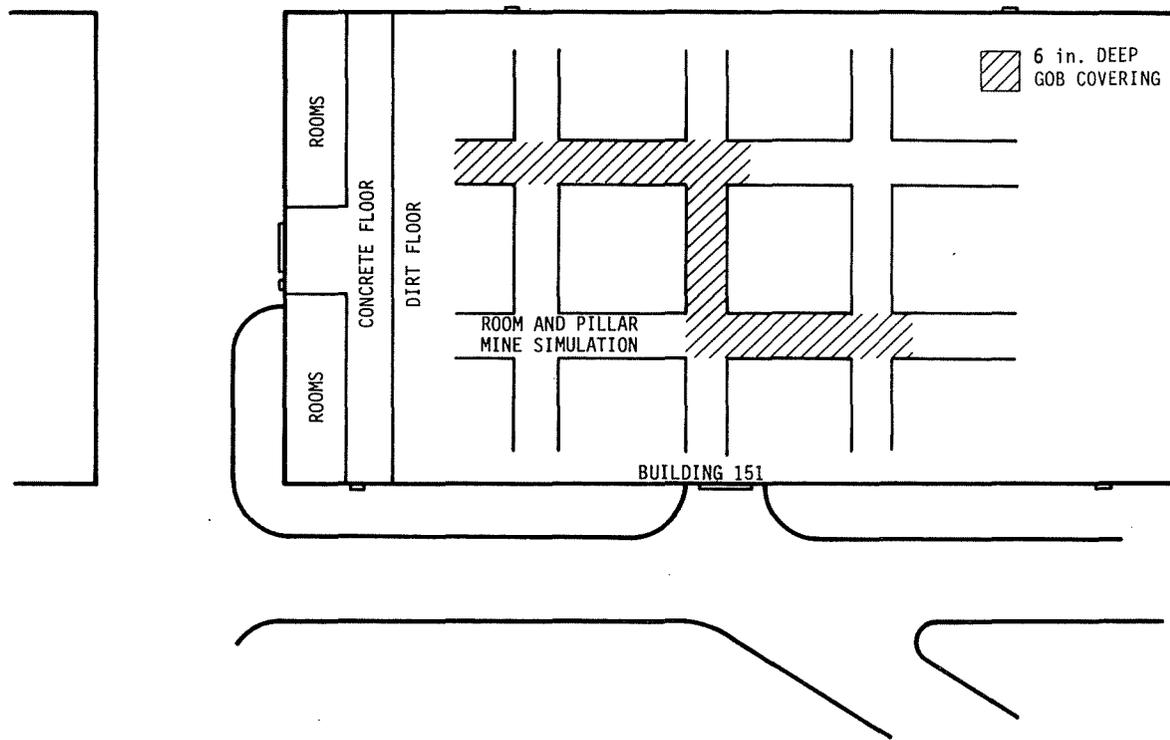


FIGURE 93. - Area covered by gob.

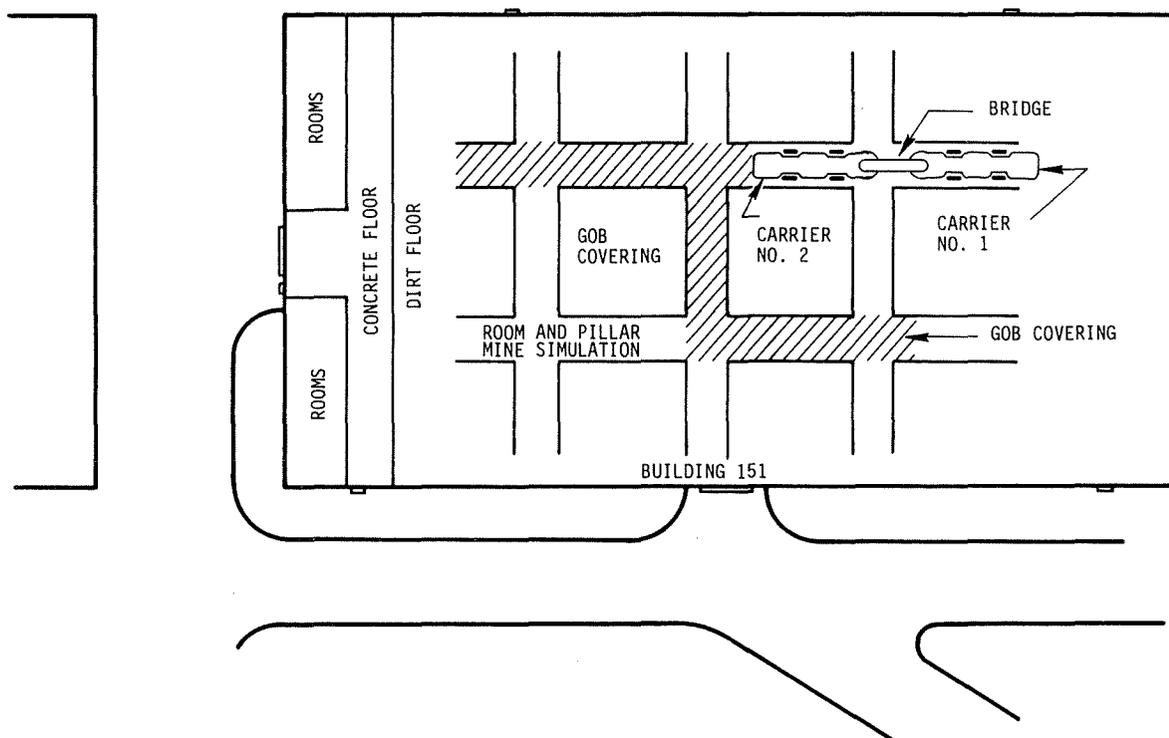


FIGURE 94. - Position of ABCT prior to moving onto the gob.

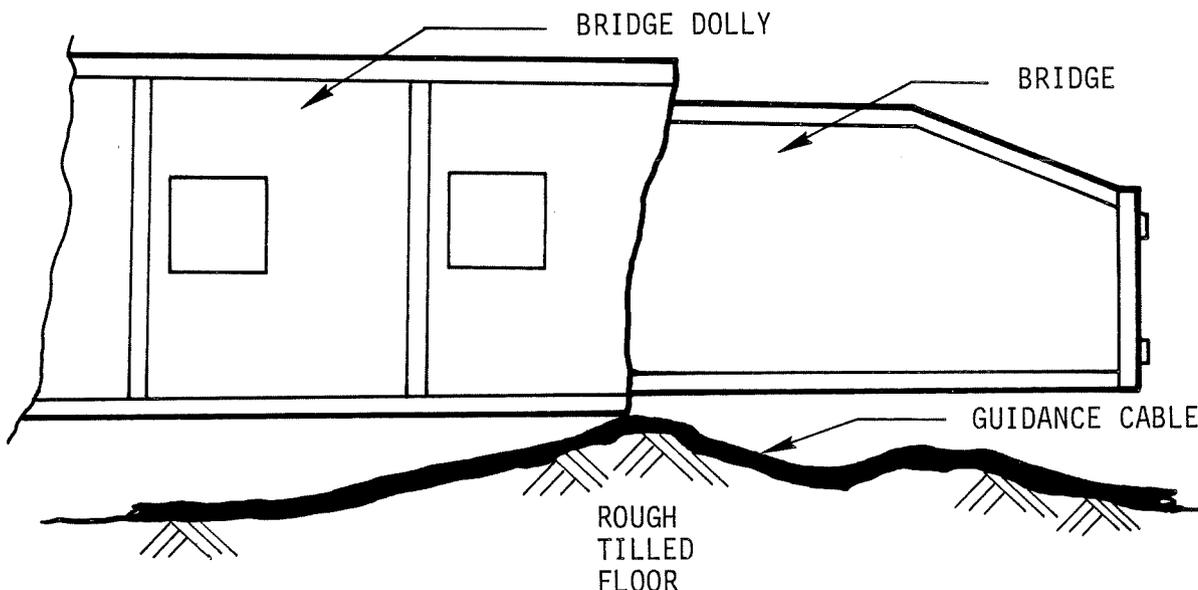


FIGURE 95. - Dolly squeezing and dragging guidance cable.

This was only the beginning of the problems with the guidance cable. As the machine continued to run over the new surface it became obvious that the cable deployment device could not cope with the high spots of the surface.

The system is comprised of a hydraulically operated reel and pancake. Together, they lay the cable on the ground at zero tension. To do this, four electronic sensors must determine the shape of the loop formed by the cable as it exits from the pancake on the bottom of carrier no. 1. If the loop is large and growing, the onboard computer stops the hydraulic system from dispensing more cable, but if the loop is small or getting smaller more cable is deployed until a nominal loop is regained. These three conditions are shown in figures 96, 97, and 98.

The problem was caused by high spots on the floor which made the loop small, thus causing the cable deployment system to push out more and more cable. Figure 99 shows the condition which caused the problem.

One of two solutions had to be incorporated into the machine. The choices were to either raise the inby carrier thus increasing the ground clearance between the pancake and the floor or to plow the floor immediately in

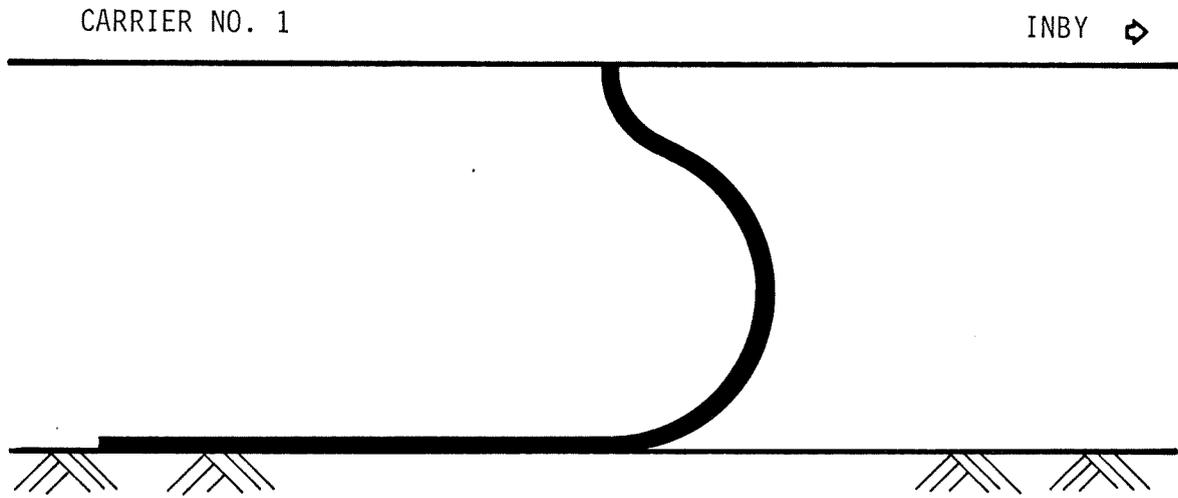


FIGURE 96. - Cable exiting pancake with nominal profile.

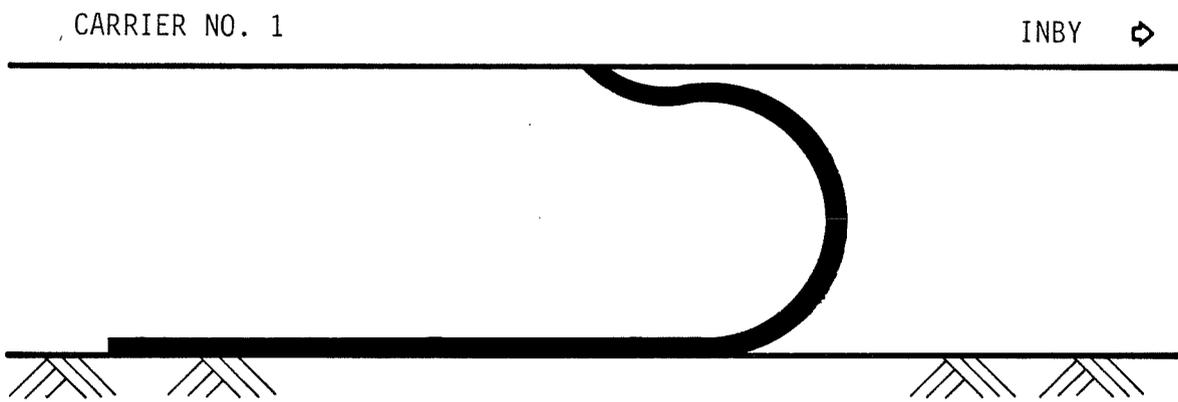


FIGURE 97. - Cable exiting pancake with large loop.

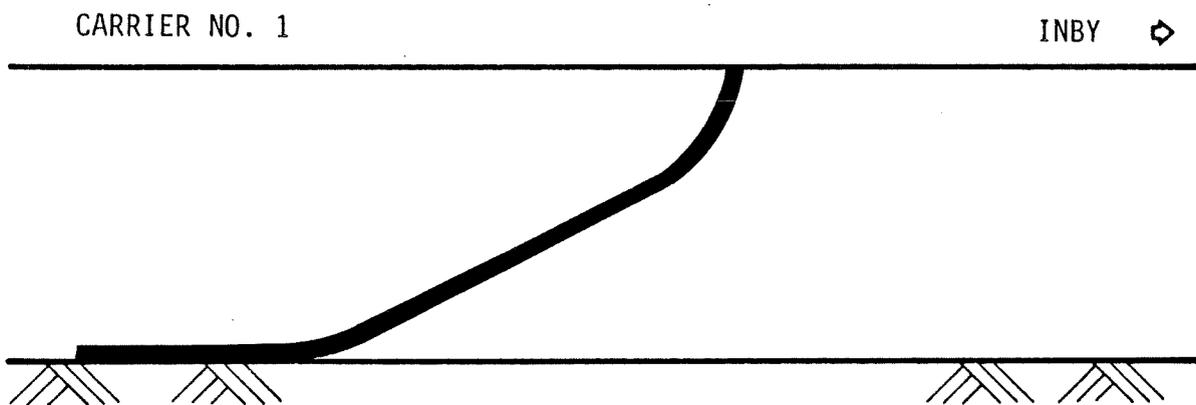


FIGURE 98. - Cable exiting pancake with small loop.

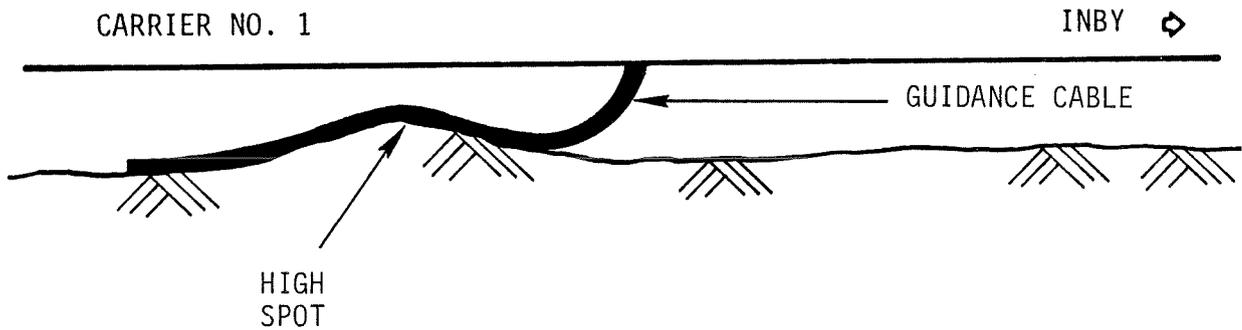


FIGURE 99. - Small cable loop caused by high spots on floor.

front of the cable deployment system. Raising the carrier was ruled out because the machine will eventually be used in a mine with low coal. Therefore, a plow was designed to push the material away from the immediate vicinity of the cable deployment system. Two views of the diamond shaped plow are shown in figures 100 and 101.

The plow was mounted so that it would clear a hard flat surface by 2 in. It was made 59-in. wide so that even when going around a tight corner, the cable was



FIGURE 100 - Top view of plow.

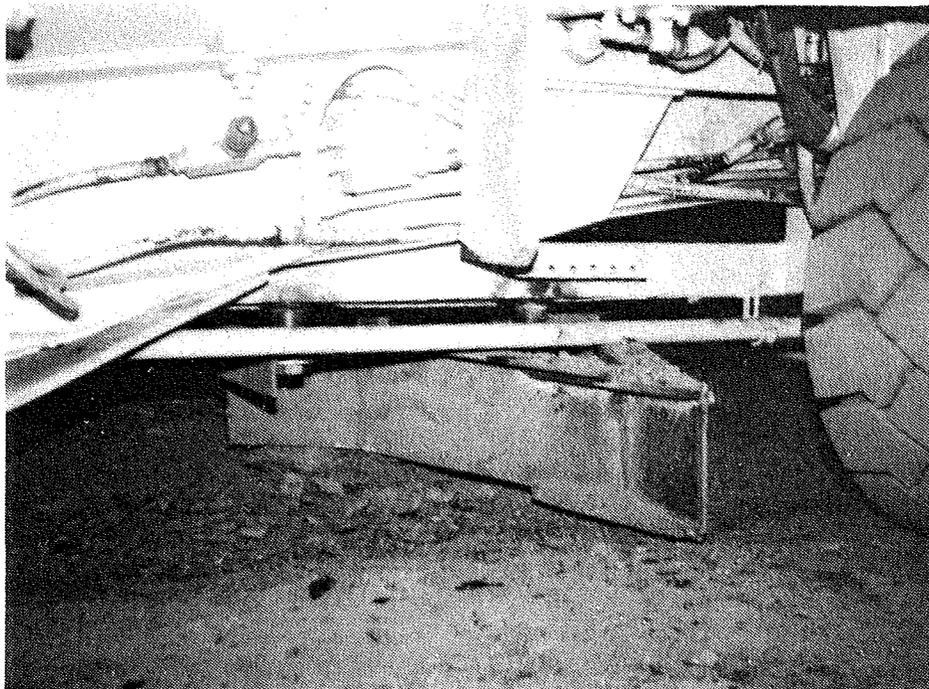


FIGURE 101. - Side view of plow.

within the cleared area. The path cleared by the plow can be seen in figure 102.

This addition solved most of the problems caused by the uneven floor. However, when the machine is trammed outby, the plow leaves a small ridge of material on its outby side that must be overcome by the cable deployment system. This situation is illustrated in figure 103. The ridge was only a minor problem when compared to running without any plow.

As tramping continued, a small amount of water was added to the gob. In general the machine had no problems maneuvering through the wet material.

At this point the method of machine operation changed. Up until now the machine was stopped whenever a problem appeared, and time was taken to make the needed repairs. Since the major problems were behind us, we decided to run the machine until forced to shut down for repairs, at which time all abnormalities would be corrected. Testing hours accumulated quicker under this mode of operation showing that the machine's reliability had increased since its introduction to the METF.

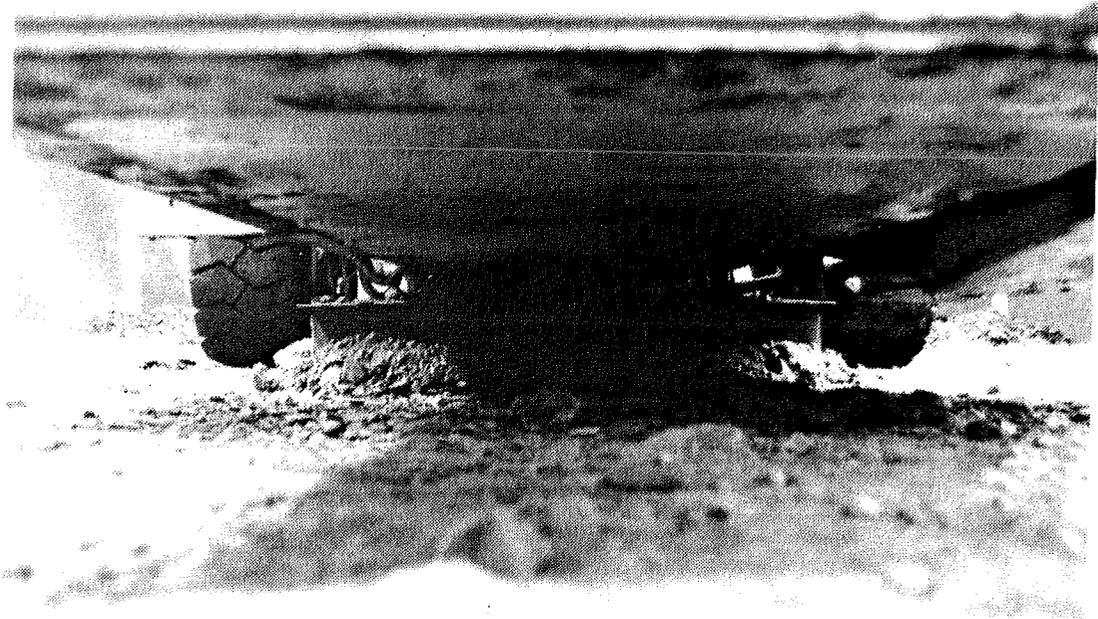


FIGURE 102. - Path cleared by plow.

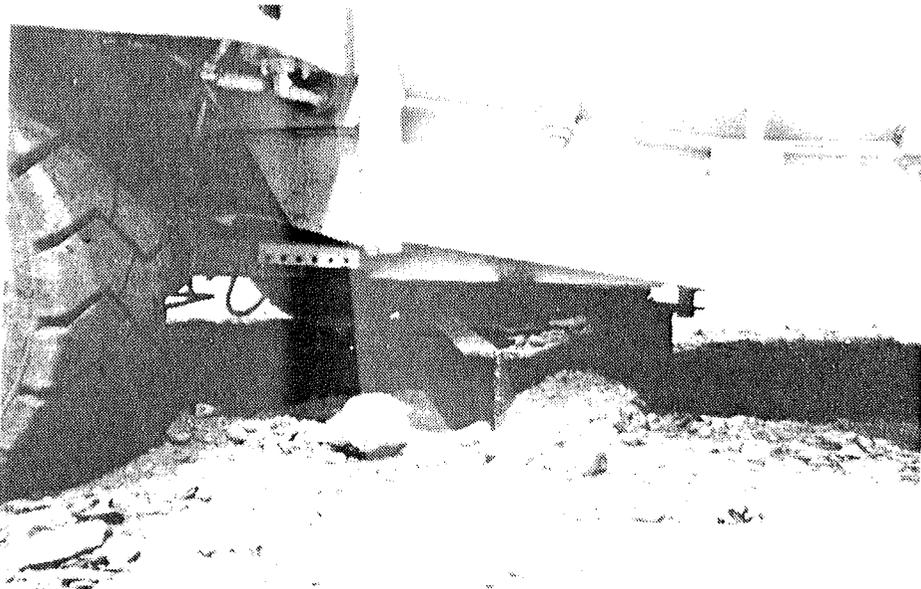


FIGURE 103. - Ridge of gob remaining after trammie outby.

As mentioned above, there were some problems that we lived with until forced to shut down the machine. They are discussed in the following subsection.

4.2.2.3 Additional Areas for Improvement

The problems which needed to be addressed before proceeding into tests over very rough floor conditions included broken brass bearing surfaces, wheel "hunting" and offset problems, bridge support wheels in the dolly, and pillow block retention problems. These problems are discussed below.

Brass Bearing Surfaces

The dolly is supported within a "U"-shaped groove provided in the yoke on the outby end of the carrier. Segmented brass bearing surfaces were bolted to the yoke to provide easy rotation of the dolly within the yoke. This area is depicted in figure 104. These were particularly important when the machine was running without coal which will act as a lubricant.

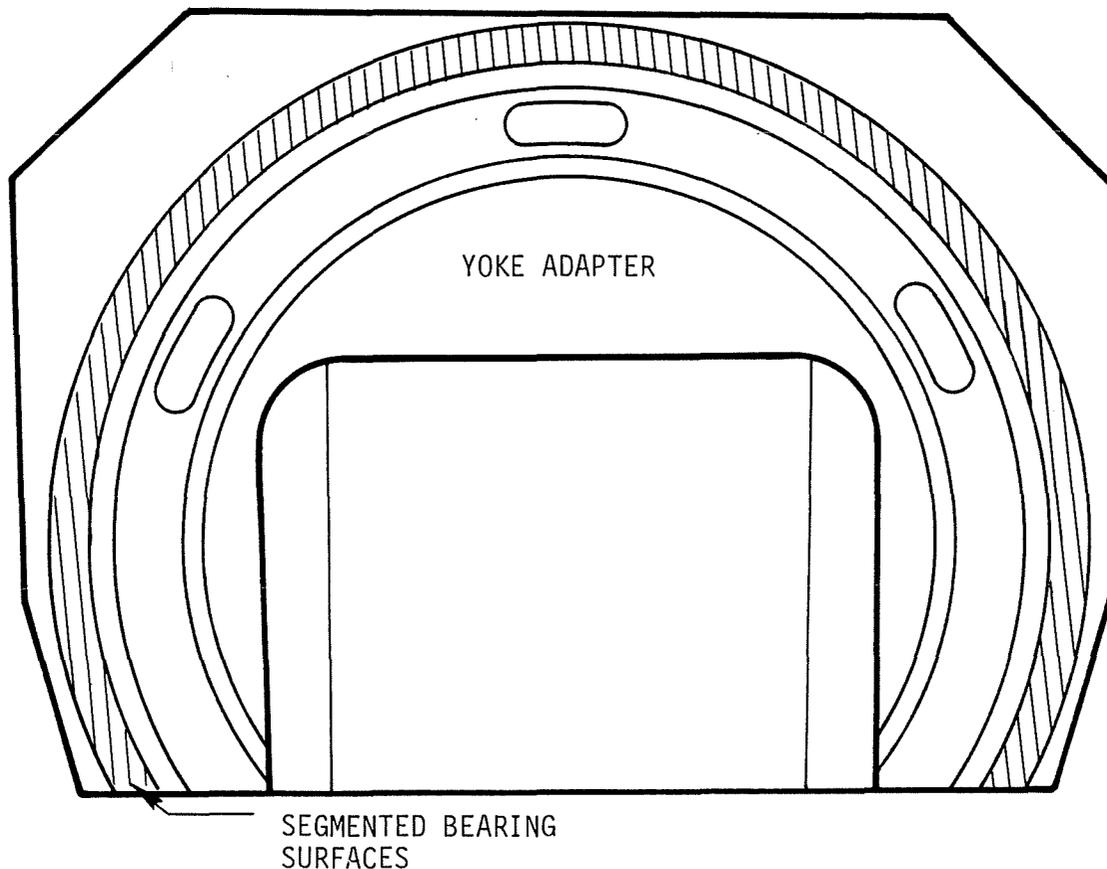


FIGURE 104. - Yoke supporting the dolly.

The brass pieces were torn loose during testing and were replaced by those in the spare dolly. An examination of the broken parts showed extreme wear on one side which may have been caused by constantly turning the machine in the same direction as was the case at Long-Airdox. Complicating this problem was the fact that the bolt heads were not recessed deep enough within the brass and were soon exposed to wear.

Wheel "Hunting" and Offset Problems

One problem that appeared during the testing period was that the outby wheels on carrier no. 2 were "hunting" in order to center themselves over the guidance cable. This hunting or dithering back and forth while tramping was accompanied by an offset, with respect to the cable, of about 4 in. It should be noted that this problem in no way hampered our tramping efforts.

Both of the problems just described were caused by the sensors and wheel potentiometers being out of calibration and once recalibrated, the problem disappeared.

Redesign Bridge Support Wheels

One problem that did require immediate remedial action was a result of the vertical support wheel shaft breaking. There are four such wheels, shafts, and bearings within the dolly. They are shown in figure 105. An examination of the broken parts revealed a stress riser in the design of the shaft. It was at that point that the fracture occurred. Although only one shaft broke, one other was beginning to bend.

Identical parts were pirated from the spare dolly and were substituted for the broken parts as a quick but temporary fix. In the meantime, the support was redesigned as shown in figure 106. Once the redesign was complete, new hardware was fabricated and subsequently installed in place of the previously substituted parts.

Pillow Block Retention Problems

When the ABCT was originally designed, the angle that occurs between the bridge and a carrier as they tram through a 90° turn was anticipated to be no more than 70°. Accordingly, the design provides for movement of just over 70°.

However, in actual practice, this angle is sometimes exceeded. When this happens, one of the pillow blocks which guide the dolly within the yoke falls out of its track. This is shown in figure 107.

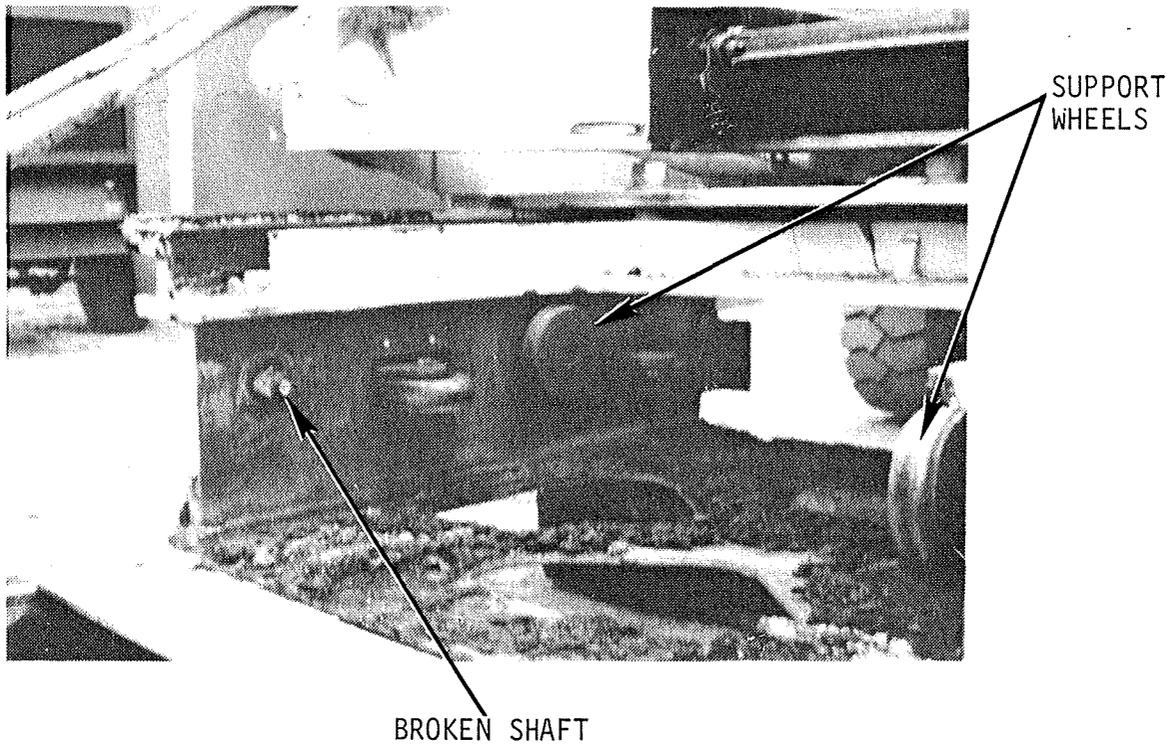


FIGURE 105. - Vertical bridge support wheels.

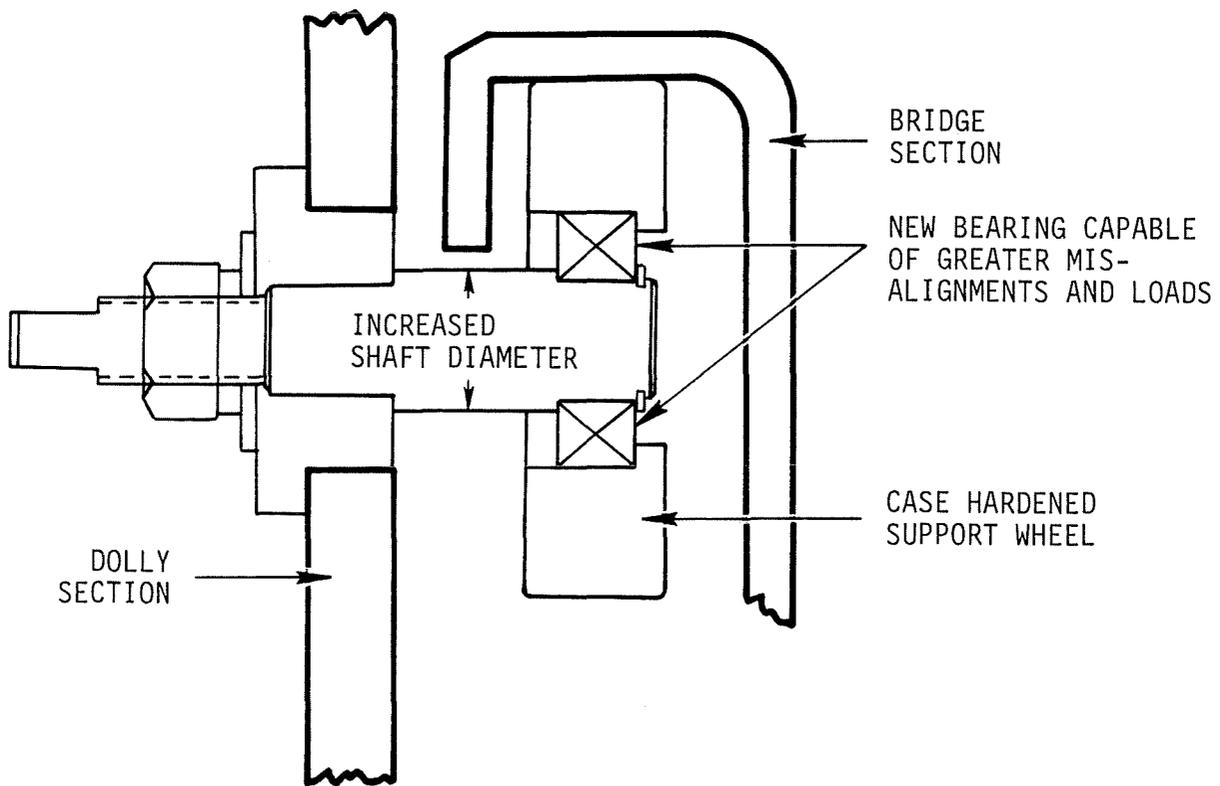


FIGURE 106. - Redesigned vertical bridge support system.

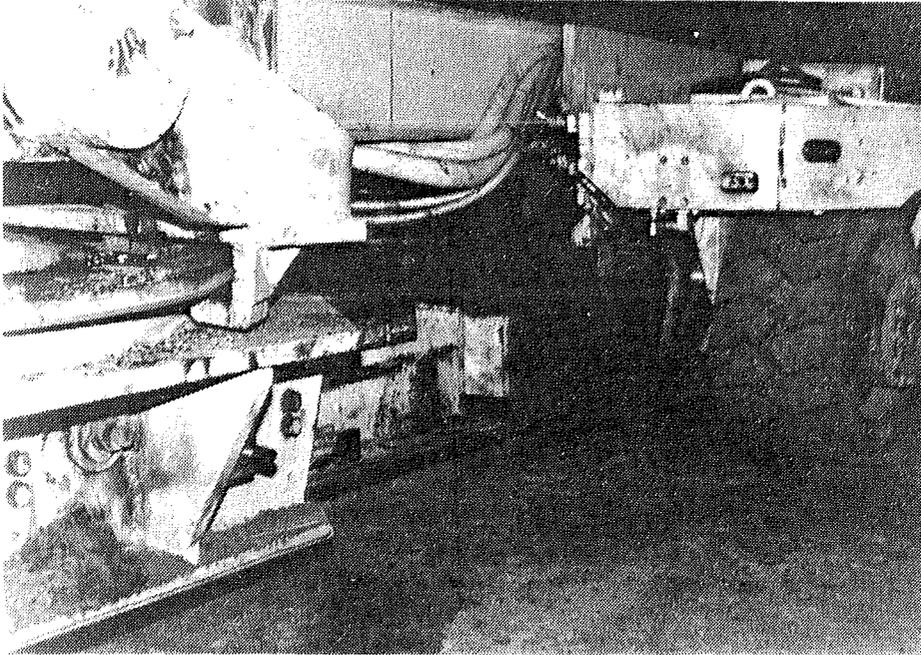


FIGURE 108. - Carrier pulling against stops on bridge.

soft spot. The only problem with this set of stops is that the stowing of the bridge under the carrier in front of it cannot be accomplished until they are removed.

As mentioned earlier, the gob was very wet and slippery, a condition which by itself did not cause any problem until a rib roll was simulated. This condition is illustrated in figure 109. The vehicles did not have any problem climbing the slope, but once on it they tended to slide toward the center of the entry. When this happened, the centerline of the vehicles were offset with respect to the guidance cable. The vehicles immediately tried to correct their position, and by the time they cleared the rib roll they were once again centered over the guidance cable.

Large pieces of coal and shale were placed in the wheel path of each carrier. They ranged from baseball size pieces to pieces of slate that were 16-in. long and 8-in. high and of irregular shape. The vehicles had no problems overcoming these obstacles. The wheel simply climbed over the slate sometimes splitting it in the process. Where the ground was very wet, the wheel would occasionally spin against the rock with the other three wheels providing the tractive effort required to tram over the obstacle.

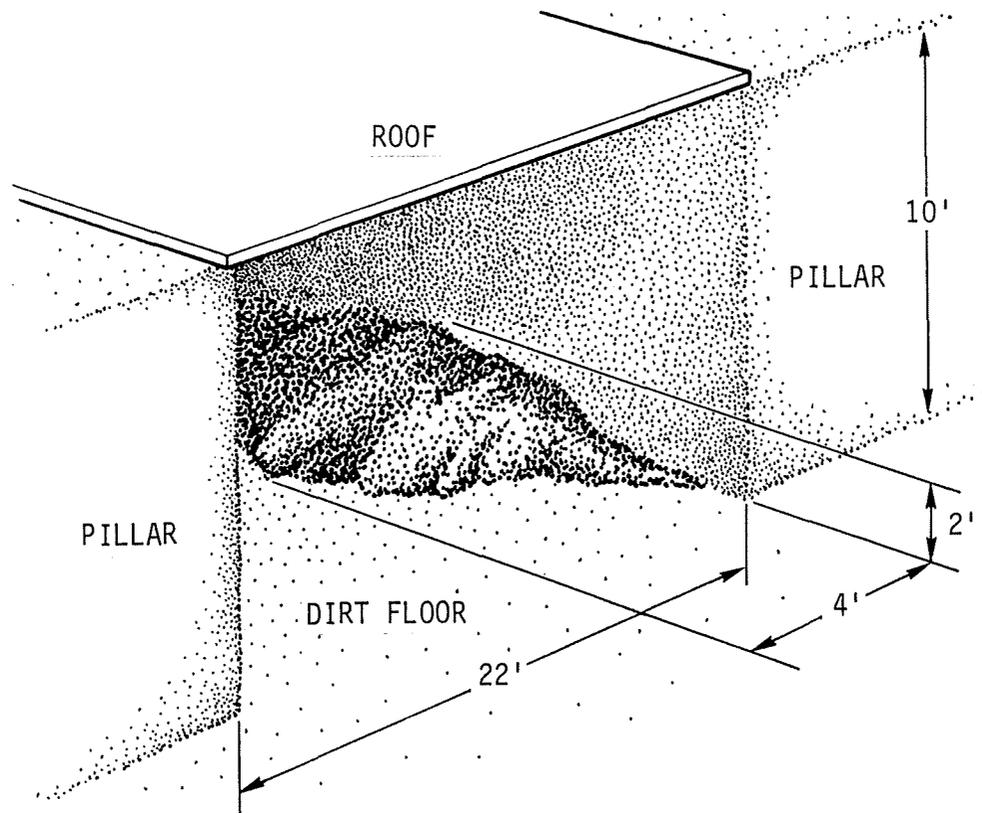


FIGURE 109. - Simulated rib roll.

The wet floor conditions caused problems with the cable deployment system. The system became jammed with mud, fines and chunks of gob and coal. The material became lodged in the gap between the pancake and the cable reel pipe.

Figure 110 shows a metal sleeve which was fabricated to slip over the pipe and thus eliminate the gap. The increased metal in this area required recalibration of the cable deployment sensors, but once this was accomplished no additional problems were encountered in that area. The cable deployment system had no problems handling water, and in fact had no problem picking up and deploying a wet, muddy cable. One additional problem is that some materials get clogged in the inlet hole. A better cable cleaning device will be required in the future.

The "knife" portion of the knife switch was also a victim of the severe conditions. This switch is located within the dolly and it controls the position of the bridge with respect to the dolly. The supports which hold it in place were too weak and had to be redesigned in follow-up work. (see section 5.1)

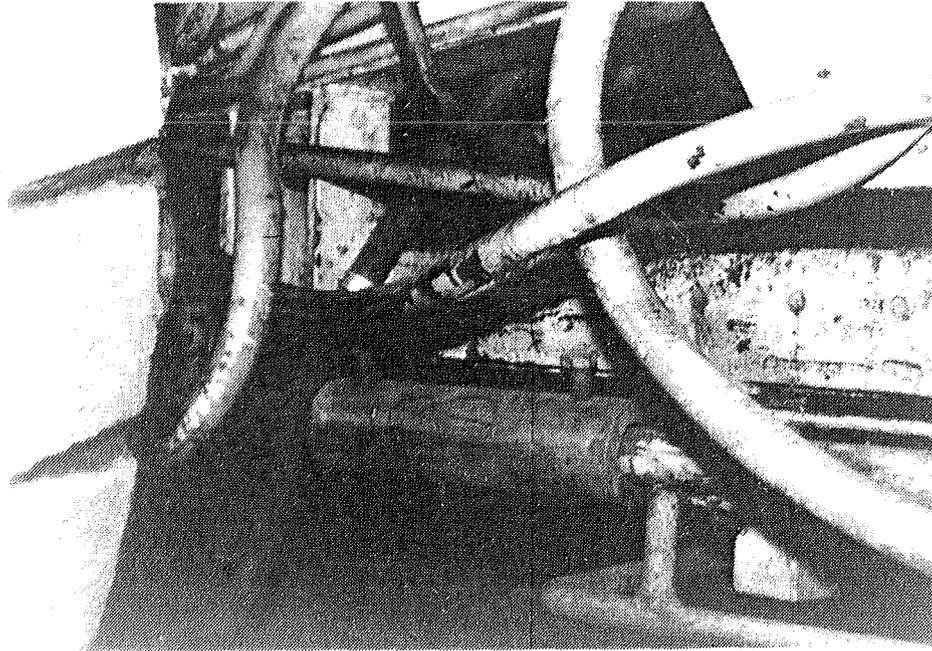


FIGURE 110. - Metal sleeve for eliminating gap.

4.2.3.3 Conclusions from Maneuvering over Severe Floor Conditions

This final series of tramping tests proved that the system is capable of handling the severe conditions likely to be encountered underground. Improvements made in earlier testing phases increased the reliability and drastically reduced the amount of downtime encountered in this 30-h test. This is not to say that further improvements were not indicated.

The biggest design problem remaining will be to keep coal from contaminating the cable deployment system. The scheme of running the cable through a brush is not sufficient as the brush gets matted with coal fines and mud. One possible solution would be to have a small water spray at the entrance to the pancake. This would ensure that from that point on the cable will be clean. Areas found to need redesign include:

- a. Bridge stops on outby side of dolly
- b. Better cleaning device at the inlet hole of the cable deployment system
- c. Knife supports.

4.2.4 Coal Haulage Tests

After successful completion of the tramping tests, preparations were made for a series of coal haulage and surge tests. The objectives of these tests were to:

- a. Determine the coal carrying capacity of the system
- b. Determine the surge haulage capacity of the system
- c. Identify any areas needing further work prior to building additional units.

4.2.4.1 Preparations for Testing

To provide uninterrupted coal haulage, a plan was devised that would use the two carriers and the two bridges of ABCT in conjunction with three piggyback bridge conveyors in a closed loop system around one of the pillars inside of the METF. Their respective positions within the facility are depicted in figure 111. Two views of the Long-Airdox piggyback conveyors are shown in figures 112 and 113. Each of the piggyback conveyors was supplied with 40 hp power packs and variable speed pump. They were wired into the same power center that was used for the ABCT.

The 51-ft long piggyback conveyor was outfitted with a special 20-ft long frame capable of receiving a Ramsey Model 10-20-1 belt scale. Its specifications are:

Maximum rate:	720 tons/h
Belt speed:	300 ft/min
Belt loading:	coal approximately 80 lb/ft
Belt width:	36 in. flat
Idler spacing:	3 ft

The weight scale sensor is a precision strain gauge load cell with special temperature compensation. The weigh scale is shown in position on the piggyback bridge conveyor frame and under the belt in figure 114.

The output from the scale was displayed on a totalizer box which was located on the wall of the building. This is shown in figure 115.

The output was displayed in two modes. A seven digit, nonresettable, electromechanical counter indicated the total number of tons hauled. The other output was an analog meter which instantaneously read out the percent of total carrying capacity. The total capacity of the scale is 12 tons/min. Therefore, if the meter was showing 60%, one would know that the belt was transferring 7.2 tons of

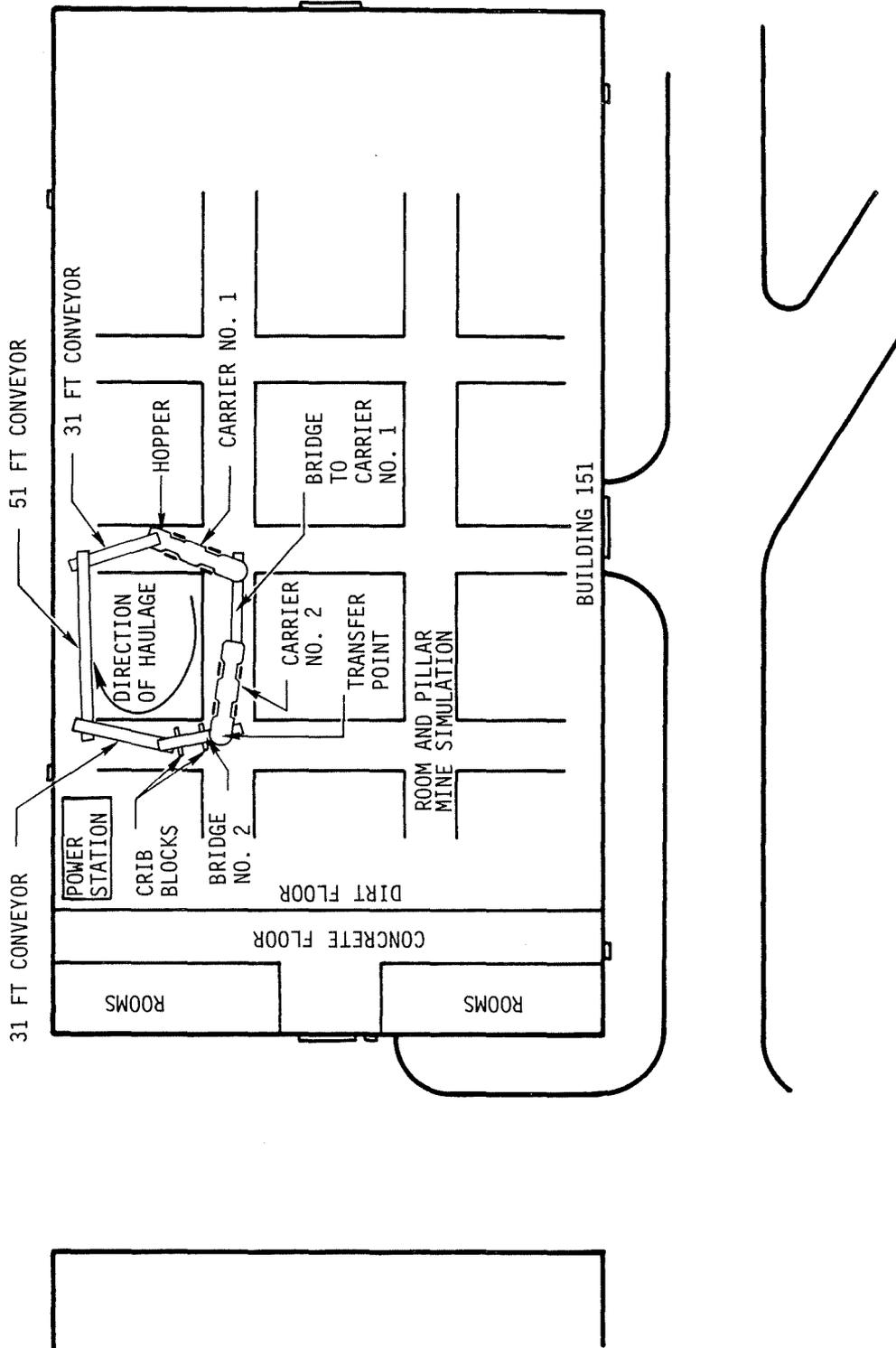


FIGURE 111. - Closed loop configuration.

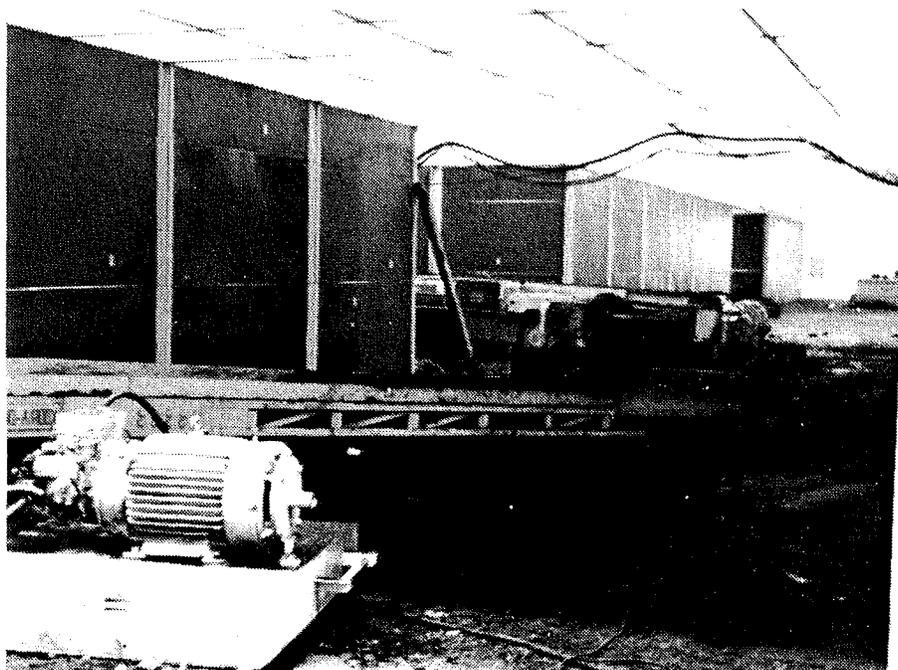


FIGURE 112. - Thirty-one ft long piggyback conveyer.



FIGURE 113. - Fifty-one ft long piggyback conveyer.

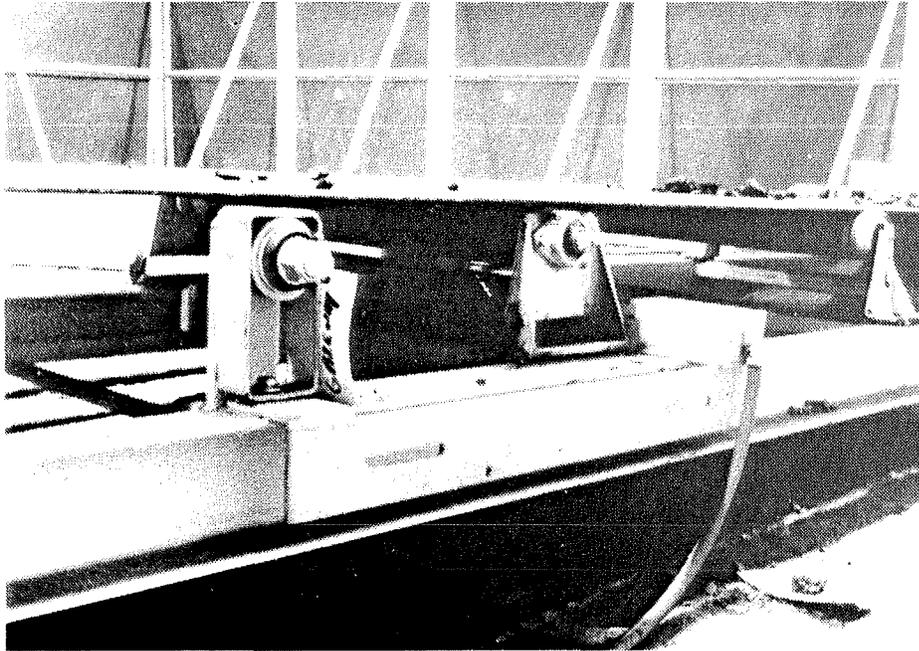


FIGURE 114. - Ramsey scale on piggyback conveyor.

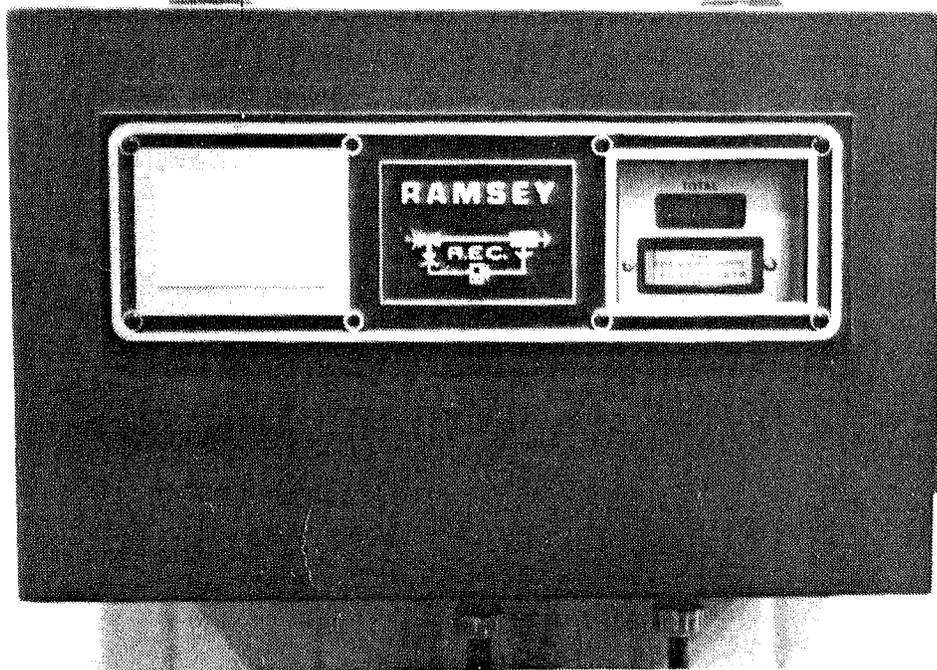


FIGURE 115. - Totalizer box.

coal at that instant. In order to obtain a hardcopy record of the analog meter, a strip chart recorder was connected to the output of the scale. An example of the output is shown in figure 116.

Final preparations were made by adding very small amounts of gob to the closed loop system and adjusting the various conveyors to optimize the transfer points. Once this was accomplished, water sprays were added to all transfer points. Finally a circuit which included two panic switches, each capable of shutting down the entire closed loop testing system was prepared and installed near the operator positions.

4.2.4.2 Coal Haulage Testing

To initiate testing, small amounts of run-of-mine coal and gob were placed on the conveyors. The amount was increased slowly until the system was transporting 2 to 3 tons of material per minute. It was at this load level that the machines began to have problems.

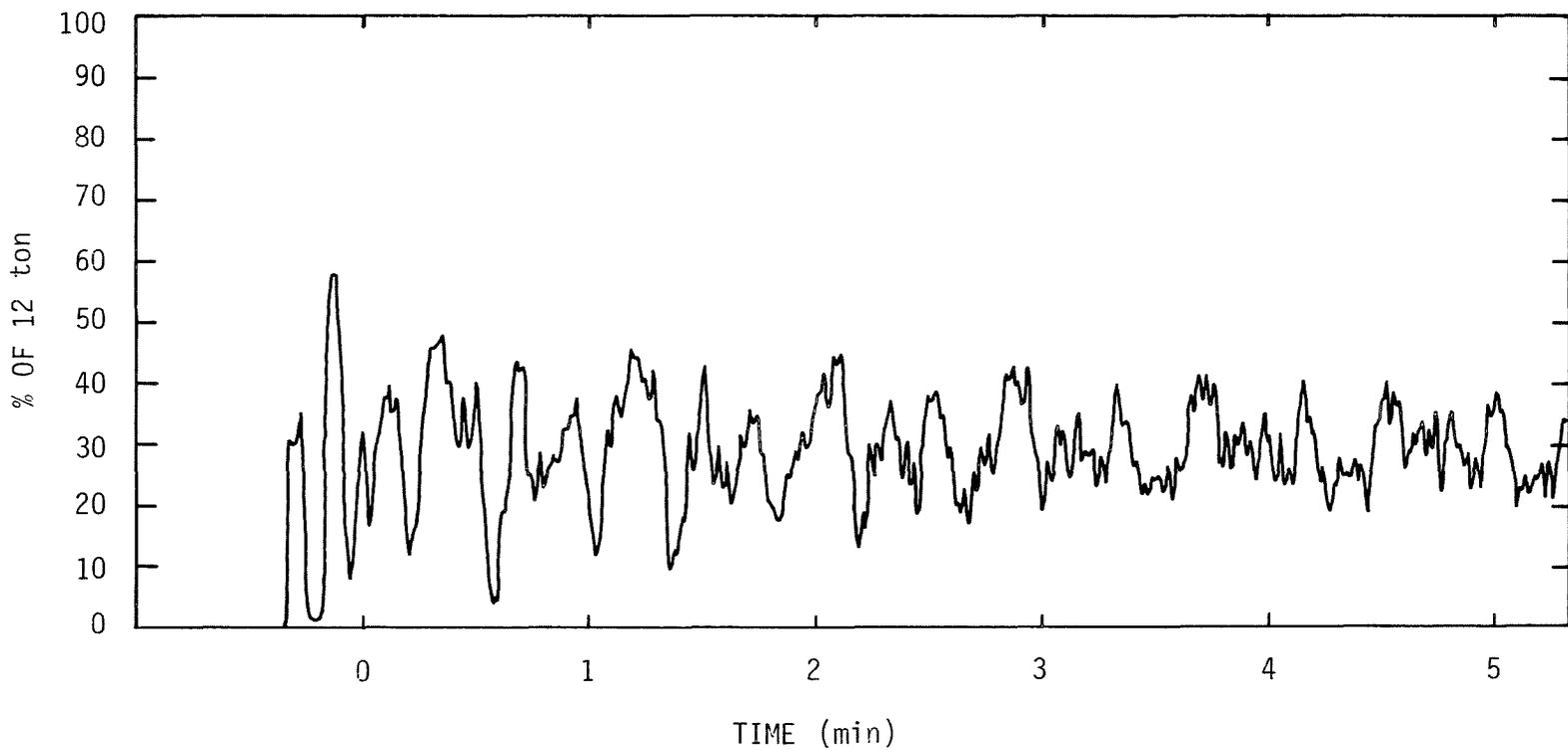
As the load increased the chain and flights tightened up. Under this condition, the nominal clearance between the chain and the lower structure of the machine was not adequate, and the flights began to bend and/or break away from the chain as they hit the structure. Figure 117 shows an example of a badly bent flight on the outby end of carrier no. 2

Each machine element was inspected, and various pieces were trimmed for clearance. However, the interference between the chain conveyor and structural cross members was more severe than had been originally anticipated. During the process of trimming excess protrusions off various cross supports, it became apparent that it would be advantageous to be able to reverse the electric motors that drive the chain conveyor. This would be particularly helpful in the event of a jam.

Once the problem of structural interference was rectified, the coal haulage testing resumed, but after running for only a short period of time the same problem reoccurred. Upon investigation, the test personnel discovered that a large amount of fines had been collecting on the inside of the pan that covered the bottom of the machine.

This accumulation was a result of continuously running the same material around the closed loop. Each time that material went through a transfer point, it got broken into smaller and smaller pieces. These pieces became hard packed and built up on the pan, reducing the amount of

FIGURE 116. - Sample output from strip chart recorder.



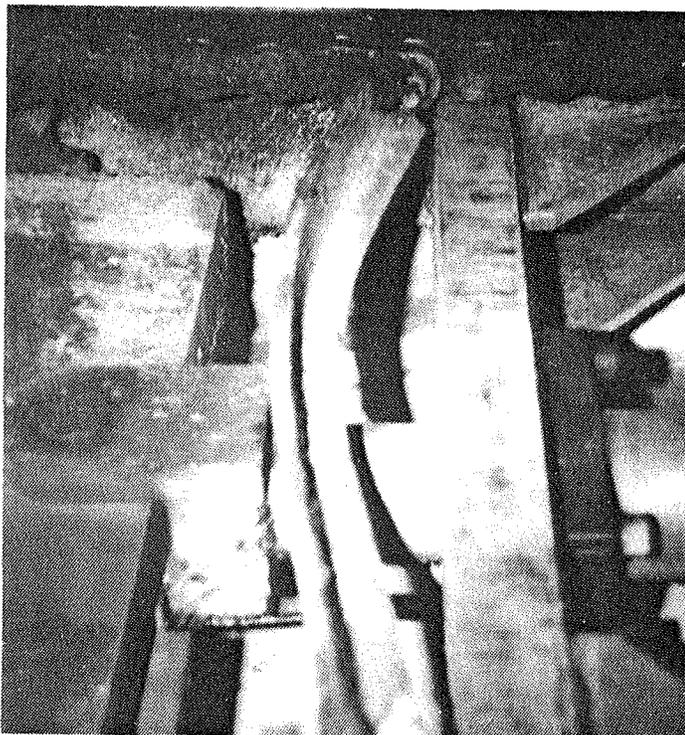


FIGURE 117. - Example of a badly bent flight.

clearance for the flights. This buildup recreated the interference problem. To avoid a reoccurrence, the pans were removed and cleaned, and periodically the system was flushed with copious amounts of water.

Once the above debugging was completed, testing personnel loaded the system with increasing amounts of run-of-mine coal and gob. This was accomplished by loading the scoop which then deposited its load onto bridge no. 2. By regulating this dumping activity, they were able to even out or make piles of material at any spot on the loop. Testing began by transporting small amounts of material and gradually building up.

In general the tests went well, and although the goal of transporting 12 tons/min was not met, the machine did manage repeatedly to transport over 90 tons of wet coal in 10-min operating periods. When trying to transport amounts over this, the conveyors of both Carrier No. 1 and bridge No. 1 began to stutter.

It is anticipated that a capacity of 6 tons/min will satisfy the output of a continuous miner with provisions for surge loading in excess of 2 tons. During the Bruceton tests the ABCT transported over 25,000 tons of material ranging in size from fines to large pieces weighing over 50 lb.

4.2.4.3 Surge Haulage Testing

The surge haulage tests used the same configuration as that for the previous tests. The entire loop was emptied of all material and then with a scoop, various amounts of coal were loaded onto bridge no. 2, conveyed over the belt scale and subsequently dumped into the inby hopper of carrier no. 1. The machine was then turned on and observations were made on the machine's ability to move the material.

When the machine was in good operating condition, that is when not plagued by interference problems between the flights and the structure, the hopper could be filled to overflowing without stalling the conveyor. Depending on the sizes of the pieces and on whether the material was wet or dry this amounted to between 1-1/2 and 2 tons.

The leveling chains located in the bottom of the hopper did a good job in controlling the amount of material that left the hopper per unit of time. During this unloading process the chain conveyor was covered to an average depth of approximately 4 to 6 in. over its full width. The hopper emptied in 3 to 5 sec.

4.2.4.4 Conclusions from Coal Haulage Testing

Despite the interference problems, the ABCT showed that it could haul coal at slightly over 9 tons/min and is capable of handling surge loads up to 2 tons. This compares with an original contract requirement for a capacity of 12 tons/min.

Further work was shown to be needed to provide greater clearances for the chain and flights. In addition an investigation of other flight designs was indicated. The design tested did not have a particularly large cross sectional area that could be welded to the chain, and when the flight received a large shock load the flight not only bent but sometimes the weld to the chain cracked.

4.2.5 Braking Tests

During use underground, there may be occasions when the ABCT will be parked on a grade. These tests involved simply parking the machine on a hill and observing any creepage.

The ABCT was driven out of the room and pillar gallery and onto the grade from building 151 toward the parking lot. Figures 118 and 119 show this sequence. The hill represented a much tougher condition than one would normally encounter underground. There are several reasons

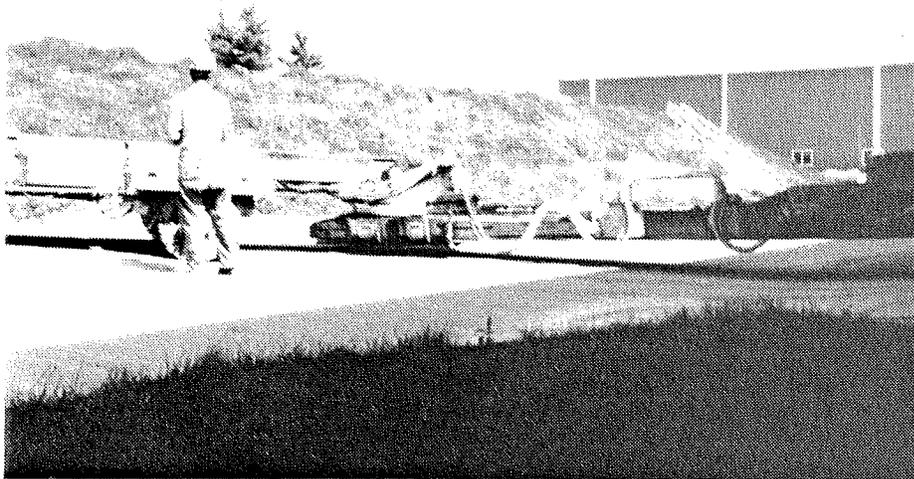


FIGURE 118. - ABCT in transit to parking area.

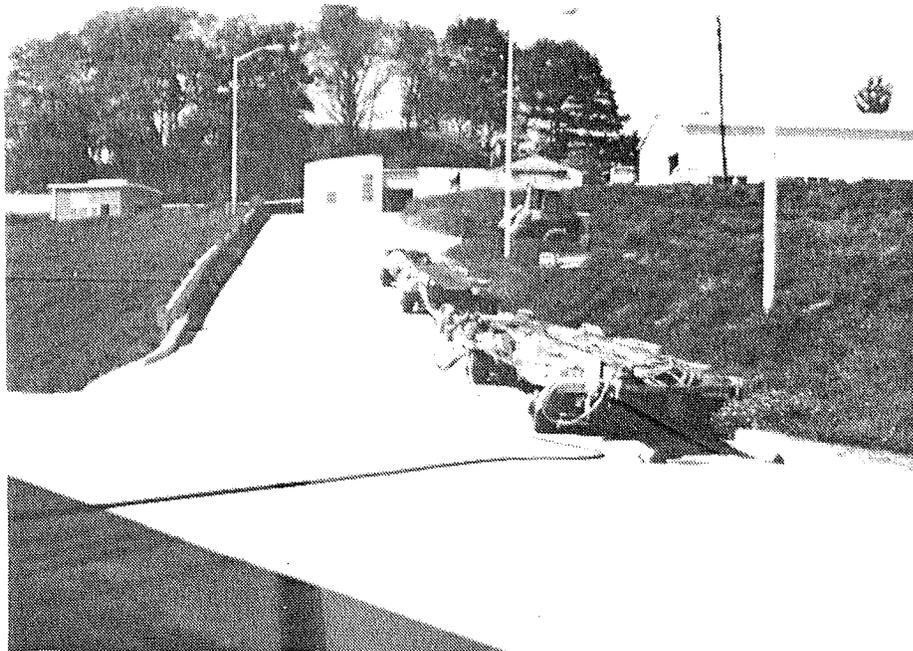


FIGURE 119. - ABCT parked on hill.

for this. In the first place, the grade is quite steep, having an average 8-1/2° slope. Secondly, the surface was paved with concrete. Therefore, there was little resistance to rolling such as would be the case on a soft dirt floor. Finally, under actual mining conditions, ABCT will be much longer than those units tested in Bruceton. In fact it will be between 375 and 500 ft long. It is not likely that the whole train would be parked on a grade, and if it were not, some portion of the system would be resisting the downward force produced by the units on the hill.

After the two carriers and the bridge were positioned on the grade, two wooden blocks were placed 36 in. behind the wheels. Periodically, measurements were taken and the blocks repositioned as required. Over the 4-h time span that the ABCT was on the hill, it rolled downward at a fairly constant rate of 20 in./h.

The ABCT has no brakes as such but depends on back pressure in the hydraulic system. When in a parking mode static hydraulic pressure is produced from the tendency of the wheels to roll downhill. This pressure tries to force fluid back through the hydraulic motor. The gear reduction between the hydraulic motor and the electric motor is so large that the pressure cannot overcome it. Creepage is probably due to hydraulic leakage through the seals of the motor.

4.2.6 Reliability

The ABCT can be broken down into major critical components. They are:

- a. The chain and chain drive
- b. Wheel drive
- c. The hydraulic system
- d. Electronics.

Each of these areas will be discussed and an evaluation of its past performance and expected future performance will be made.

4.2.6.1 Reliability of the Chain and Chain Drive

The surface tests pointed out some serious, but easily rectifiable, problem areas. Problems associated with machine clearances, the type of flight used and workmanship problems associated with welding the flights to the

chain were exposed. In addition, the advantages of having a reversible chain drive were shown.

Tests at the METF highlighted the need to make changes but, no extension of the state-of-the-art was required. What was required was an examination of the clearance problem and the use of a mine proven chain and flight system. Chain conveyors are not new to underground mining and there was reason to believe that this system could work as well as or better than systems currently in use.

4.2.6.2 Reliability of the Wheel Drive

The reliability of the tramming system depends upon a number of other systems such as the hydraulic system, the electronics, and the cable deployment system.

There is one feature of the tramming system that was of particular benefit during the tests and which should be of equal benefit underground. That is the ability to operate the entire system from the inby control panel in an automatic mode or to operate individual units in the manual mode. There may be cases when, because of breakdown, one or more units will have to be removed from the system. The manual mode of operation will be required to accomplish this task. Both of these modes of operation operated flawlessly during the testing at Bruceston and this should continue to be the case in the future.

In early testing, problems associated with running the machine at 40 ft/min were revealed. Tests were needed to determine whether the wheels were being hydraulically starved or whether the Dynex valves were inadequate. (It was later determined that the wheels were hydraulically starved.) From a reliability point of view, this was a very important question because a forward tram speed of 50 ft/min will be desired in the future. In summary, at speeds of 24 and 32 ft/min, tramming reliability was not a problem, but for higher speeds, additional work was needed.

4.2.6.3 Reliability of the Hydraulic System

The hydraulic system was plagued with problems in the early tests. The only testing performed prior to that in Bruceston was at the Long-Airdox facility where the machine was never operated longer than a few minutes. Just prior to shipment to the METF, the machine was turned on and run as preparations for the move were nearing completion. The outside air temperature was quite warm and there was some concern regarding the temperature of the oil. After the temperature was checked and found to be well over 200°F, a decision was made to add an oil cooler. The design prohibited use of a larger oil tank.

There were also problems due to poor hose construction. Testing personnel had to make several hose substitutions when fittings began to break away from the hoses. This situation was aggravated in some cases by poor hose routing, particularly around the wheel units; but as before, experience is a good teacher and after a trial and error process, optimum hose routing was achieved.

Finally, there was the need to increase the machine tram speed. This problem was left to be addressed in future work.

In summary, many of the problems were solved early in the testing and caused no additional problems afterwards. All the hydraulics in this system are comprised of standard commercial parts, and therefore spares and servicing in the field should not pose any more of a problem than does mining equipment in use today.

4.2.6.4 Electronics Reliability

Reliability of an electronic system is dependent upon the number of components in the system and the stress applied to those components. The amount of energy dissipated (stress) by a component is directly related to the useful life of the component. The greater the stress within the maximum allowed stress limit, the lower the expected useful life. Operating temperature is another important factor that affects component life. Vibration, shock and humidity are factors that must also be considered, especially at the system level.

All electronic components and subsystems on the ABCT were designed such that they have a minimum amount of applied stress. Selection of these components and subsystems was made to ensure that their maximum stress ratings are conservative in relation to the applied stress and environmental conditions, thus ensuring a maximum useful life.

Components and systems used on the ABCT worked remarkably well in testing when one considers that the environmental conditions encountered may have been worse than those that will be encountered underground. During one long stretch, the system was stored outside and as a result was exposed to the hot sun and to rain which leaked into the explosion-proof enclosures. When operating within the METF the heavy covers to the explosion-proof enclosures were removed, thus exposing the electronics to dust and humidity.

Most of the problems encountered were what should be classified as electromechanical problems. These included loose wire connections and a cable harness that did not have a large enough service loop for slide-out assembly modules. These kinds of problems were addressed and solved in the early portions of this phase and no subsequent electronic problems appeared.

5. PREPARATION FOR UNDERGROUND APPLICATION

The previous section (section 4) discussed surface testing of a two-unit (two MBCs and two bridges) portion of the ABCT. This section describes FMI's activities in preparation for underground tests of a five-unit system. Our efforts are covered in the following sections:

- a. Section 5.1 details the redesign of troublesome areas identified during the surface tests
- b. Section 5.2 discusses fabrication of three additional units and modification of the two existing units
- c. Section 5.3 describes our efforts in obtaining the necessary MSHA approvals for underground operation of the ABCT.

5.1 REDESIGN AND MODIFICATIONS

During surface testing, a number of deficiencies appeared with regard to individual components of the ABCT and/or the interaction of those components. However, most of the problems were permanently corrected during the testing program and the surface tests were brought to a successful conclusion.

While the system performed well in its surface evaluation, the tests did point out certain areas requiring redesign prior to incorporating the ABCT into the day-to-day operations of an underground mine. Areas in need of modification included:

- a. Increasing tram speed to 50 ft/min. (This is typical of a continuous miner's tram speed when it is place changing)
- b. Increasing haulage capacity to 12 tons/min
- c. Replacing Hubbel switches (sequential shutdown)
- d. Redesigning proximity switch activation arms (on dollies).

Other items requiring action prior to sending the ABCT underground involved the addition of components not required for surface tests, but which would be required for underground operation. These items included:

- a. Crossover switches
- b. Illumination
- c. Voice communications.

Still other items addressed at this time were not essential to operation of the ABCT, but they were likely to enhance reliability and, therefore, operator acceptance. These items were:

- a. Pillow block retention
- b. Adjustable plow height
- c. Quick-release bridge stops.

5.1.1 Increasing Tram Speed

Of those items found to require modification or improvement, the single most critical (and the most complex) was the ABCT's tram speed. Discussions with industry personnel led to the conclusion that unless the system had a top speed of at least 50 ft/min, it could, at times, become a limiting factor to the productivity of current mining systems. If that became the case, operator acceptance would be quite difficult to obtain.

Increasing the tram speed was not a simple matter. The ABCT had been designed for a maximum speed of 40 ft/min. While the original contract contained no specific requirement for tram speed, 40 ft/min had been selected as a design goal. Tramming tests found that rate to be near the limits of the hydraulic system's capabilities. Occasional wheel hangups occurred at the higher speed due to the lower available torque.

In order to increase tram speed, a series of changes were necessary:

- a. New stepper motor/servo valve combination to handle higher oil flow
- b. Addition of a rotary union at the top of the wheel unit to provide room for the larger stepper motor
- c. New hydraulic pump to accommodate the increased requirements for hydraulic oil
- d. Larger electric motor to drive the larger hydraulic pump

- e. New oil cooler to dissipate the additional heat generated by the higher capacity hydraulic system.

5.1.1.1 New Stepper Motor/Valve Combination

The previous stepper motor had been selected for a maximum tram rate of 40 ft/min, but it was not capable of greater speeds. Therefore, a new stepper motor was chosen which can produce tram rates of up to 60 ft/min.

Calculations indicated that the existing dynex valve, with some modification, could handle the higher oil flows. These calculations were proven to be correct in component tests performed by Olson Controls.

Figure 120 shows the previous wheel unit design. Although the new stepper motor is larger than the old one, we were able to redesign the motor/valve combination to take up a minimum amount of space. By adding a rotary union to the top of the wheel unit, we made better use of the space available. This allowed us to get rid of a number of hoses and to replace others with tubing. Figure 121 shows a new wheel unit design.

5.1.1.2 New Hydraulic Pump

The former, fixed-delivery pump could not provide enough oil at a high enough pressure for a tram speed of 50 ft/min. That pump was replaced with a Sundstrand variable delivery, pressure compensated pump. This new pump is quieter and produces less hydraulic hammer in the system.

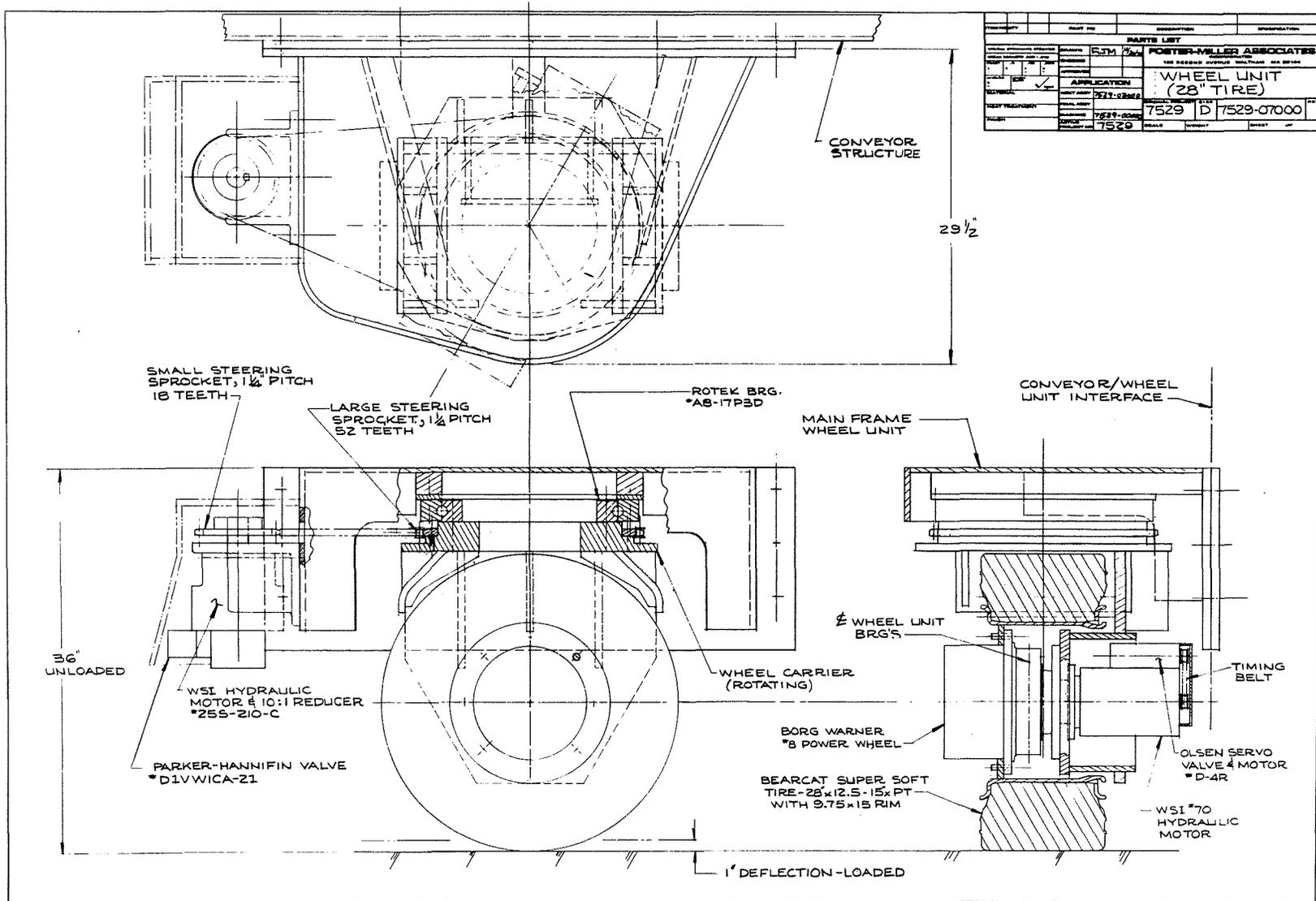
The former pump was driven by a 50 hp electric motor. The Sundstrand is driven by a 75 hp motor and is shown in figure 122.

5.1.1.3 New Heat Exchanger

Calculations showed that the Modine liquid-to-liquid heat exchanger was not adequate for the new hydraulic system, and a liquid-to-liquid cooler of sufficient size would require excessive quantities of cooling water. The chosen solution was to install a Modine air-to-liquid cooler as shown in figure 123.

Space for the new heat exchanger became available when the electronics system was converted from Intel 8080-4 to Pro-Log (see section 5.1.3.4). All electronics from the former interface and control electronics boxes were combined in the control electronics box; thus eliminating the interface box.

FIGURE 120. - Old wheel unit.



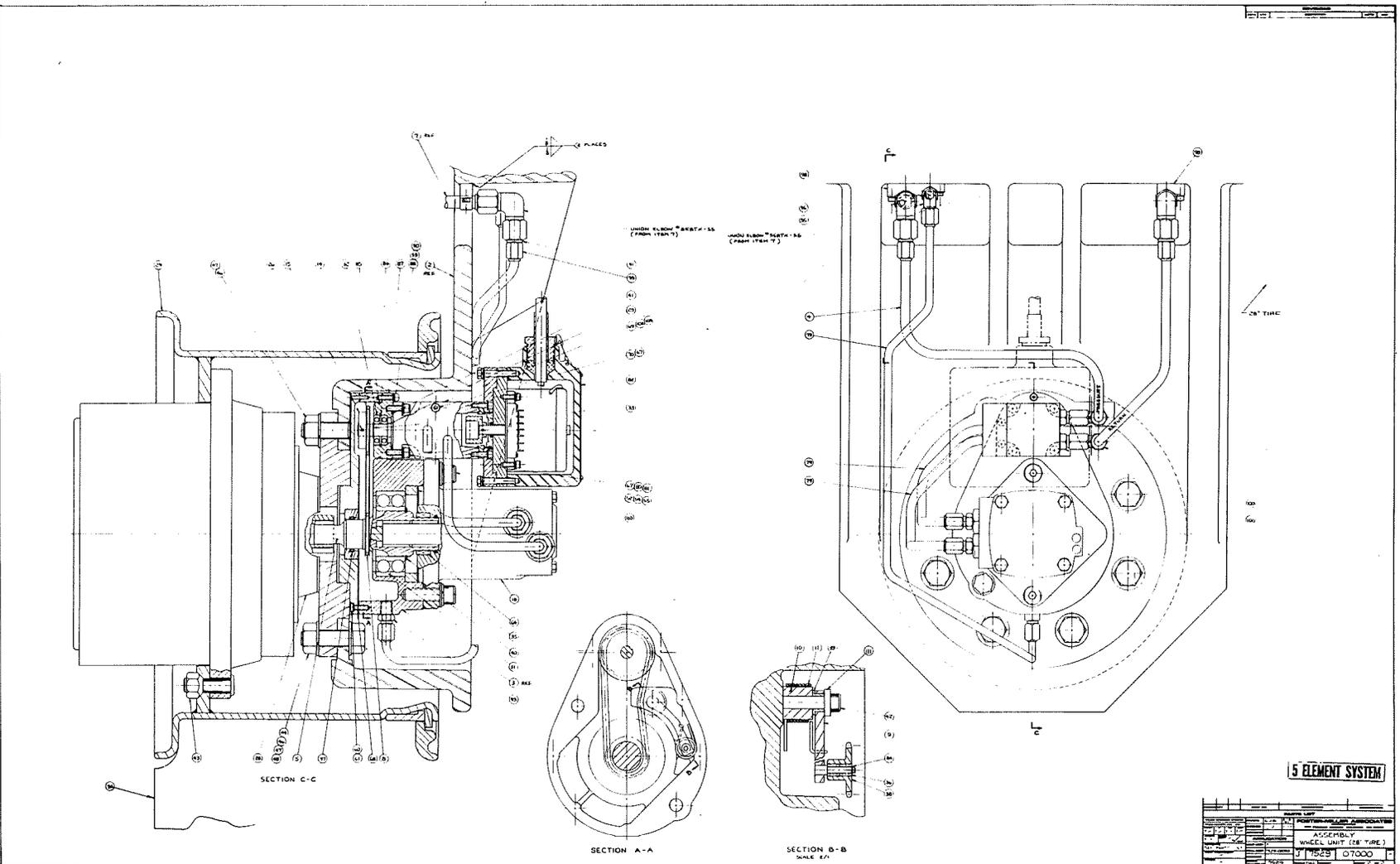


FIGURE 121. - Modified wheel unit.

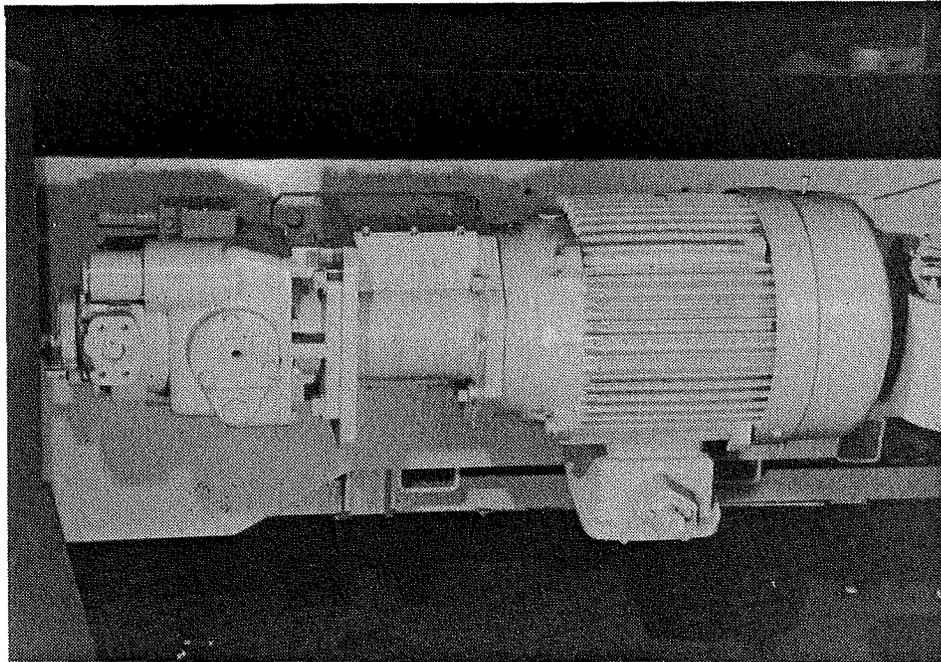


FIGURE 122. - New hydraulic pump and motor.

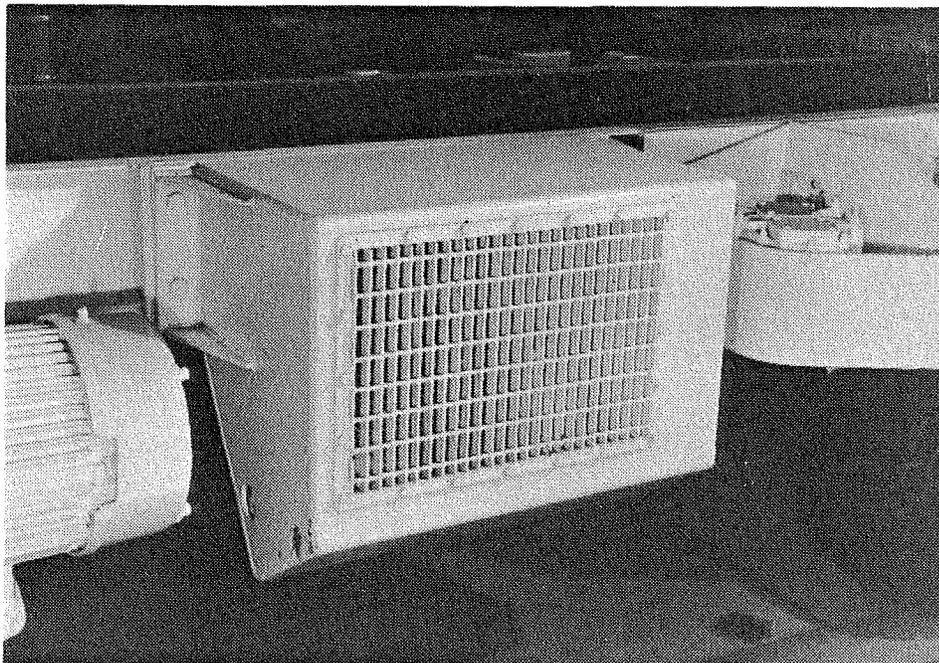


FIGURE 123. - Modine air-to-liquid heat exchanger.

5.1.2 Increasing Haulage Capacity

During surface testing of the 4-element portion of the ABCT (section 4.2.4), a maximum sustained haulage capacity of just over 9 tons/min was achieved with surge capacity. That rate would be adequate for most underground applications but our design objective of 12 tons/min is needed to hold surge requirements to a minimum.

To obtain a haulage capacity of 12 tons/min, two key changes were instituted:

- a. Conveyor drive modifications
- b. Extra clearance for chain and flights.

5.1.2.1 Conveyor Drive

Analysis of the conveyor drive system showed that, with no other problems, the 20 hp drive motor should move 12 tons/min, but only marginally so. This motor was upgraded to a 30 hp unit.

On the bridges, we had problems with failure of the inby turnaround shaft during the coal haulage tests. The bearings both on the turnaround shaft and in the take-up assembly were redesigned to use heavy Timken bearings in a back-to-back configuration. They are now mounted in a housing with a grease fitting.

The combination of new drive motors along with new bearing design for the turnaround shaft should insure a haulage capacity of 12 tons/min.

5.1.2.2 Extra Clearance and Flight Redesign

Early in the haulage tests, severe problems were caused by interference between conveyor flights and cross supports beneath the conveyor pan. During the testing, additional clearance was obtained by cutting out those supports. More room has now been provided by redesigning the supports so that they do not extend as far beneath the pan.

Stresses induced in the flights, primarily as a result of jamming, caused a number of those flights to bend or break free. The previous flights had an "L" shaped cross section with each end of the flight welded to a plate that attached to the conveyor chain (see figure 124). That design proved to be of less than satisfactory strength.

A stronger flight design has now been incorporated into the conveyor. The flights are cast, inverted "T's"



FIGURE 124. - Old flight design.

with each end of the flight forming a two-hole flange. This flange bolts directly to the conveyor chain. Figure 125 shows a flight and its attachment to the chain.

5.1.3 Hubbel Switches

Surface tests in Bruceton showed that the Hubbel switch, which was used for sequential shutdown of conveyors in an emergency mode, did not work properly. The mechanical drive of the switch and electrical noise generated in the system caused contacts to operate erratically. To solve this problem we changed to a noncontacting, solid state, zero speed switch on the conveyor turnaround shaft at the outby ends of the carriers and bridges. The device is contained in an explosion proof enclosure.

5.1.4 Other Mandatory Modifications

5.1.4.1 Knife Switches

The knife switch used to control the position of the bridge with respect to the dolly caused numerous problems during surface tests. The activation arm proved to be the weak point. To correct the situation the delicate jointed pins, which were used to connect the arm to the dolly

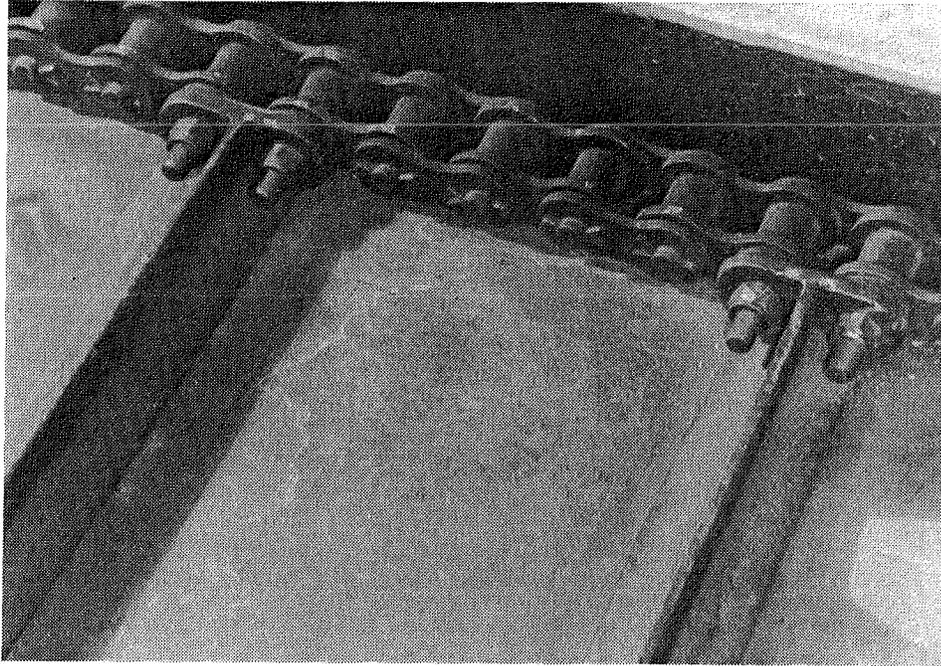


FIGURE 125. - New flight design.

frame, were first replaced with a piece of conveyor belt material. This material seemed to provide the necessary flexibility while being able to withstand the dirty environment within the dolly.

Further analysis of the situation, however, convinced us that the best solution would be to eliminate the actuator arm altogether. The entire knife switch was replaced with a Hamlin Reed magnetic switch. In subsequent component testing, the proximity switch proved to be quite effective and far more reliable.

5.1.4.2 Conveyor Reverse

It was discovered during haulage testing that the ability to reverse an individual conveyor would be highly desirable as a means of freeing a jammed conveyor. The necessary electrical modifications were made and a control switch was provided on each conveyor which can be used to reverse that particular drive.

5.1.5 Addition of Systems Required for Underground Operation

For surface testing, certain safety features were not required in the closely monitored environment of the test

facility. Following the tests, these features were incorporated into plans for modification of the existing units and for fabrication of the additional units.

A number of items, along with certain safety functions, are centralized in the system control electronics. Centrally controlled functions include:

- a. Sequential start-up of pump motors
- b. Initiation of start-up and back-up horns
- c. System shut down (as caused by activation of the cross-over switches)
- d. System shut down caused by overheated hydraulic oil.

Discussions with MSHA revealed that, for underground use, lighting would be required on the inby carrier of the ABCT. In accordance with MSHA's requirements, two fluorescent lighting units were installed on the inby carrier; one on each side of the hopper.

To provide voice communication, phones were located on each carrier.

5.1.6 Additional Modifications

A number of items were redesigned not so much out of necessity, but for convenience of operation and maintenance. It was felt that these changes would enhance operator acceptance.

5.1.6.1 Pillow Block Retention

Surface testing revealed a problem with the pillow blocks used to guide the dolly within the yoke. When the turning angle between the carrier and the bridge exceeded 70°, the pillow block fell out of its track. This caused no damage, and angles greater than 70° would not often occur in day-to-day operation, but each occurrence was a "nuisance" in that time had to be taken to replace the block.

To eliminate pillow block loss during sharp turns, we replaced those blocks with self-aligning spherical sleeve bearings. These bearings "find" their tracks even when the angle between a carrier and bridge exceed design limits for normal operation.

5.1.6.2 Plow Height Adjustment

As discussed in section 4.2.2.2, addition of a plow solved numerous problems caused by an uneven floor. The plow was mounted at a fixed distance above the floor (2 in.), but situations could arise in which it would be desirable to adjust that height.

To provide for plow adjustment, manually operated screws, shown in figure 126, raise and lower each side. Hydraulic adjustment had been considered, but it was concluded that a complex system was not called for since such adjustments would be made only occasionally.

5.1.6.3 Quick Release Bridge Stops

New dolly stop blocks were installed on the bridges. The original blocks were bolted to the frame and, although they worked effectively, they would not allow the bridge to be stowed under a carrier without removing the bolts. The new blocks can be swung easily out of position.

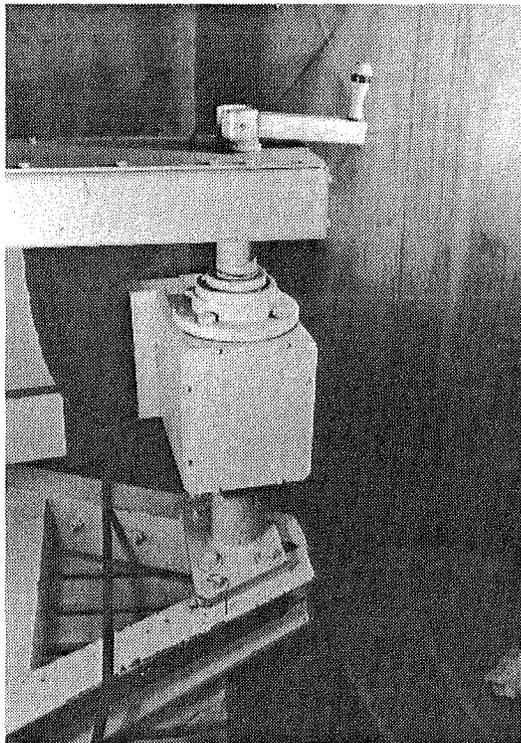


FIGURE 126. - Plow adjustment screw.

5.1.6.4 Other Modifications

Other changes to the system intended to increase its reliability or improve maintainability include:

- a. Change of control electronics from Intel system to Pro-Log system. The Pro-Log system is completely self-contained. The entire system, in turn, is housed within a second, explosion-proof box. This makes servicing much easier since a module is replaced simply by unplugging the defective unit and substituting a new one. The Pro-Log design features much smaller printed circuit cards which are more tolerant of vibration than was the Intel system
- b. Provision for automatic stowage/unstowage. To collapse the ABCT to its minimum length, an automatic override is provided so that individual carriers can ignore the dolly switch commands. Since the bridge which is being pushed under an adjacent carrier must be in line with it for proper stowage, a series of switches along the bridge assembly monitors the angle between the units. If preset angular limits are exceeded during stowage, the microprocessor makes steering corrections; thus restoring alignment of the units.

5.2 CONSTRUCTION OF A FIVE-UNIT ABCT

The previous section described design changes resulting from surface tests of a two-unit system. The tests showed that, with some modifications, the two units were capable of underground operation. For practical in-mine application, at least five double-units would be needed. That would give a total reach of 278 ft.

To make up a 5-unit ABCT for underground testing, it was decided that the two existing units would be modified and three new units would be fabricated. Specifications were as follows:

- a. Each carrier is 35 ft 1-1/2 in. long except for the inby unit which is 36 ft 1-1/2 in. long. Each bridge is 25 ft 4-1/2 in. long, and it telescopes from a minimum of 8 ft 3 in. to a maximum of 22 ft 9 in. (That is the exposed portion of the bridge between adjacent carriers.)
- b. Maximum height is 42 in.

- c. Ground clearance in general is about 12 in. However, there are local areas that clear the bottom by only several inches.
- d. Each carrier weighs approximately 25,000 lb, and each bridge weighs approximately 10,000 lb.
- e. The wheel rim has an OD of 15 in.
- f. Tires are 28 in. diam, foam filled.
- g. The ABCT is hydraulically driven with power provided by a 75-hp electric motor.
- h. Power is transmitted through a planetary drive.
- i. Each carrier has four-wheel independent steering and drive.
- j. The tramming speed is 24 ft/min in automatic mode and 32 or 50 ft/min in the manual mode.
- k. Each carrier has a central processing unit which controls the steering and rotational speed of each of the four wheels.
- l. All of the electronics are enclosed in explosion-proof housings which are located on the side of each carrier.
- m. The trough of the inby carrier can hold up to 2 tons of material.
- n. Each conveyor is driven by a 30-hp electric motor.
- o. Conveyors are double chain drive, welded to the ends of the flights.
- p. The chain conveyor extends the full length of each unit.
- q. Each conveyor is 30-1/2 in. wide.
- r. Conveyor speed is 300 ft/min.
- s. A guidance cable deployed by the inby carrier, guides the ABCT in both forward and backward directions.
- t. Guidance information is provided by electromagnetic sensors for each pair of wheels which sense the position of a guidance cable on the mine floor.

5.2.1 Fabrication of New Frames and Refurbishment of Existing Frames

Two potential subcontractors were considered for fabrication and assembly:

- a. Long-Airdox in Pulaski, VA
- b. Plainville Machine in Plainville, MA.

Visits to the facilities of the potential vendors confirmed the ability of each to perform the anticipated work. However, since Long-Airdox had fabricated the two original units, each company was asked to quote only the items to be fabricated. Each then gave us an hourly labor rate for assembly. Based on their lower price plus a shorter delivery time, Long-Airdox was awarded the sub-contract for fabrication of the three new units. Work began in November 1981. The two existing units were shipped to Pulaski, VA at that time for rework.

By February 1982, the work load at Long-Airdox had increased to the point that it became necessary for FMI to provide a full time on-site liaison. Liaison personnel inspected weldments and machined parts, monitored progress versus schedule, and solved problems as they came up.

The first two new units (two carriers and two bridges) were delivered to FMI's Saxonville, MA facility in April 1982. Examination of the hard plumbing from the wheel unit rotary union to the tram motor revealed some problems with workmanship. Long-Airdox corrected those problems.

In October 1982, Long-Airdox completed fabrication of the third new unit along with refurbishment of the existing frames. All three units were received in FMI's Saxonville facility in November 1982.

5.2.2 Assembly of ABCT Units

Final assembly of the ABCT took place at Saxonville. A number of subassemblies were prepared by subcontractors who then shipped those items to Saxonville. Some components, such as the new cone drives for the larger conveyor motors, were ordered through Long-Airdox since their larger volume of business resulted in volume discounts and/or better delivery times.

Based on competitive bidding, a purchase order was released to Plainville Machine for explosion-proof (XP) boxes.

A subcontract was issued to Louis-Allis for 30 hp conveyor motors and 75 hp motors for the hydraulic system.

Tram motor assemblies which were built under a previous phase of the contract were shipped from Long-Airdox to Saxonville. The assemblies were reworked by FMI with new parts manufactured at a local machine shop.

It had been intended to subcontract assembly of the control valve/stepper motor subassembly, but a cost analysis showed that the work could be done more efficiently in house. After disassembling and reviewing an old unit, a disassembly procedure was written to guide a technician. An assembly procedure for the new design was written and fixtures required for the procedures were prepared. Piece parts for the assembly were machined by an outside vendor.

Since all hydraulic hoses and electronics were to be assembled and subsequently tested at Saxonville, 1000 V electrical service was required. Two alternatives existed. A government owned power distribution system was available in Bruceton, but the cost of transporting it to, and installing it at, Saxonville would have been quite high. The chosen alternative was to purchase a 135 KVA, 960 V autotransformer. That provided enough power to operate two units at a time for less than one-fourth the cost of transporting and installing the larger power center.

As the units were assembled in Saxonville, minor problems arose with the installation of hydraulic lines. For example,

- a. When the modified Olsen control valve and tram motor assembly was attached to the wheel unit motor, the hydraulic tubing did not mate correctly. The tram motor manifold was redesigned and appropriate changes were made
- b. When the first two units were received from Long-Airdox, examination showed potential difficulties installing hydraulic hoses and fittings in the pump area. New manifold blocks were designed and installed to reduce the number and complexity of those fittings.

Due to the minor changes that were occurring during installation of the hydraulic system, we decided to plumb one complete carrier and then order predetermined hose assemblies and fittings for the remaining four carriers. This decision minimized potential delays and made the ordering of hydraulic parts more efficient.

The electrical and hydraulic systems for the first carrier were completed in August 1982 and a system check was conducted. After fixing the normal leaks that occur when a hydraulic system is first pressurized, we found that we could not set the main and charge pump relief valves. Severe cavitation problems were occurring with the Sundstrand pump. To correct the problem, we replumbed the main relief valve sending the flow of oil over it to the intake manifold rather than the tank. The main pump had been oil starved and the charge pump could not make up the quantity of oil required by the Sundstrand pump.

A procedure was established for setting the main relief valve. The charge pump relief valve was set at 40 psi and when the compensator screw of the Sundstrand pump was fully in, the main relief valve was set at 2500 psi. The compensator screw was backed off until a system pressure of 2000 psi was obtained. Cavitation still occurred for 5.2 s on initial start up, but that is well within the Sundstrand pump's limits.

The oil cooler pressure valve was set at 600 psi which allowed proper fan rotational speed. The manual steering operation of the wheels was tested and found to work within normal limits. Then rotation of the wheels was checked and the maximum speed was recorded at 49.48 ft/min; essentially equal to the design goal of 50 ft/min. The wheels were run through their full speed range and proper ramping speeds were observed.

In November 1982 plumbing and wiring of the second carrier was completed. By early 1983, when work ended, the remaining three units were 78% complete and more than half of the necessary testing at Saxonville had been conducted.

5.3 MSHA CERTIFICATION

Two types of certification were required for the electrical systems of the ABCT:

- a. Those systems whose voltages were low enough that no potential existed for ignition of explosive gases (due to sparks) could be certified by MSHA as intrinsically safe (IS approval)
- b. Those systems which did hold the potential for ignition of explosive gases had to be housed in enclosures that could withstand an internal ignition without allowing that explosion to propagate to an external explosive atmosphere. It was necessary that MSHA test and certify those enclosures as XP.

FMI's efforts to obtain MSHA certification are described in three sections:

- a. Section 5.3.1 discusses the XP approval process
- b. Section 5.3.2 discusses our efforts to obtain IS approvals
- c. Section 5.3.3 gives some observations and recommendations for dealing with the approval process in the future.

Events are presented in chronological order.

On June 4, 1980 applications were submitted to MSHA for both XP and IS approvals. Each application consisted of:

- a. An application letter
- b. The corresponding drawing package
- c. A checklist for each package.

Since work on the ABCT, at the time of application, was being funded by the United States Department of Energy (DOE), MSHA required that all applications be submitted by, and subsequent approvals be granted to, DOE. MSHA estimated that the XP certification would begin in August 1980, but consideration of the IS applications might take until April 1981 due to a heavy backlog.

5.3.1 Explosion-Proof (XP) Certification

Seven XP certifications were originally requested:

- 1) Data Bus Enclosure, 24 V dc
- 2) Power Connection Box, 1000 V ac
- 3) Carrier Starter Assembly, 1000 V ac
- 4) Stepper Motor Enclosure, 2 V dc
- 5) Control Electronics Assembly, 120 V ac/24, 12 and 5 V dc
- 6) Interface Electronics Assembly, 120 V ac/24, 12 and 5 V dc
- 7) Inby Carrier Starter Assembly, 1000 V ac.

For each application, the following was submitted:

- a. An application letter
- b. A drawing list
- c. A checklist
- d. A factory inspection form
- e. A complete drawing package.

The drawings were taken from standard Long-Airdox designs for XP enclosures already approved by MSHA.

October 1980

We were notified by MSHA that they were preparing to begin evaluation of the XP applications. Since the boxes already on the ABCT would be difficult to use for testing, we ordered a second set from Long-Airdox. A model shop was contracted to prepare mock-ups of the internal components.

It should be noted that actual components are not required for testing, but mock-ups are necessary to duplicate internal flame paths. For XP testing it is not a question of whether or not the components can cause an explosion; in the test it is assumed that they will. The question is whether or not the box itself will totally contain the heat generated by the ignition.

November 1980

MSHA pointed out a problem with the stepper motor enclosure that was caused by the tight space constraints of the original wheel unit design. When the unit was redesigned with the stepper motor being moved to the top of the wheel unit, it allowed more room. Using the extra space, we redesigned the stepper motor enclosure and that design was resubmitted to MSHA.

A meeting was held in Triadelphia, PA to review our applications. As a result of that meeting, a large number of relatively minor, but time-consuming changes had to be made on our drawings. Many of the changes resulted from the fact that more information was given on the drawings than was absolutely required by MSHA. As a result, that information had to be further explained and/or added to every drawing.

December 1980

MSHA found a flame path problem between the power connection box and the bulkhead connector manufactured by Pyle National. Investigation showed the pilot diameter on the piece to be too short and MSHA asked us to interface with Pyle National to solve this problem. It is interesting to note that this item had been approved in the past and is currently used throughout the industry.

February 1981

The XP boxes were completed by Long-Airdox and shipped to FMI. Inspection revealed a number of mistakes that were made during fabrication to the point that the boxes did not match the prints. The enclosures were returned to Long-Airdox for rework.

March 1981

Long-Airdox corrected the problems with the XP boxes, but it was decided that the boxes should be held there until MSHA was ready for testing. The enclosures then would be shipped directly to Pittsburgh.

April 1981

MSHA notified us that XP tests were scheduled for the last week of May 1981.

May 1981

Six XP enclosures were shipped to Pittsburgh (all except the modified stepper motor enclosure). MSHA notified us that XP tests were rescheduled for mid-June.

June 1981

All six enclosures passed the MSHA tests.

July 1981

MSHA reviewed the drawings for the new Stepper Motor Enclosure and suggested several changes. Those changes were made and the drawings were resubmitted within the month.

September 1981

Even though six XP boxes had passed the required tests, no approval numbers had been issued to DOE. MSHA indicated that the numbers would be forthcoming. MSHA

also notified us that the subcontractor selected to build the XP boxes for the ABCT would have to request permission to do so.

November 1981

The new Stepper Motor Enclosure was shipped to Pittsburgh where it underwent successful testing.

Redesign of the ABCT had required gland changes on three of the XP boxes. The glands were resized and relocated. Applications were submitted for extensions to the XP approvals for those boxes.

March 1982

The cover for the Control Electronics Enclosure had been modified to provide a viewing window. This cover was shipped to Pittsburgh for retesting.

April 1982

The above cover passed the ignition tests.

5.3.2 Intrinsically Safe (IS) Certification

Five IS evaluations were originally requested:

- 1) Remote Operator's Control Station Circuit
- 2) Steering Valve Control Circuit, 10 V dc
- 3) Guidance Sensor Signal Circuit, 100 mV (maximum) ac (5 kHz)
- 4) Dolly Switch-Microprocessor Input Circuit, 24 V dc
- 5) Guidance Cable Deployment System.

As stated previously, the submission date was June 4, 1980. MSHA's backlog delayed the start of IS evaluations for over a year.

September 1981

A meeting was held in Triadelphia, WV to discuss the IS applications. In addition to the original applications, FMI had submitted a number of revisions over the previous year. Key results of that meeting were:

- a. It was decided that an "experimental" permit should be pursued since the review process is shorter for it than for regular certification
- b. An experimental permit allows the use of a "device" that has been approved by another agency such as UL
- c. The granting of an experimental permit might allow concessions to CFR 30 when necessary
- d. DOE had to send MSHA a letter asking that the experimental approval be granted to them
- e. FMI had to provide a statement of concurrence to MSHA stating that all circuits were built according to the drawings
- f. FMI would provide MSHA with a functional description of each of the 5 intrinsic safety packages as well as a description of how each design would achieve its goal
- g. MSHA estimated that the intrinsic safety evaluation would require 3 to 6 months.

FMI also was to provide an overall assembly drawing of the ABCT showing all XP boxes and IS circuits along with power cable runs and circuit breakers. This drawing would be used for machine inspection prior to the granting of an experimental permit.

October 1981

Due to the number of design changes that had occurred since June 1980, MSHA requested, and FMI submitted, the following:

- a. Updated drawings
- b. New IS application letters
- c. New data sheets.

November 1981

Based on further discussions with MSHA, FMI resubmitted the entire IS package.

February 1982

A review meeting was held in Triadelphia to discuss the IS application. More information was needed from manufacturers of individual components.

Problems had arisen in obtaining cable marked "MSHA Approved" due to long lead times. To avoid long delays, sample cable was ordered from ITT. The 30 conductor, 18 AWG sample was flame tested in accordance with CFR 30. Having passed the test, that cable could then be used with the IS systems.

March 1982

MSHA responded to our five IS applications with five letters. In response to those letters, several schematics were revised and five new schematics were created. In addition, the force motor barriers were redesigned. Other items requested by MSHA, but not completed within the month, were:

- a. Other drawing changes
- b. Serialization of each IS sensor for each bridge and carrier
- c. Photographs of each IS assembly and control case internal wiring
- d. Inductance values for the sensor cable including both cable reels.

May 1982

MSHA requested that the following items be shipped to them for testing:

- a. Three Dynex force motors
- b. One +5 V supply
- c. Three ± 12 V power supply power transformers
- d. Five kHz constant current supply
- e. Twenty 1500 ohm resistors
- f. Sensor electronics card
- g. One ± 12 V supply.

July 1982

Based on additional requests from MSHA the following work was performed:

- a. Redesign of the Grad Line Servo Amplifier boards
- b. Redesign of the IS power supply
- c. Rework of the +5 V power supply
- d. Rework of the ±12 V power supply
- e. Procurement of additional parts for testing
- f. Additional documentation of designs.

At the end of July MSHA notified FMI that the investigator assigned to the ABCT was being replaced.

August and September 1982

We attempted to continue the IS approval process but were informed by MSHA that there was no investigator for the ABCT.

April 1983

Control of, and responsibility for, the ABCT was transferred from DOE to the U.S. Bureau of Mines. As of that date, MSHA had taken no further action on the IS application and no investigator had been assigned.

August 1983

Following a phone conversation with DOE in Pittsburgh, MSHA cancelled the IS application.

5.3.2 Conclusions Regarding the MSHA Approval Process

As stated earlier, XP testing assumes that components contained within the enclosure will ignite an explosive gas mixture, so the actual specifications for those components are not critical. XP testing is fairly straightforward as far as MSHA personnel are concerned.

IS approvals, on the other hand, are based on being able to demonstrate that neither any component, nor the system as a whole, can possibly cause an ignition. That leads to an analysis of "What-if's":

- a. "What if a limiting resistor jars loose?"
- b. "What if a short occurs to a coil?"

IS evaluations are inherently time consuming. Most of MSHA's work in this area deals with relatively minor changes to existing electrical systems in an "evolutionary" process. When a totally new system (new at least to the mining industry) is introduced, MSHA might tend to be overly cautious but that is the nature of the investigation they are being asked to perform.

In cases where, as with the ABCT, design changes are occurring as the IS investigation is in progress, even more delays will result. Each change in one component must be evaluated for its potential effect on other previously checked components.

For cases where electronic design changes are anticipated after the approval process begins, we recommend that serious consideration be given to XP housings for all components of the electrical system including those items known to be intrinsically safe. Changes within an XP enclosure are simpler from a regulatory standpoint than are changes to a system already certified as intrinsically safe.

After a prototype has been tested, proven, and finalized, application can be made for IS certification. With the ABCT, over three years passed after the initial filing and the evaluation still had not been completed.