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AUTOMATED LONGWALL GUIDANCE AND CONTROL VERTICAL CONTROL SUBSYSTEM

VOLUME I

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1. EXECUTIVE SUMMARY

This final report describes the results of a research and development program conducted by Foster-Miller Associates, Inc. (FMA), on behalf of the National Aeronautics and Space Administration (NASA). NASA, in turn, provided the program management on behalf of the United States Department of Energy (DOE). The objective of the program was to develop a mineworthy automatic vertical control subsystem (VCS) for longwall shearers. Benefits associated with this type of automatic control system over normal manual control include:

1. Increased productivity

2. Enhanced worker health and safety

3. Technology advancement toward full-face automation.

The results of the research and development program were somewhat mixed. The VCS was developed and successfully demonstrated aboveground on the Joy Manufacturing shearer at the DOE aboveground longwall facility at the Pittsburgh Mining and Technology Center. The field test, however, can only be considered a partial success. The VCS was installed on an Eickhoff 300-EDL shearer at Old Ben Coal Company's second longwall at their Mine No. 27 in Frankfort County, IL. Schedule slippage due in part to the 71-day United Mine Workers Association strike forced the test on to this longwall, rather than the preplanned installation at Mine No. 21. Although the VCS was successfully installed and inspected and approved by MSHA, geological difficulties at the mine prohibited operation of the automatic control system. These activities are discussed in subsequent sections of this report.

Following the VCS field test, an intensive effort was made to answer key questions regarding the utility of sensor subsystems through field testing. A very successful test of the Natural Background coal interface detector (NBS-CID) was conducted at Carbon County Coal Company. This test demonstrated the functional nature of the NBS-CID in guiding the shearer based on the coal seam horizon.

A third major development effort was conducted by Adjunct Systems, Inc., under a subcontract to FMA. This was the development and subsequent aboveground demonstration of a small portable display processor which enables utilization of the VCS sensors and simplified control algorithms while eliminating the requirement to interface electrically with the candidate shearer. All of these efforts, conducted under Contract No. NAS8-33591, are discussed in detail in the following report.

2. VCS INTRODUCTION

The key objective of this program was the development of a mineworthy control system for automatic positioning of the cutting drums of a double-ended longwall shearer. The intent of this system is to provide the ability to automatically follow the coal seam based on the absolute position of the upper coal/shale interface. This objective was, in large part, met; however, problems were experienced at the underground test site which prevented demonstration of the VCS.

FMA became involved in this program after a breadboard VCS had been installed by Marshall Space Flight Center (MSFC) personnel on the Joy shearer at the DOE's Mock Longwall Facility (MLF) in Bruceton, PA. FMA's initial charter was to take this basic system configuration and perform redesign and repackaging to enable underground service. The activities which took place to accomplish this are described in Section 5 of this report.

Once the VCS was formally demonstrated at the aboveground MLF, it was shipped to the Old Ben Coal Company in Benton, IL, for underground testing. From a scheduling point of view, this underground test was ill-fated from its outset. Delays in the MSHA approval process caused the field test to slip several months from the time the system was demonstrated aboveground. This delay brought the project right into the nationwide United Mine Worker's (UMW) strike. The progress of the negotiations between the UMW and the Bituminous Coal Operator's Association (BCOA) was watched closely and as soon as an agreement seemed near, the VCS was shipped to the mine selected by Old Ben for this test.

Originally Old Ben management had selected a new longwall, planned for startup in March at their No. 21 mine, as the best site for field testing of the VCS. Mining conditions were expected to be good and the crews were experienced longwallers. However, due to the delays, that face at No. 21 went into production without the VCS. When the VCS became approved for underground service and when the UMW strike ended, the only siting option available within the framework of our schedule was a new longwall at Old Ben's Mine No. 27. Conditions there were somewhat unknown; however, this was the second longwall at No. 27 and conditions at the first were not good. Secondly, since this represented an expansion in the longwall capacity at No. 27, the crews were somewhat inexperienced in longwall operations in that they were transferred from continuous miner sections.

This effort is described in greater detail in Section 6 of this report. Despite the fact that the VCS was never fully demonstrated underground, the experience was not fruitless. A number of things were learned and design changes were implemented. These all involved survivability of the VCS components under rigorous conditions. This "education" will significantly improve the chances for success of any future VCS field demonstration.

Subsequent to our "orderly retreat" from the Old Ben field test, several in-mine tests of critical VCS components were conducted. The Natural Background coal thickness sensor (NBS) was tested as a stand-alone at Carbon County Coal Company. These tests were successful. The operator found the equipment useful and has asked to keep the equipment for further activity with DOE. This activity is discussed in Section 8 of this report.

In addition to this baseline activity during the course of the contract, FMA supported the development of what has come to be known as the Man-in-Loop system. This unit was designed and developed by Adjunct Systems, Inc., of Huntsville, AL, and was based on the Hewlett-Packard 41-CV pocket calculator. The intent was to utilize this device as the processor of state-of-cut data generated by the VCS sensors. The system was to be battery-powered and output shearer control information to an operator who would in turn operate the shearer. Taking this approach eliminates all requirements for electrical interface with either the machine or mine power. This part of the program is discussed in Section 7 of this report.

Sections 9 and 10 discuss conclusions and recommendations on all aspects of the work conducted under Contract No. NAS 8-33591. Generally, in summing those conclusions up, it is fair to say that:

1. A VCS system has been developed and tested. Another field test should be conducted, however, in order to evaluate the utility of such a system to a mine operator.

2. A portable display/processor has been developed which is very versatile. It can be used for tasks ranging from control of a machine to balancing a checkbook.

3. Several useful sensors have been developed and tested which could be used in control systems of various levels of sophistication. These include the NBS coal thickness sensor and the acoustic distance measuring sensor.

The remainder of this report will provide further bases in support of these conclusions.

3. VCS CONTROL TECHNIQUES AND ALGORITHMS

3.1 INTRODUCTION

The primary objective of the VCS is to provide horizon control for a longwall shearer such that a more productive face may be realized. Earlier studies, performed by the U.S. Bureau of Mines, had indicated that to a first order of approximation the top of a coal seam follows the floor. On this basis, it would seem that if one could control using the roof as a reference for the front drum while slaving the rear drum to a constant height cut that the seam could be efficiently extracted. This is in fact the basis of the VCS control strategy.

Earlier studies conducted by NASA MSFC (ref. 1) on the types, location, and uses of the sensors required to accomplish this objective revealed two possible algorithms that could be used for control. They were what will be referred to as Mode I and Mode II, respectively. The primary difference between these modes is that in one case, Mode I, the cutting strategy is based on historical coal interface detection (CID) data while Mode II utilizes real-time information to control the roof cut. In both cases, the rear drum is essentially slaved to a constant height cut.

The peculiarities of the underground demonstration site dictated the definition of a modified Mode II to be used at Old Ben. In all the control strategies, roof and floor measurements are related to the centerline of the shearer drums, as much as possible. This way the shearer body geometry does not enter into the control decisions, resulting in a simpler and more accurate control. In all cases, the control systems developed are for one direction of shearer motion only. Sumping and return operations are handled manually.

In all modes of control, the following sensors are required:

1. *Last Cut Follower (LCF)* - This instrument measures the vertical distance between the centerline of the lead drum and the previously cut roof.

2. *Present Cut Follower (PCF)* - Measures the vertical distance between the trailing drum centerline and the presently cut roof.

3. *Coal Interface Detector (CID)* - This nucleonic sensor measures coal thickness left on the roof.

4. *Sensitized Picks* - These differentiate between cutting coal or rock by sensing the cutting forces.

5. *Arm Position Indicators* - These measure the angular position of the shearer arm with respect to its body.

6. *Downface Distance Measurement* - This sensor measures the distance of the shearer from the headgate, along the entire face of the longwall.

After a brief description of the Mode I and Mode II types of control strategies, the rest of this section will describe the control algorithms developed for use of Old Ben mines.

3.2 MODE I CONTROL

Mode I operation utilizes information about coal thickness left on the roof of the last cut and stored in memory as a function of downface distance. With reference to Figure 1, the lead drum is controlled by utilizing:

1. Last cut distance to the roof (h)

2. Stored last cut coal thickness (d), and by detection of rock from the sensitized picks. The task of the lead drum controller is to maintain the drum height at such a level as to keep the roof coal thickness (t) as close as possible to a desired value. This is subject to the constraint that the step size between two consecutive cuts must be limited to ±2 in. within this allowed step size, the lead drum is controlled to go up and down to maintain a constant roof coal thickness. A rock signal given by the sensitized picks will move the lead drum away from the rock within the allowed step boundaries.

Figure 2 shows a simplified flow diagram for Mode I type operation. Note that the deadband parameter (Δ) can be set at any value such that if the measured parameters indicate the drum is in the proper position $\pm\Delta$ then no control is attempted. In actual practice, the value chosen for Δ was ±1 in. Zero can be used for this parameter, but the resulting control system will always hunt, causing unnecessary wear on components.

The rear drum is slaved to keep a constant seam height with reference to the present roof. This is done by utilizing a present cut follower sensor, which measures the rear drum centerline distance to the roof.

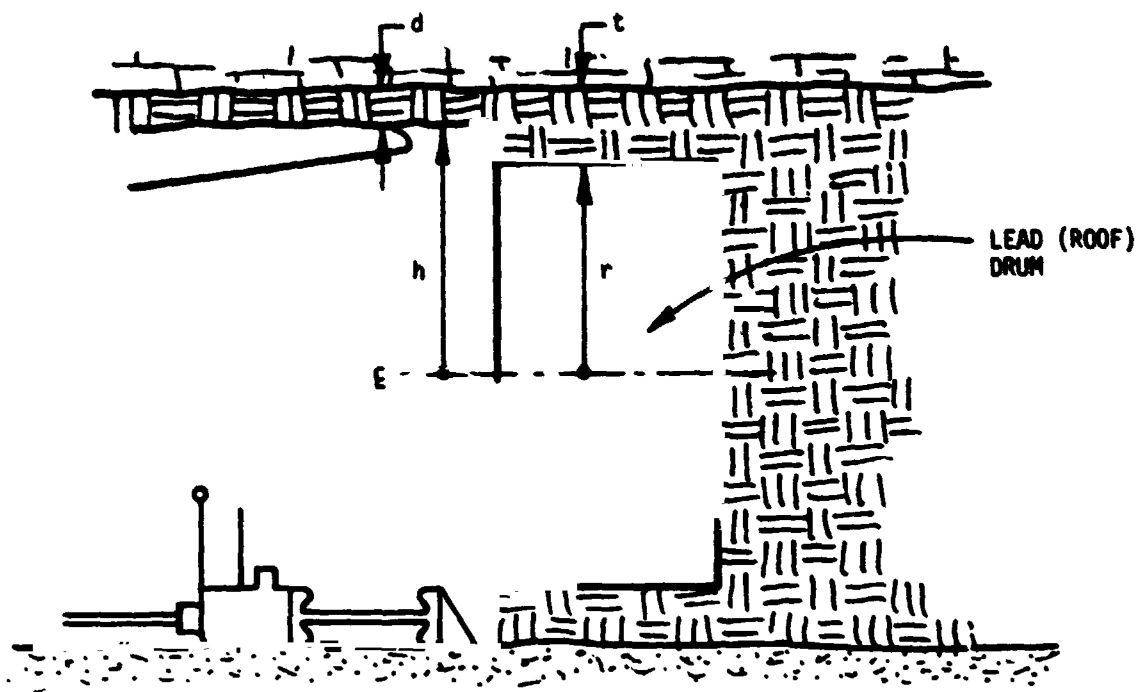

Figure 1. - Longwall face cross-section.

3.3 MODE II CONTROL

Mode II operation is similar to Mode I except the coal thickness is measured in the present cut as close behind the lead drum as possible (see Figure 3). A simplified logic flow diagram for this mode of operation is shown in Figure 4.

The rear drum control strategy is exactly the same as that described for Mode I operation.

3.4 OLD BEN CONTROL STRATEGIES

It was determined at the early stages of the program that the underground VCS tests would be carried out at the Old Ben Mine in Benton, IL. Old Ben has several longwall face operations, utilizing Eickhoff 300L shearers with radio remote control. Some peculiarities of the Old Ben Mine are:

1. Take all the coal on the roof

2. Make a constant thickness cut (nominal 7 ft) to the floor

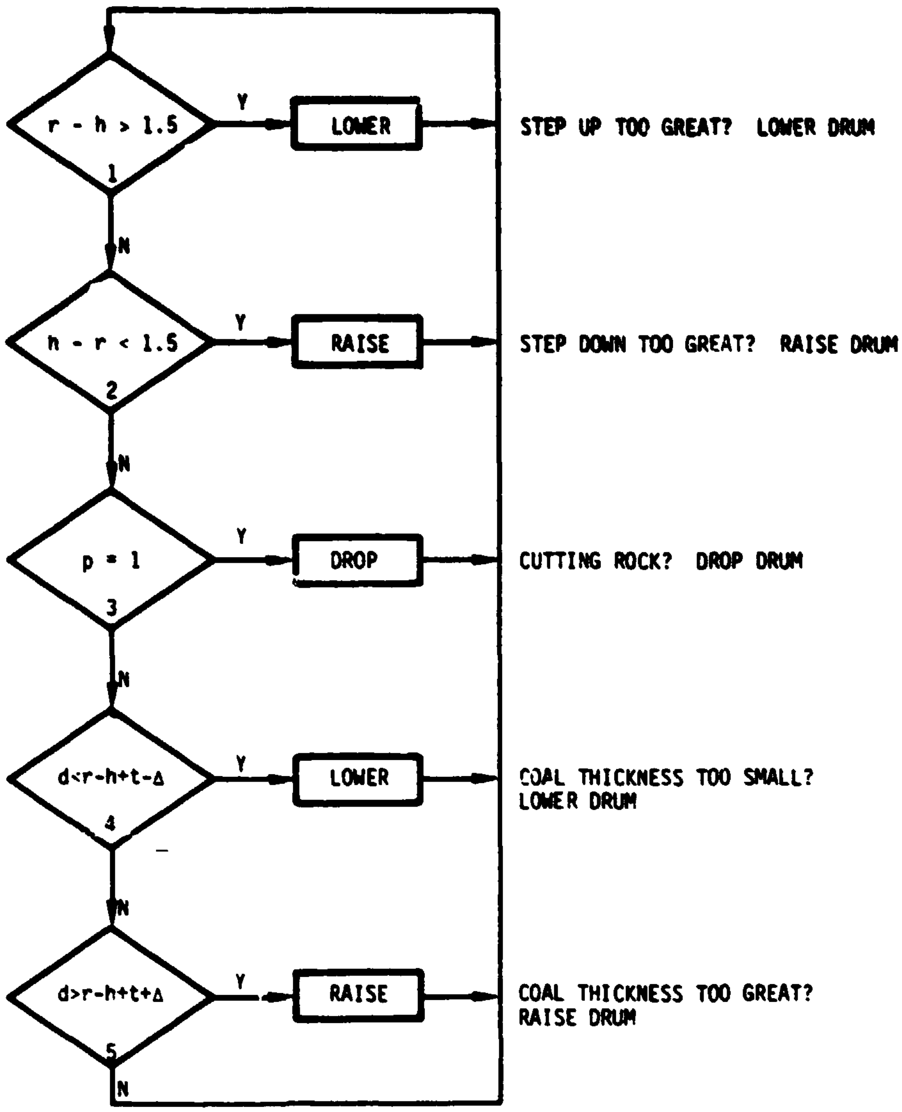

Figure 2. - Simplified flow diagram for Mode I control.

3. Seam cut cannot be less than 6-1/2 ft and not more than 8 ft, to enable shield advance

4. Up to 3-1/2 ft rock perturbations can be present in the coal seam.

The VCS control strategies developed by FMA were tailored for these specific needs of Old Ben. At the same time, the controller software was designed with the capability of switching to Mode I or Mode II control. The following subsections describe the Eickhoff shearer arm dynamics and the control algorithms developed for Old Ben.

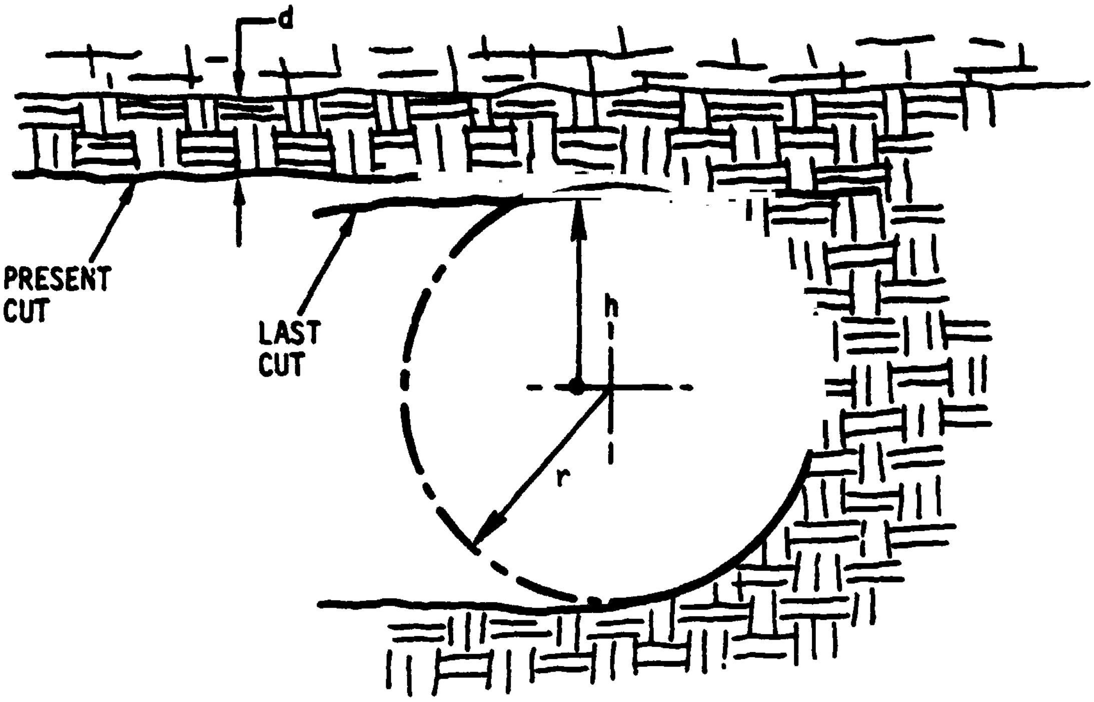

Figure 3. - Lead drum cutting in Mode II.

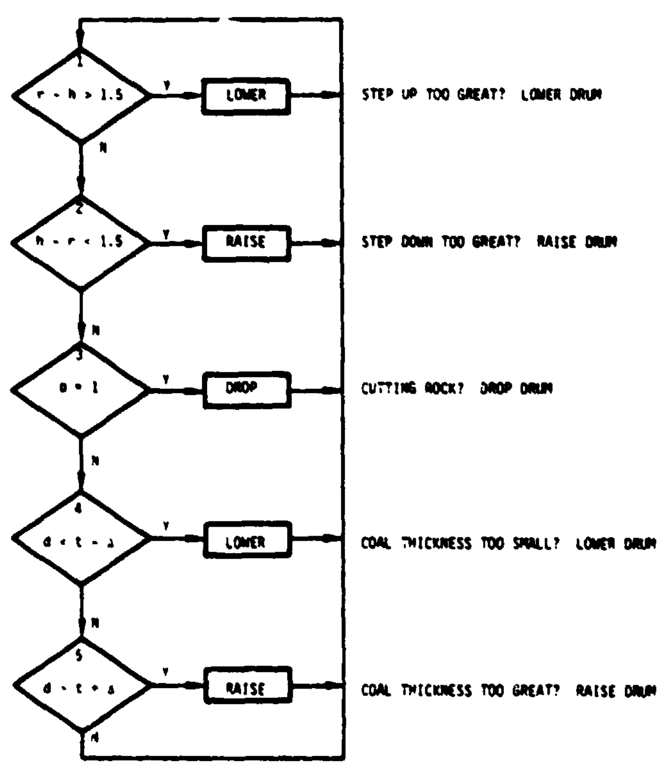

Figure 4. - Simplified flow diagram for Mode II control.

3.4.1 Eickhoff Shearer Dynamics

The 300-L Eickhoff shearers used at Old Ben have double ranging arms. Each arm is independently powered to move up and down by double-acting hydraulic rack-and-pinion drive (see Figure 5). The shearer ranging arm and hydraulic circuit data are given in Table 1.

Under normal operating conditions, the arm moves at about 1.8 in./sec in a vertical direction. Figure 6 shows the approximate pulse input response of the arm, which was determined experimentally. The arm has 0.5 sec deadband and acts like a linear integrator. The approximate differential equation of the arm for a step input of 39V is

$$z = \frac{0.046}{S(1 + 0.5S)} V \qquad (1)$$

where

z = vertical motion of the arm at drum centerline

v = voltage input

3.4.2 Control Strategies Considered for Old Ben

A study was made to determine the various options available for controlling the Eickhoff shearer at Old Ben. Three different strategies were considered for the lead and trailing drum control:

1. *Lead Drum* -

   - Use pick information only to raise and lower the drum around the roof coal/rock interface.

   - Use picks and stored arm angle position of the previous cut.

   - Use picks and LCF.

2. *Trailing Drum* -

   - Use stored leading drum angle position as the basis of roof height, then control the rear drum to obtain desired constant cut.

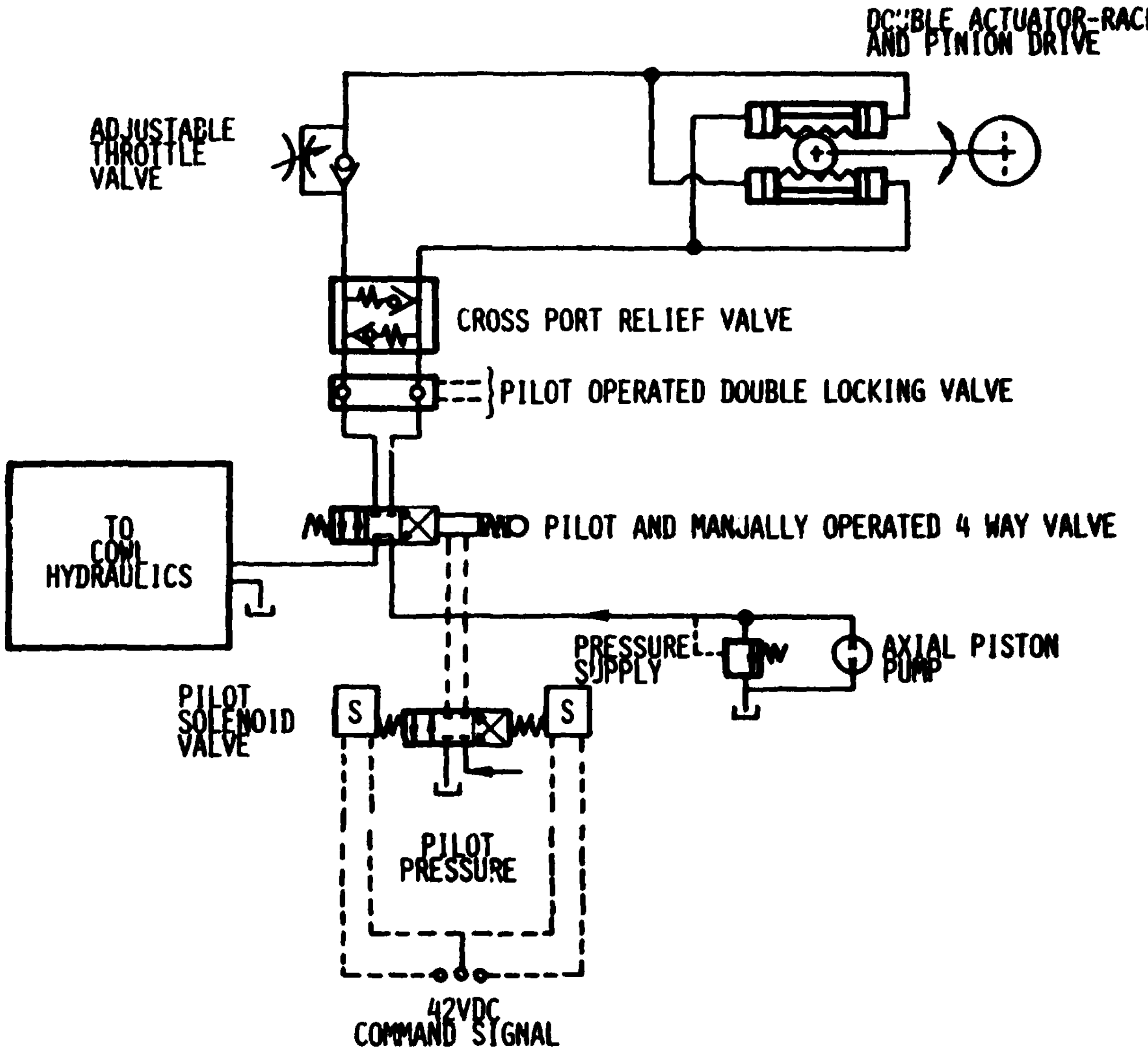

Figure 5. - Eickhoff 300-L shearer arm hydraulics.

TABLE 1. - EICKHOFF SHEARER, RANGING ARM AND HYDRAULIC CIRCUIT DATA

Main supply pressure	=	2,200 $lb/in.^2$
Pump flow rate	=	6 gal/min
Pilot supply pressure	=	250 $lb/in.^2$
Main value flow rate	=	3.2 gal/min
Drive actuator diameter	=	5.9 in.
Drive actuator stroke	=	10.77 in.
Total piston area	=	54.68 $in.^2$
Total trapped oil volume	=	589 $in.^3$
Pinion diameter	=	15.8 in.
Pressure to overcome arm weight and friction	=	1,100 $lb/in.^2$
Arm weight (including cowl)	=	10,900 lb
Arm moment load	=	4.47×10^5 lb-in., minimum
	=	5.68×10^5 lb-in., maximum
Arm calculated inertia	=	94×10^3 lb-in./sec^2 (max.)
	=	53×10^3 lb-in./sec^2 (min.)
<u>Other Arm Data</u>		
Drum diameter	=	66 in.
Arm length	=	63 in.
Arm response time	=	0.5 sec
Arm vertical speed	=	1.8 in./sec
Drum rotation	=	48 rpm
Cowls rotation	=	180^o over the top

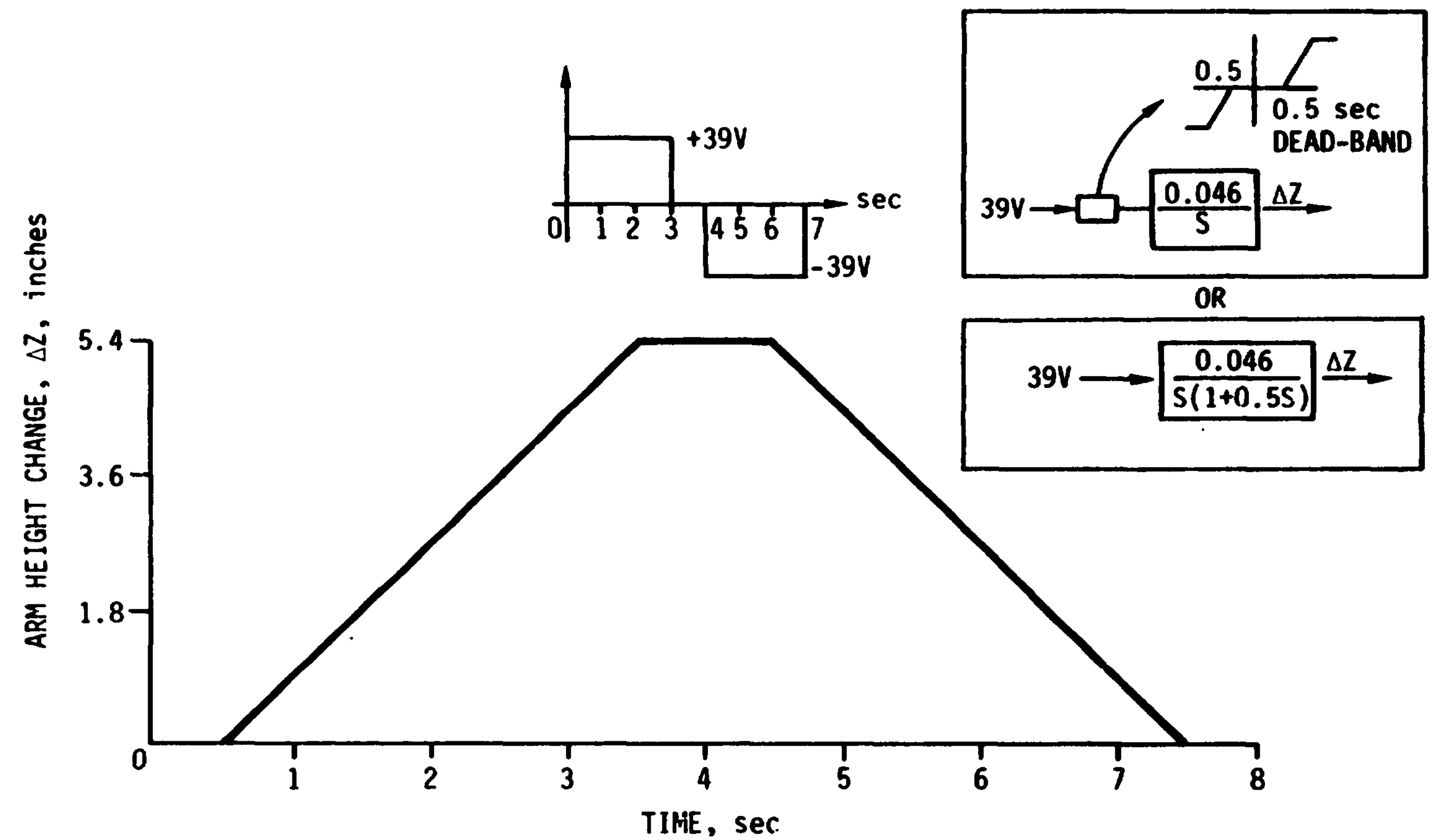

Figure 6. - Eickhoff shearer, approximate pulse input response.

- Use the stored rear drum angle position to control the rear drum on the next pass.

- Use PCF with arm angle position.

Using the shearer geometry, the accuracy of all these strategies was analytically calculated, with the following assumptions:

1. Conveyor panel can only encounter a maximum of ±3 in. vertical obstruction.

2. All sensors have ±0.25 in. accuracy.

3. Servo system positioning errors are ignored.

The results of these analyses are shown in Table 2. As seen from the table, No. 3 control for both drums results in the best accuracy. This is modified Mode II control which formed the basis of the control algorithm developed for Old Ben.

3.4.3 VCS, Control Algorithm at Old Ben

This is a simplified Mode II type of control, tailored for specific needs of the Old Ben mine, that is:

1. Take all coal to shale interface of the roof.

2. Make a constant thickness cut to the floor.

As shown in Figure 7, the necessary sensors are:

1. Sensitized picks - two located on lead drum

2. LCF

3. PCF

4. Downface distance measurement

5. Arm position indicators.

Since no coal is left on the roof, the CID is not required at Old Ben. The controller is, however, designed to include a CID unit when necessary.

TABLE 2. - CONTROL STRATEGIES CONSIDERED FOR OLD BEN

	±3 in. obstruction from last cut (in.)	Body tilt from obstruction (in.)	Instrument error (in.)	Cumulative error (in.)	Total maximum deviation from last cut (nominal ±2 in. added) (in.)
Leading drum					
1	0	0	±1/4	±1/4	? depends on coal seam
2	±3	±0.1	±1/4	±3.6	±5.6
*3	0	0	±1/4	±1/4	±2-1/4
Trailing drum					
1	±3	±0.1	±1/4	±3.6	±5.6
2	±3	±0.1	±1/4	±3.6	±5.6
3	±0.06	±0.02	±1/4	±1.12	±3.12

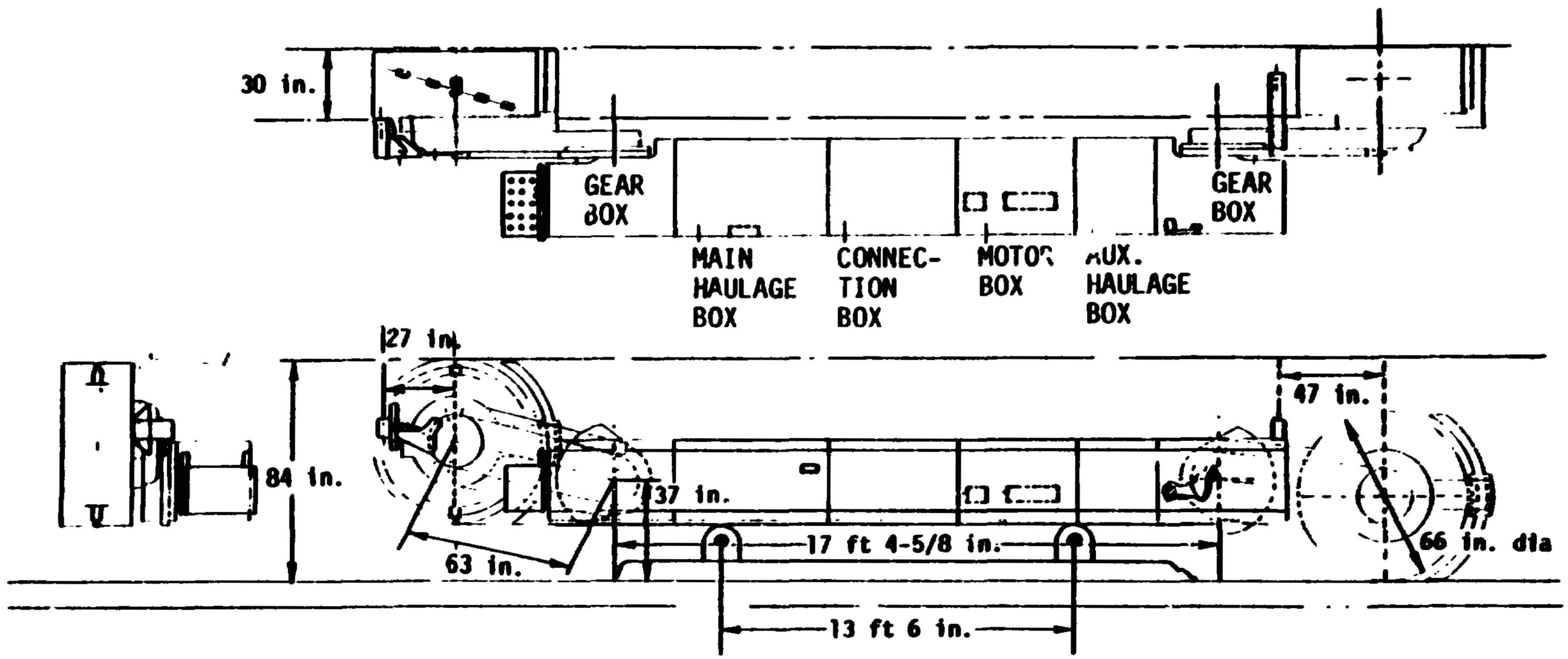

Figure 7. - VCS layout (Old Ben).

Lead Drum Control - Modified Mode II

Lead drum control flow and block diagrams are shown in Figures 8 and 9, respectively. As seen from these diagrams, the "coal" or "rock" signal from the sensitized picks becomes the primary control function. When a coal signal appears, the drum is raised slightly; when the rock signal appears, it is lowered slightly. The last cut follower is used to limit the excursion of the lead drum to ±2 in. from one cut to the next. The last cut has priority over the picks, so that the step size from one cut to the next will be limited for ease of roof support advance.

As seen in Figure 8, using the last cut distance to the centerline of the drum (X_{LC}) and drum radius (r), the step size (ε) is calculated, that is,

$$\varepsilon = X_{LC} - r \tag{2}$$

If the step size is within ±2 in., then the coal/rock information will be used. The coal/rock input will only be effective if $\varepsilon \leq |1.5|$ in. This way, a command to move the drum by an increment of 1 in. will not result in overshooting the last cut step limit by more than 0.5 in. Once a decision is made to move the drum up or down, the controller will activate the solenoid valve in the appropriate direction.

Once each second, a decision is made by the controller to update the drum cutting position. An *UP* or *DOWN* command will result in 1 in. vertical motion of the drum. This is adequate for nominal shearer tram speed of 10 to 15 ft/min.

The rock/coal decision is made on three consecutive readings from the sensitized picks. This is a simple and effective way of minimizing any false pick data.

With the aid of the arm position indicator (ϕ), the controller is able to calculate the total cutting height of the drum (z) and hence maintain a check on upper and lower limits of seam cut (6-1/2 and 8 ft, respectively), that is,

$$z = a + b \sin\phi + r \tag{3}$$

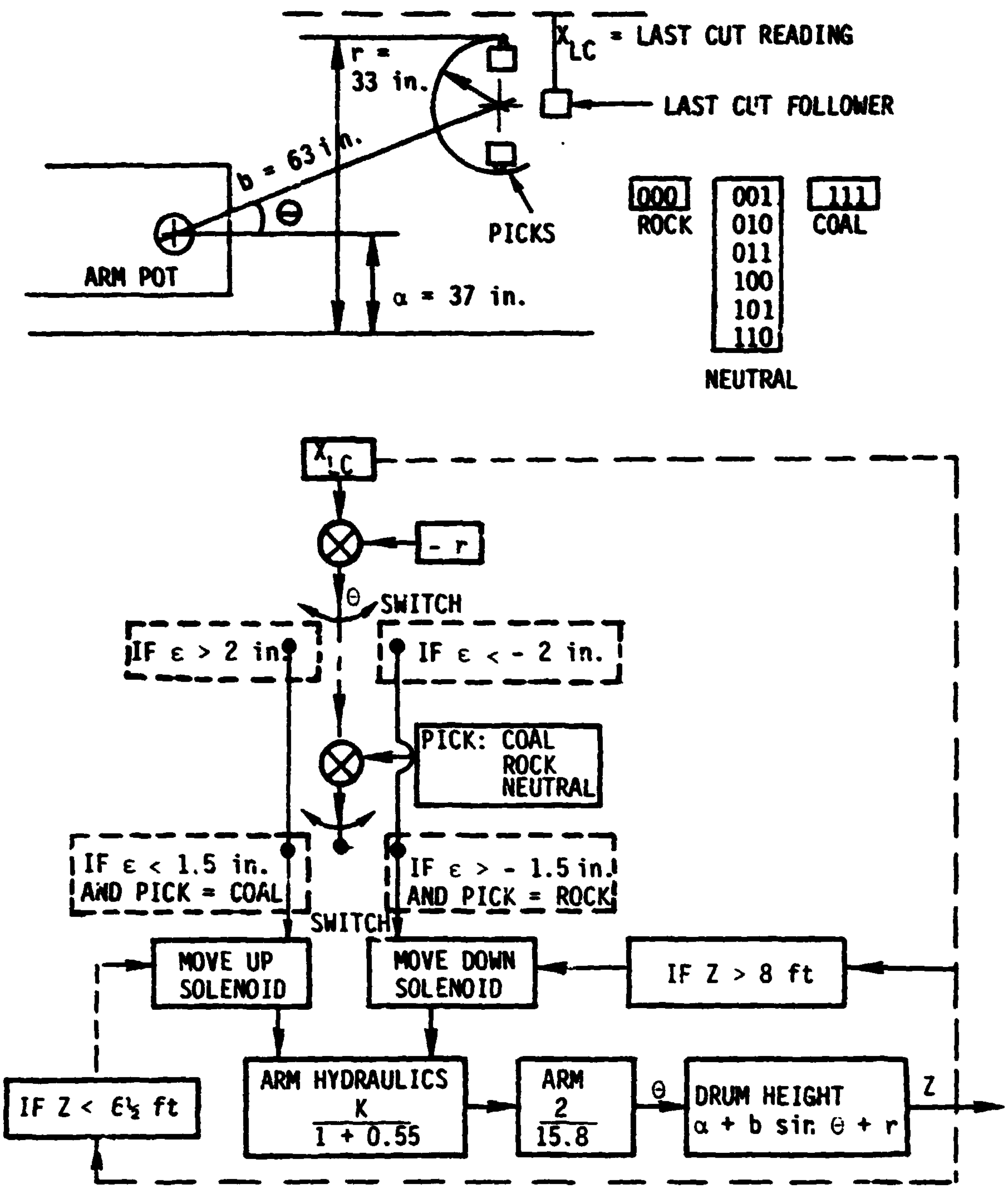

Figure 8. - Block diagram of lead drum control (Old Ben control strategy).

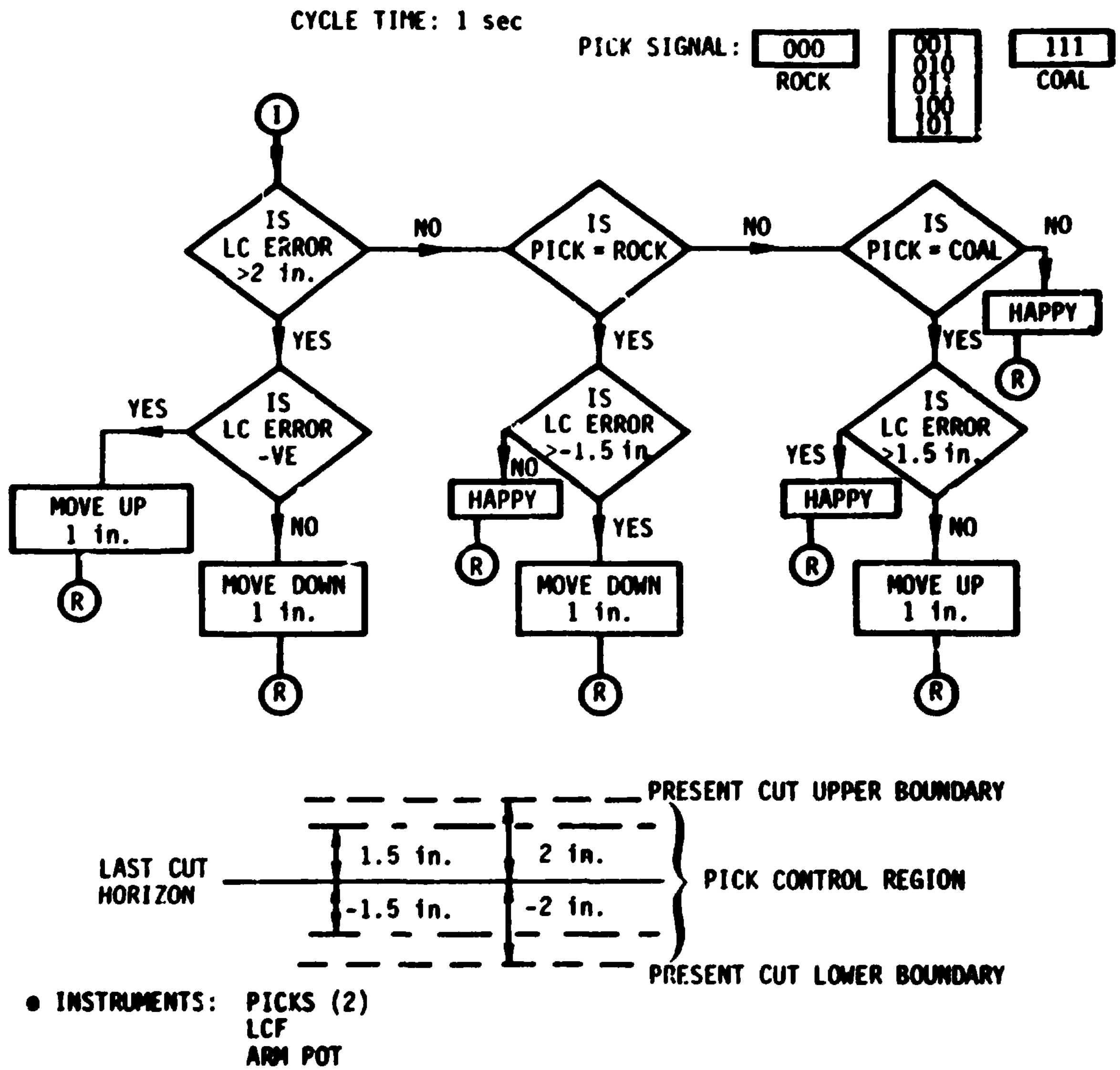

Figure 9. - Lead drum control flow diagram (Old Ben control strategy).

where

a = distance of floor to pivot point of arm

b = arm length

r = drum diameter

Trailing Drum Control

The rear drum control flow diagram and block diagram are shown in Figures 10 and 11, respectively. In this case, the controller slaves the drum such that a constant seam height is maintained. The PCF and the arm position indicator are used to calculate the seam cut (z), that is,

$$z = x_{pc} + r + 47 \sin\phi \tag{4}$$

where

x_{pc} = PCF distance to the roof

r = drum radius

ϕ = arm angular position

Once each second, a decision is made by the controller to update the position of the drum, such that a seam height of 7 ft ±1 in. is maintained.

Another method of controlling the rear drum was to slave it to the lead drum position. This method was tried at Bruceton MLF and proved to be very effective. Basically, the lead drum arm position is stored with respect to downface distance, then the rear drum is slaved to follow the stored information.

3.4.4 Other Control Considerations

The controller is designed in such a way that the operator can switch to manual operation by pressing any one of the normal shearer control pushbuttons either at the machine or at the remote radio control module. The philosophy is such that the operator will monitor the automatic control of the shearer from

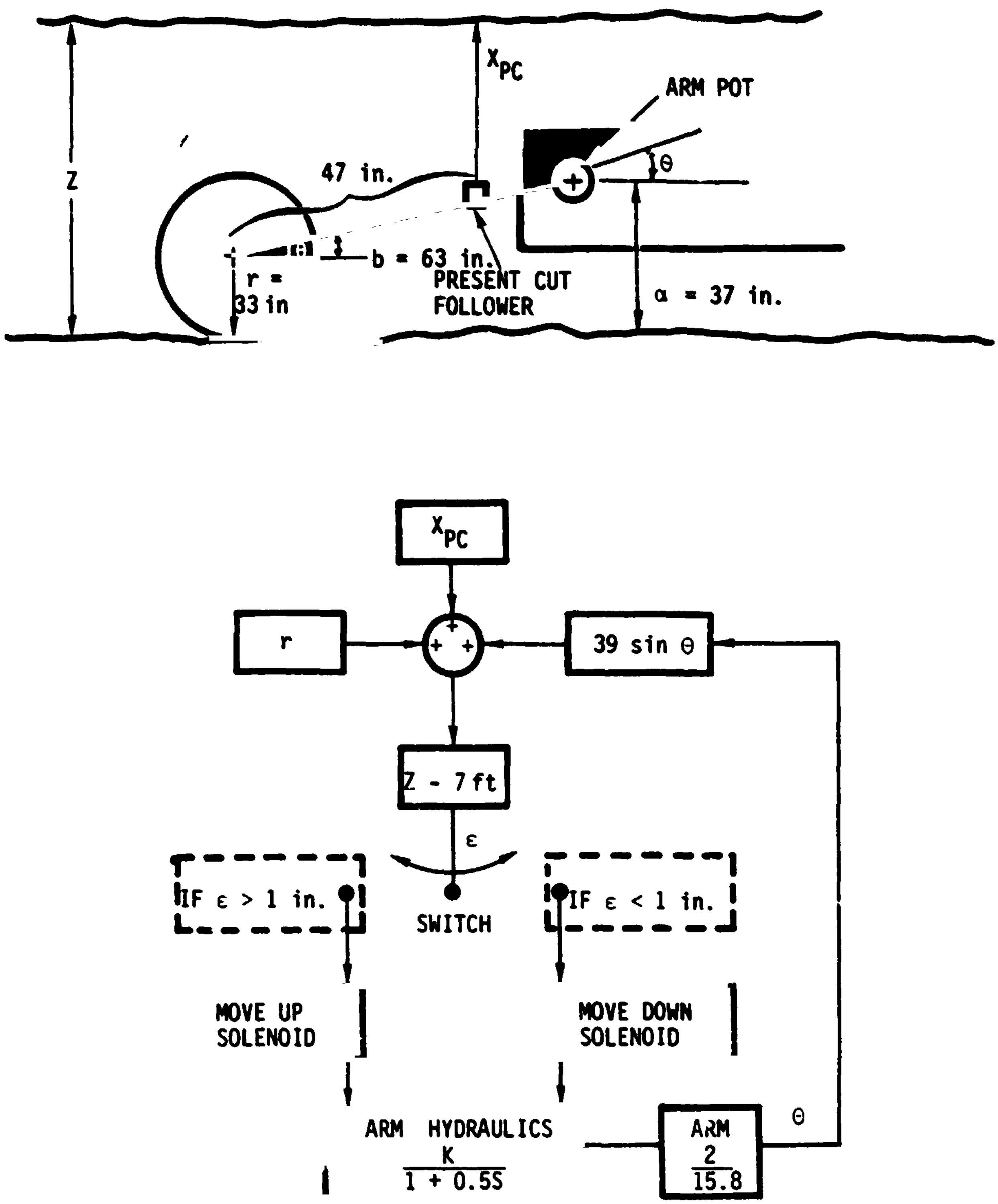

Figure 10. - Block diagram of rear drum control (Old Ben control strategy).

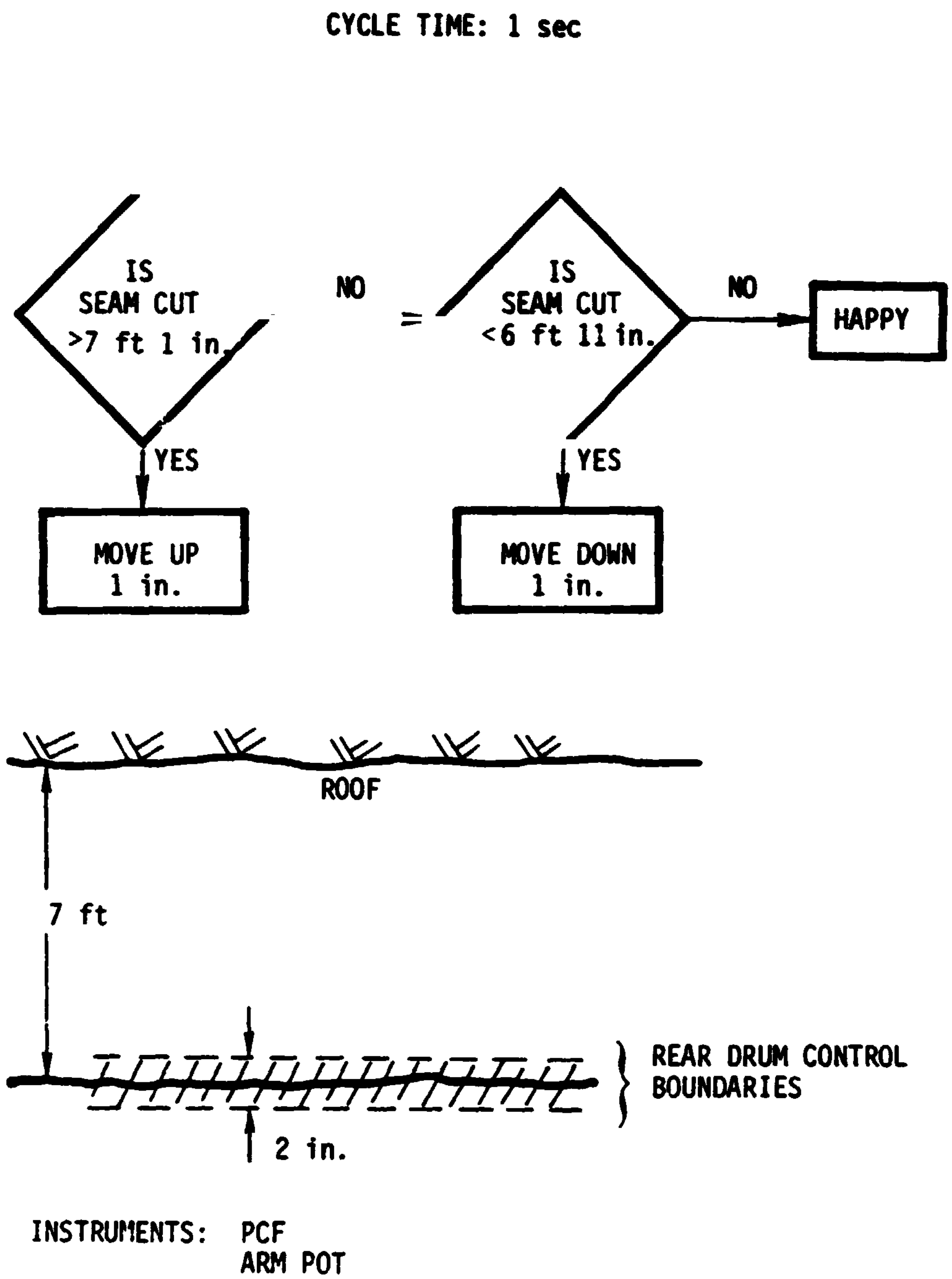

Figure 11. - Rear drum control flow diagram (Old Ben control strategy).

the distance allowed by the remote radio control, and if he notices anything wrong he will return to manual operation instantly.

Large rock perturbations (up to half a seam thick) and large roof falls are pretty common at Old Ben mines. The controller is designed to detect these conditions and return to manual operation. Whenever the control is dropped to manual, the operator is flagged to take control. A roof fall is detected by a sudden change of more than 4 in. in the PCF reading. Rock perturbations are detected by the fact that the sensitized picks are continuously reading rock signals. Any of a collection of standard rules regarding the sensor data can be selected to validate the readings before control action is taken. Data from each sensor can be put through a limit or range check. It can also be put-through a rate-of-change check. If any of these tests are failed, the controller will return the machine to the operator.

These elective routines were put in because of the experimental nature of the VCS. The current configuration requires an "engineering" type of individual to interface with the machine to set control points, sensitivities, and to elect different modes of control (for example, Mode I, Mode II, front drum only, rear drum only, both, etc.). Once these parameters are elected, the underground operator only has two switches to deal with. These are *AUTO/MANUAL* and *EMERGENCY STOP*.

The software is fully documented in Appendix A of this report. Ideally, people dealing with the microprocessor would become fluent in the details of the program. Understanding, however, that the world is not ideal, the operator's manual (a separate document) is written from a procedural prospective and does not require that line-by-line understanding.

4. DESIGN OF VCS HARDWARE

4.1 INTRODUCTION

Section 3 described the control strategies employed in the Vertical Control Subsystem. In that description, the sensors, instruments and data processing equipment were casually mentioned or otherwise implied. This section will provide the background information on each of the major subsystem components. When reviewing this section, it is recommended that the reader be familiar with or have access to the approved VCS drawing package. The following VCS subsystem components are covered in this section:

1. Last/present cut follower

2. Arm position indicators

3. Down-face-distance unit

4. Coal interface detection (NBS, pick)

5. Controller (microprocessor, signal processing electronics, power supplies, and Eickhoff interface).

4.2 CUT FOLLOWERS, PRESENT AND LAST CUT

The last cut follower (LCF) and present cut follower (PCF) were developed as "relative" sensors. Both were designed to measure distance and relate it to previously measured roof distances, and to utilize this information to control ranging arm movement. This differs from CIDs, which sense an "absolute" distance. The LCF and PCF were designed to be mounted near and/or on the drums utilizing swing back brackets (Figure 12).

The LCF was mounted on the front of the lead drum and measured the distance to the roof on the previous cut. Its input to the controller was used to maintain the current roof cut at ±2 in. relative to the roof of the previous pass.

The PCF was mounted ahead of the trailing drum under the roof of the present cut. It measured the distance to the roof and its input to the controller resulted in the slaving of the trailing drum to take the proper depth of cut.

The acoustic sensor (Figure 13) was developed by FMA as a LCF and PCF utilizing a modified Wesmar SLM 15B level monitor and LMS15K sensor.

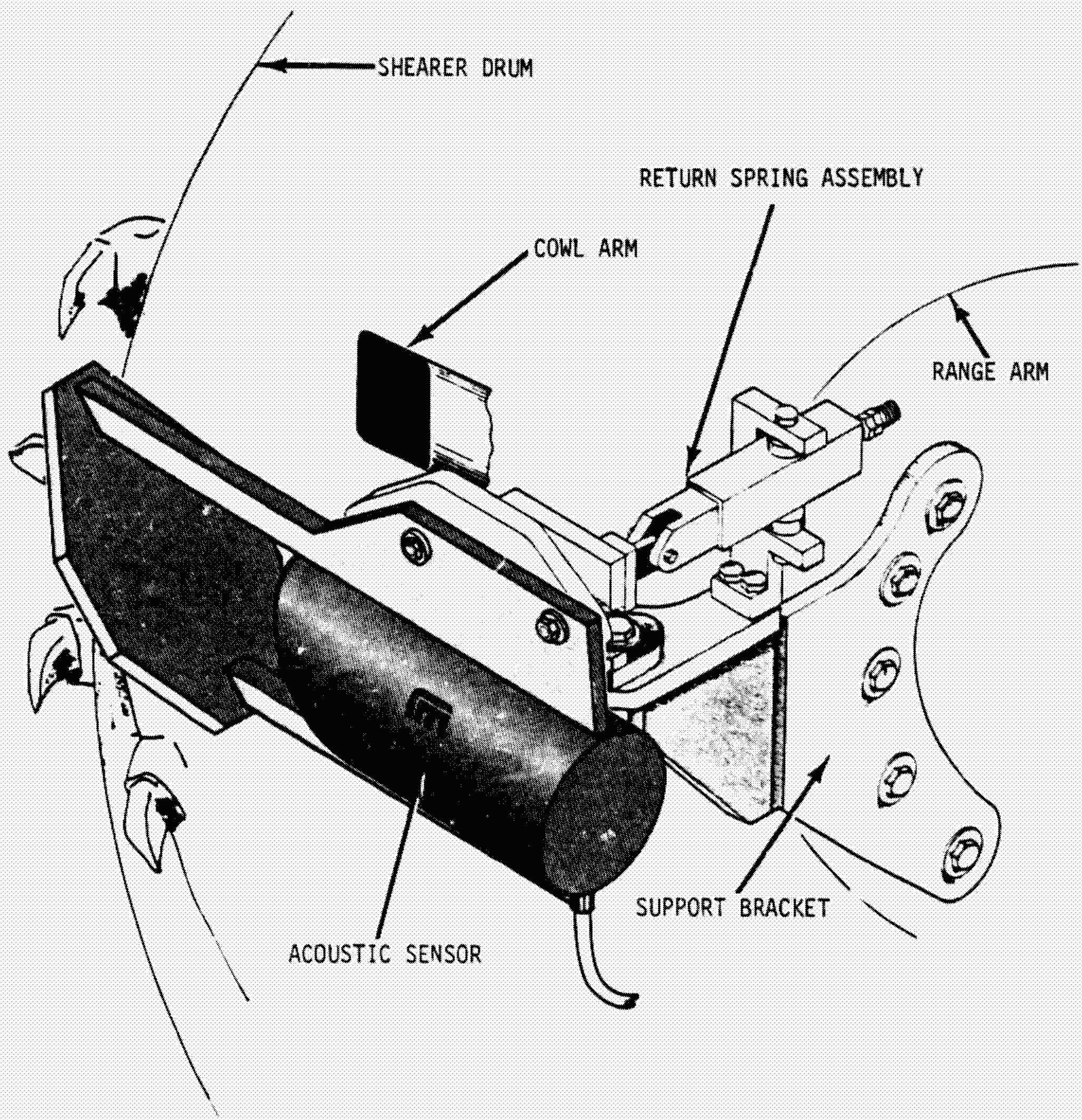

Figure 12. - Cut follower.

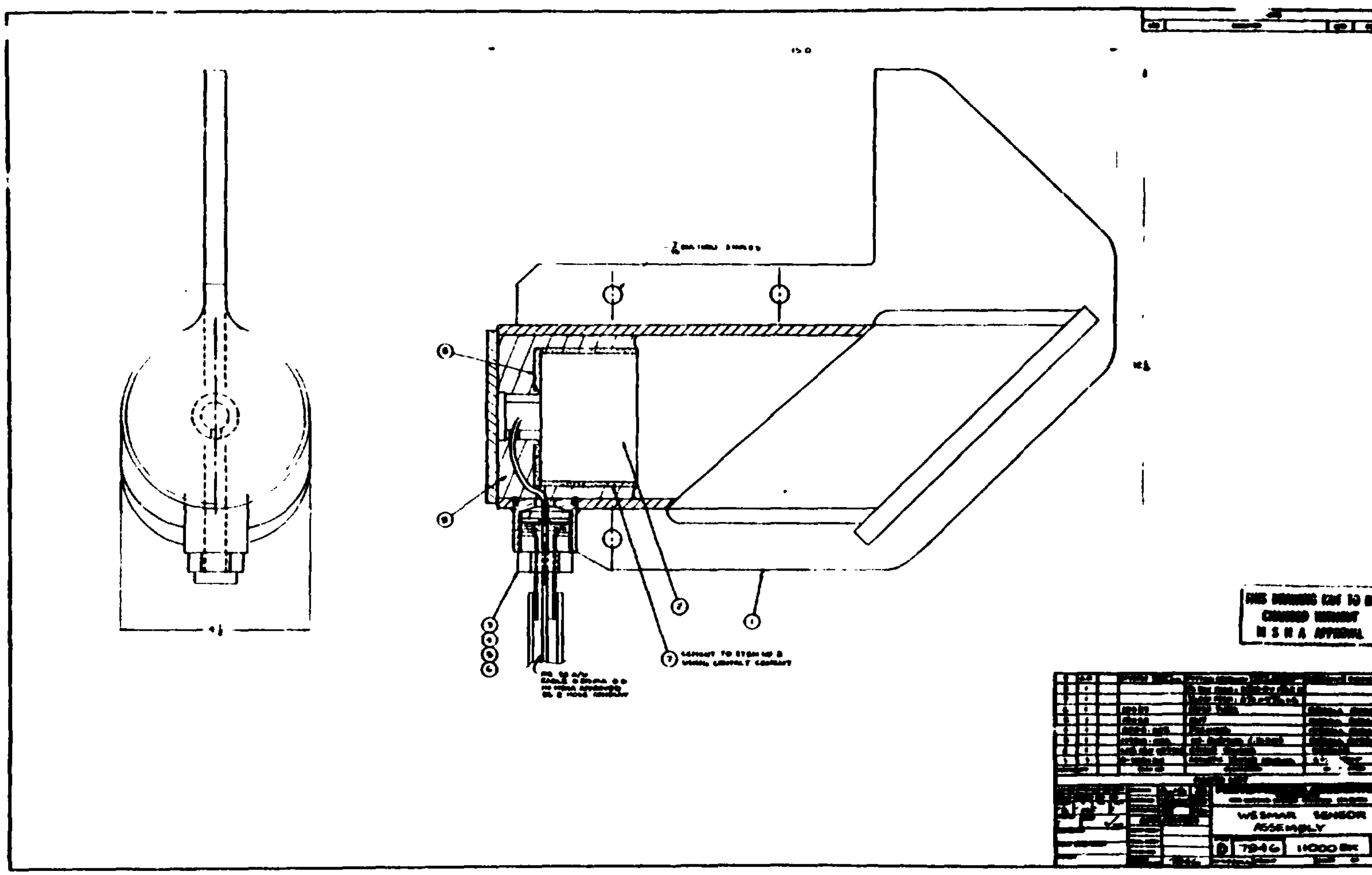

Figure 13. - Wesmar sensor assembly.

The SLM 15B is a general purpose ultrasonic measuring unit designed for noncontact material level sensing. In operation, the solid-state electronics of the SLM 15P excite a crystal in the LMS 15K sensor, producing high-energy ultrasonic (47 kHz) pulses. The same crystal receives the returning echoes and the SLM 15B converts the resulting tune into a distance. The Wesmar sensor typically is used with a range of 5 to 20 ft, but for use in the VCS the ramp time and (dead man) time were reduced, thereby reducing the range to 18 to 54 in. Also, the circuit boards were modified to reduce their size. The input voltage for the SLM 15B is +20 Vac and the output signal range is 0 to 5 Vdc. The LMS 15K sensor itself consists of a piezoelectric transducer encased in the Kynar housing which contains the appropriate shielding to ensure that only the acoustic signal from the front lobe of the transducer is sent and received. This sensor was potted in steel housing designed by FMA (Figure 13) for physical protection. A reflector was mounted in front of the sensor as an integral part of the housing.

The design of the housing allows the pulses from the sensor to reflect up to the roof and back to the sensor while allowing the sensor to remain horizontal. This reduces the possibility of sensor damage and keeps the sensor face clean of debris which would disrupt the sensor signal. The reflector support bar is "knife-edged" to reduce signal interference. It is located over the center of the sensor to provide improved physical protection from roof material falling on the unit.

4.3 ARM POSITION INDICATORS

The Arm Position Indicators (AP) (Figure 14) utilized a Celesco Position/Displacement Transducer Celesco Model No. PT 101 to determine the height of the cutting drums and provide this input to the system controller. The transducer uses a stainless steel cable to drive a potentiometer which provides an output which is proportional to the linear extension of the cable.

The excitation voltage to the transducer was +5 Vdc, which resulted in an analog output range of 0 to 54.2 Vdc. The AP was mounted on the face side of the shearer gearbox under the gearbox cover plate (Figure 15). The cable from the transducer is attached to the shearer arm, extending and retracting as the arm is raised or lowered. This action causes the potentiometer shaft to turn.

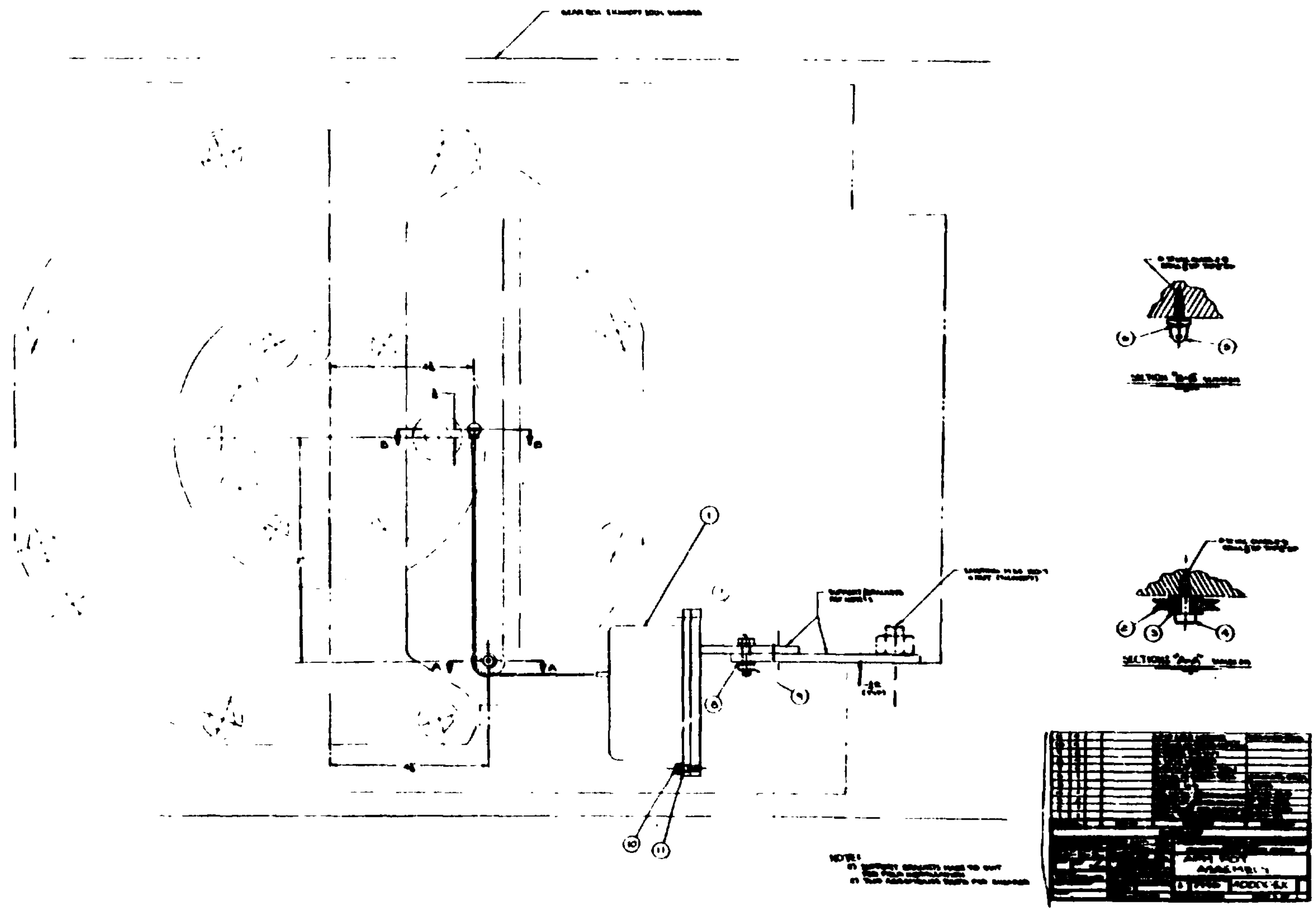

Figure 14. - Arm Position Indicator.

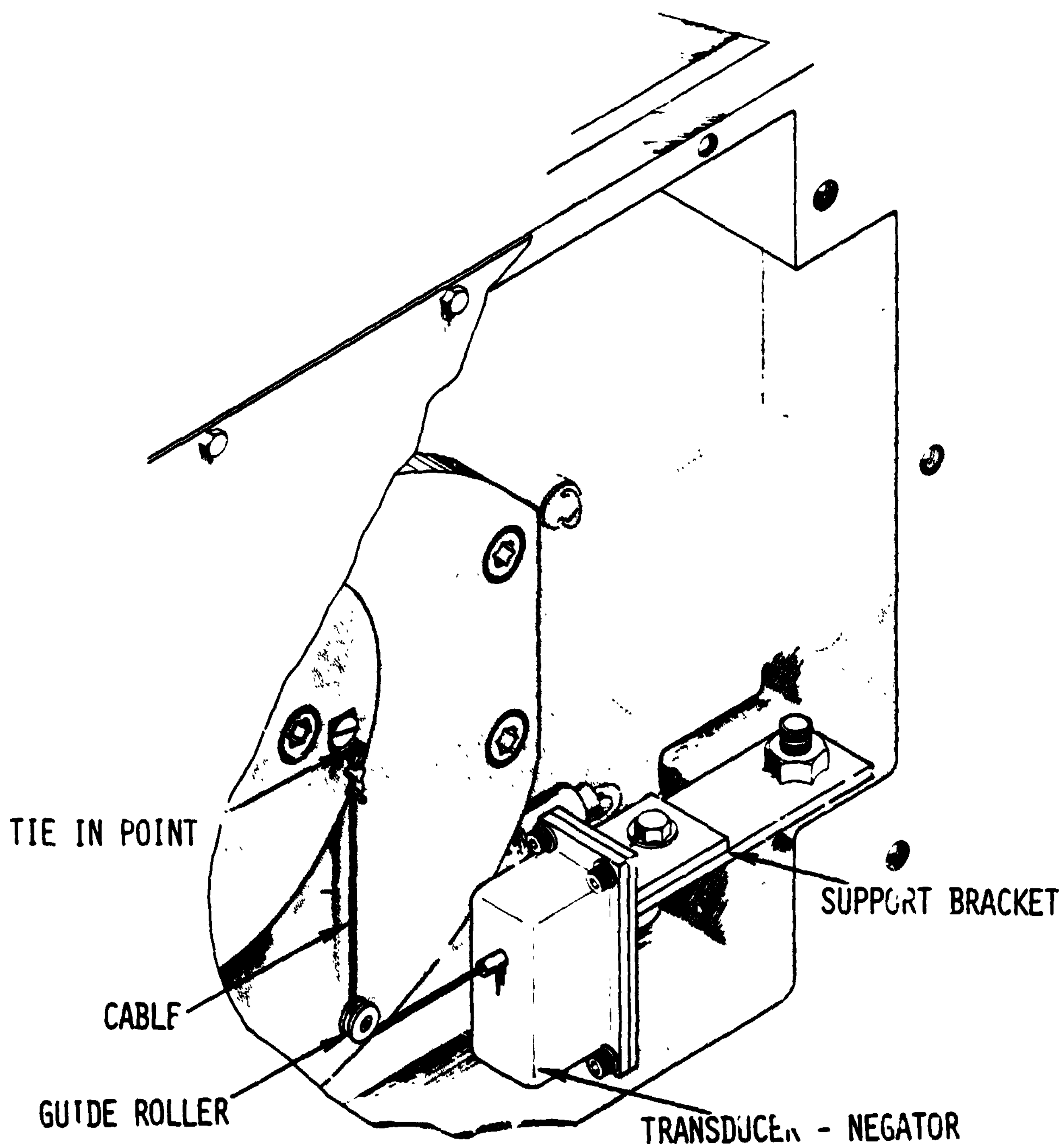

Figure 15. - AP mounted under gearbox cover plate.

4.4 DOWNFACE DISTANCES (DFD)

A DFD sensor was developed to determine shearer position as was required for Mode I operation. The design criteria for the sensor were as follows.

1. Provide shearer position to ±6 in.

2. Provide shearer position independent of shearer direction.

3. The DFD should provide an "absolute" shearer position, thereby being independent of power loss to the VCS.

4. The overall size of the DFD must be small enough to be added internally to the shearer or to be mounted externally without interfering with the normal operation of the machine.

5. Ease of obtaining MSHA approval.

There were several basic types of sensor options available which could suit these requirements: a potentiometric type; a pin contact encoder; and a Radio Frequency type of proximity sensor. The potentiometric sensor was developed based on a combination of the design criteria. The DFD was designed to tap off the drive shaft of the haulage unit on both the Joy 1LS shearer (surface test) and the Eickhoff 300L shearer (Old Ben test). Keeping the drive location common meant that only the sensor/shearer mechanical interface changed and not the sensor itself. The DFD sensor (Figure 16) used a flexible shaft off the drive shaft to drive a speed reducer (stock drive products Model No. 2Z18-E0160) having a ratio of 16 to 1. The output from the speed reducer was attached to a ten-turn 5KΩ potentiometer (Spectrol Model No. 534). The input to the potentiometer was +5 Vdc, resulting in an output of 0 to 4.2 Vdc.

The DFD sensor was attached on the haulage box, external to the machine. It protruded from the cover of the haulage box by 3.45 in., not far enough to interfere with the normal cable handling procedure on the face.

4.5 COAL INTERFACE DETECTION

The most basic parameters in the horizon control of a longwall shearer are:

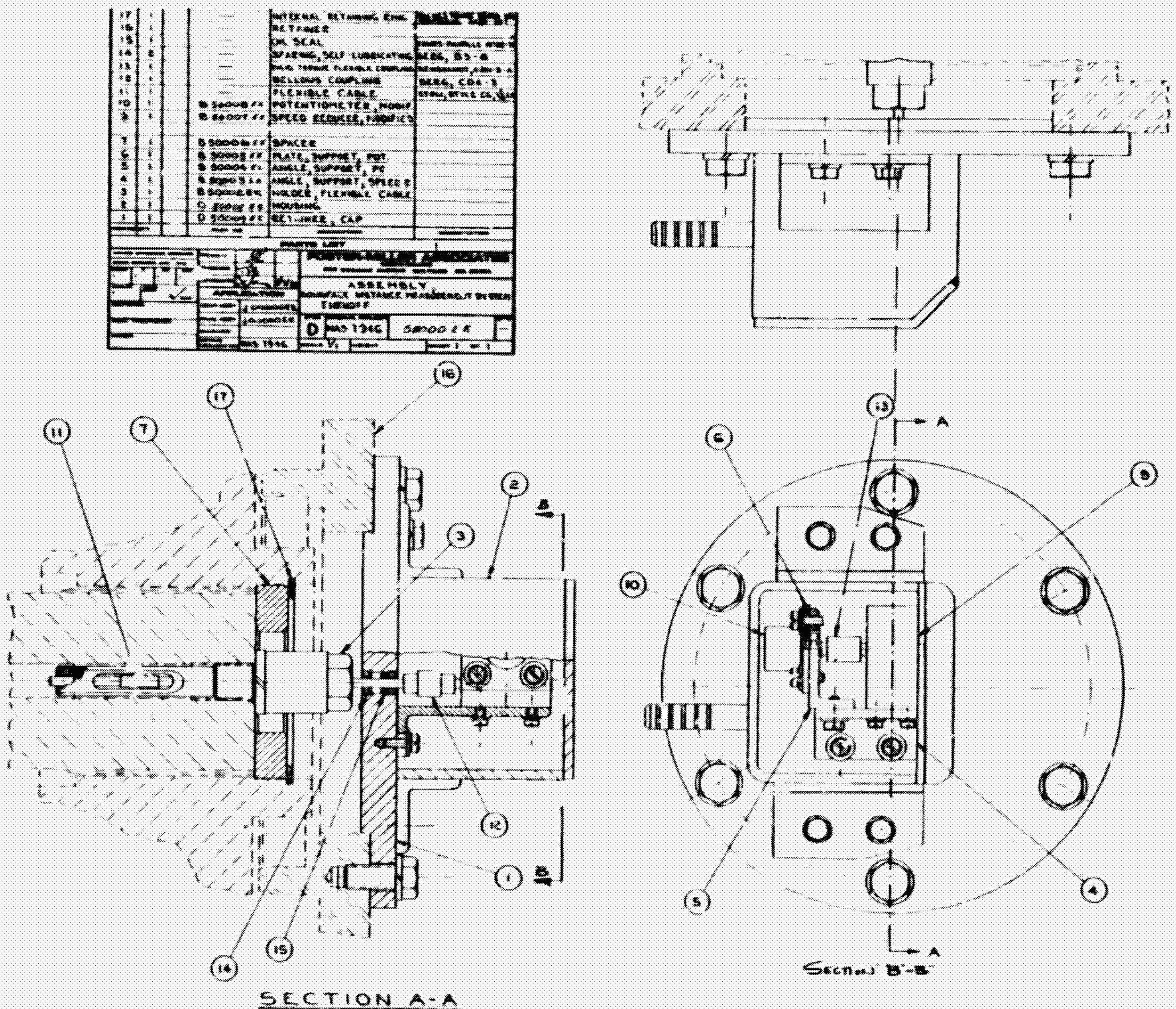

Figure 16. - Downface distance measurement system.

1. Where is the roof/coal interface?

2. Where is the floor/coal interface?

These are the "frames of reference" used in both the initial set-up and the day-to-day mining of the panel.

Typically, a longwall panel in the United States is mined taking all the coal to the roof and floor. Sometimes for one or more of the following reasons it is necessary to leave a layer of coal on either the roof or the floor:

1. Roof or floor rock is not competent and coal band will improve ground control.

2. The coal near the roof or floor is poor quality and is not cost effective to mine.

3. Coal seam is too thick to be successfully mined with the mine's existing equipment.

In these situations, it is difficult to maintain proper horizon control because the frame of reference is not visible to the operator. For the VCS, the coal/roof interface was used as the system frame of reference and two sensors were developed to determine this interface location; they are the sensitized pick and the NBS. The sensitized pick is an effective CID in applications where the amount of coal to be left on the roof (or floor) is small (less than ~1 in.). Any thickness greater than that will affect the resolution of the output, as described in subsection 4.5.1.

The NBS, on the other hand, cannot be used when a "no coal left" condition is desired. It senses the radioactivity of the roof rock and is only effective when there is some coal to attenuate the radioactivity (that is, it cannot detect the difference between no coal left and cutting 2 in. of roof rock).

4.5.1 Sensitized Pick

The sensitized pick (Figure 17) consists of a modified cutting pick (narrower shank) mounted in a pick block and loading a load cell mounted in the bit block (Figure 18). The load cell (Figure 19) is made of 415 stainless steel which has been treated to a Rockwell C31 hardness. The throat of the FMA load cell was reduced in diameter from the General Electric load cell to allow more compression to take place in the load cell (while staying within the elastic limits of the material) thereby increasing its

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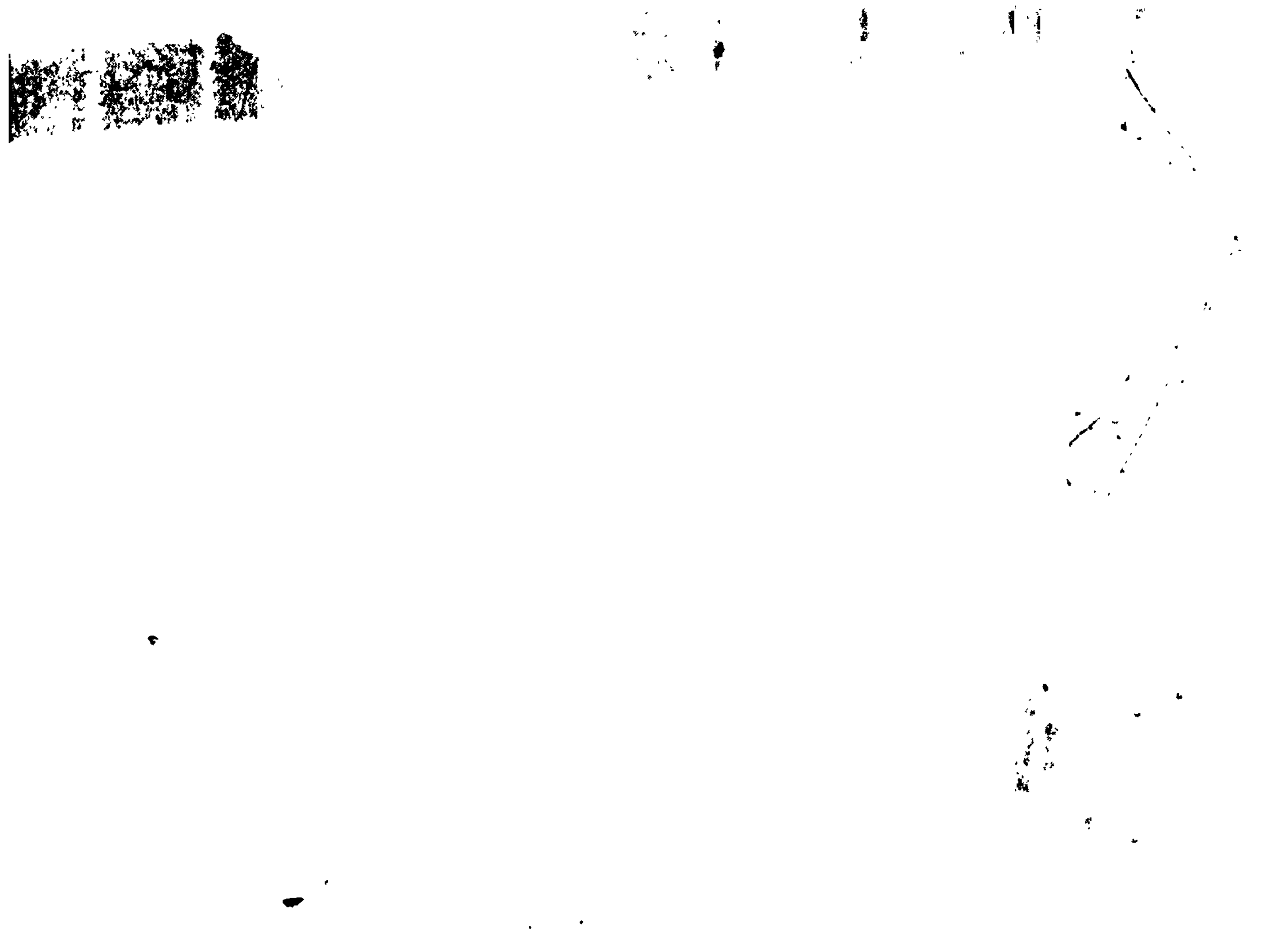
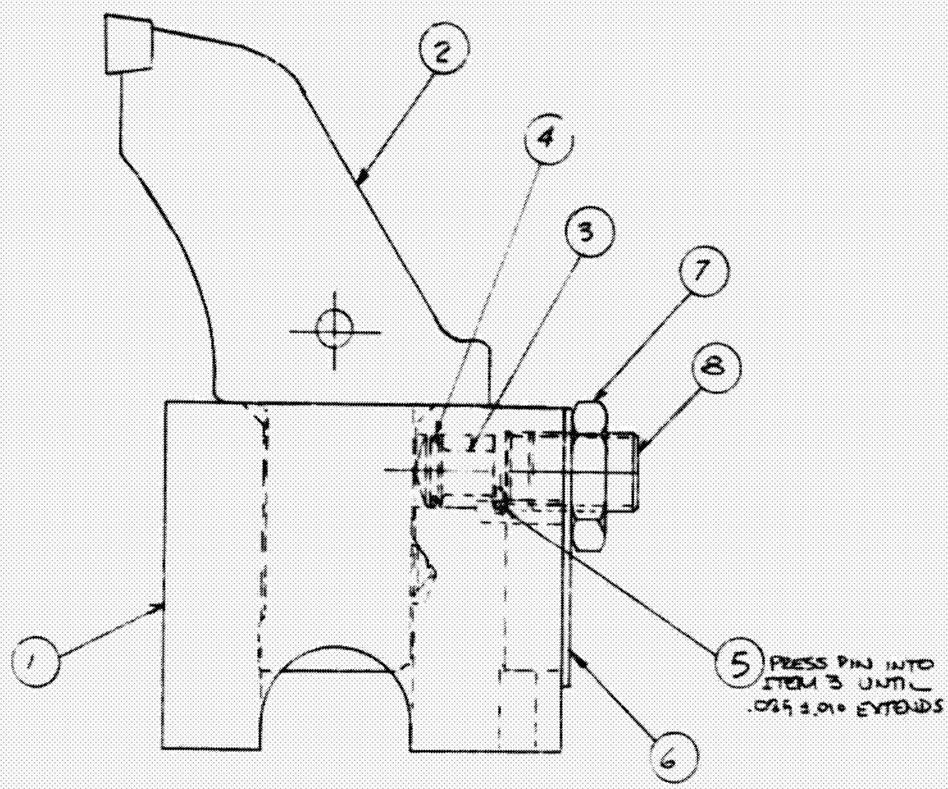


Figure 17. - Sensitized Pick.



8	1			3/8-16 NC x 1 1/4 LG HEX DG PT.	SOC SET SCR.
7	1	–		3/4-16 NC JAM NUT	
6	1		A-12004EK	COVER	
5	1		D3-375	DOWEL PIN	PIC
4	1		2-015N674-70	O RING	PARKER
3	1		C-12003EK	LOAD CELL	
2	1		C-12002EK	PICK	
1	1		D-12001EK	PICK BLOCK	
[illegible]			[illegible]	[illegible]	[illegible]

PARTS LIST

FOSTER-MILLER ASSOCIATES

SENSITIZED PICK ASS'Y 4" NOM.

APPLICATION

60000EK

100000EK

C 7946 12000EK

SCALE N/A

Figure 18. - Sensitized Pick Assembly.

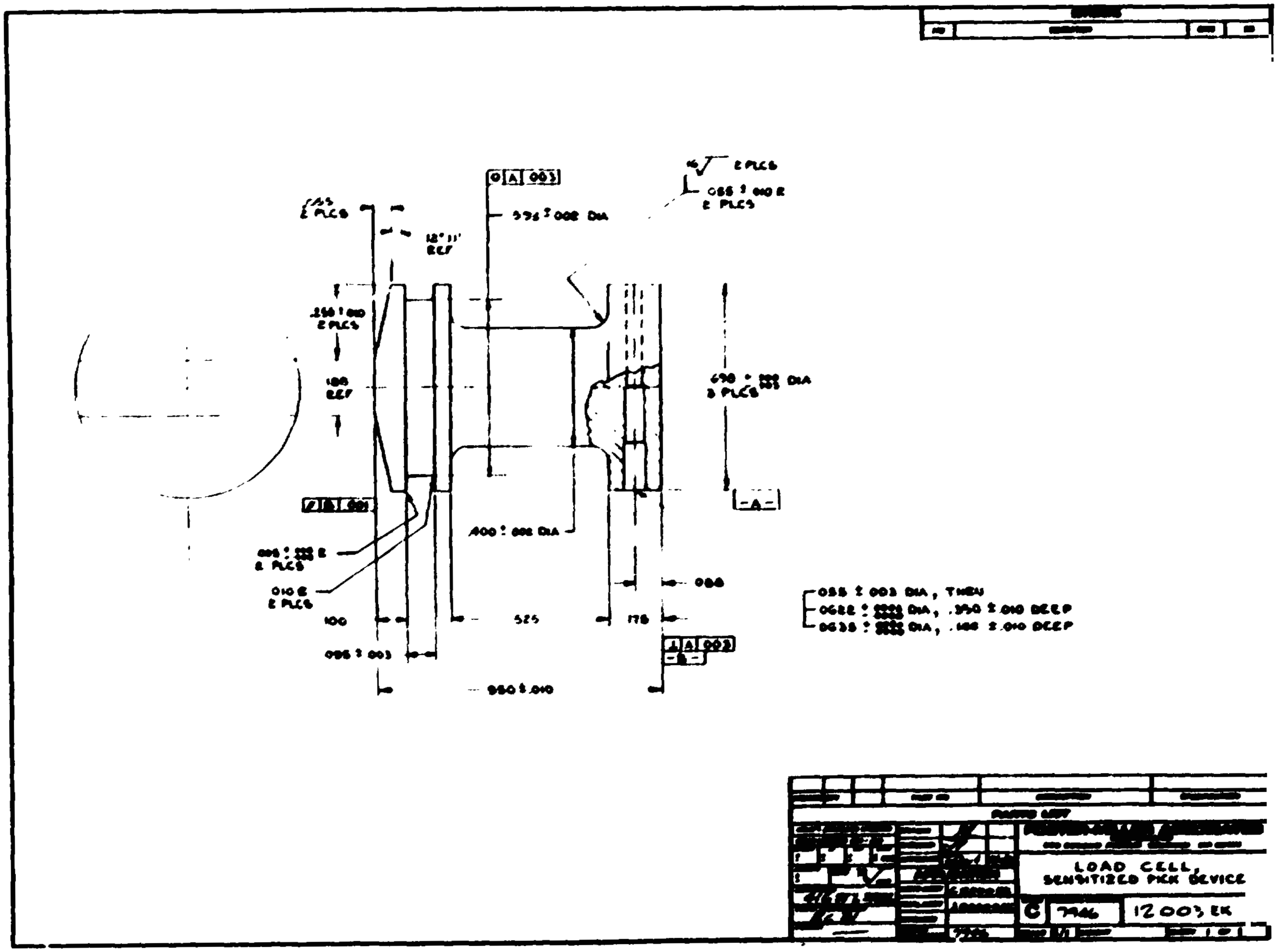


Figure 19. - Load cell, sensitized pick device.

sensitivity. There are two strain gages (Micro Measurements Model No. SK-06-125 TB 10C located on the throat of the load cell located 180 deg apart from each other (Figure 20). With these gages in this configuration the effects of the pick eccentrically loading the load cell are eliminated. A terminal strip is located on the load cell throat also with a gage wire carrying the signal to the terminal strip and 6 gage wire carrying the signal to a preamplifier board located in the pick block. This arrangement protects the strain gage from the inertia generated by the 6 gage wire. The strain gages and terminal strip are coated with a polysulfide-epoxy compound (Micro Measurements M-Coat G or equivalent) forming a rubber-like moisture and physical protective barrier for the strain gages. A small preamplifier circuit (Figure 21) with a gain of 100 was installed in the pick block which increased the signal output from the 0 to 1 mV to the 0 to 100 mV range. The input voltage and output signal cables were brought through a modified pick face flushing water tube assembly utilizing an Airflyte Electronics Model No. CA4-12 located on the face side of the assembly (Figure 23). Two sensitized picks are required in each drum. The picks are located 180 deg away from each other on the cutter drum and extend approximately 1/4 in. higher than the normal pick height. The sensitized pick "shadows" a normal pick on the pick pattern (Figure 22), resulting in a large percentage of the load on the sensitized pick being generated by the top 1/4 in. (coal/roof interface), thereby increasing the signal sensitivity.

The output signals from both load cells on one cutting drum are compared to each other by the controller. This comparison is used to determine the appropriate arm movement required for successful horizon control. This comparison will be discussed further in subsection 4.6.

4.5.2 Natural Background Sensor

The MSFC-designed NBS (Figure 24) is in actuality a sodium iodide scintillation detector. It detects the natural gamma ray emissions from common coal mine roof which occur as a result of their K^{40} content. Thus, as greater thicknesses of coal intercede between the sensor and the roof, the scintillation activity drops off exponentially.

The sensor output consists of random pulses from a photomultiplier tube which occur at a high rate when the coal is thin and at a lesser rate when coal is thick. This sensor has been interfaced with the VCS controller through a digital counter which counts incoming pulses over a sample period of 1 sec, latches the count for examination by VCS software, and resets the counter.

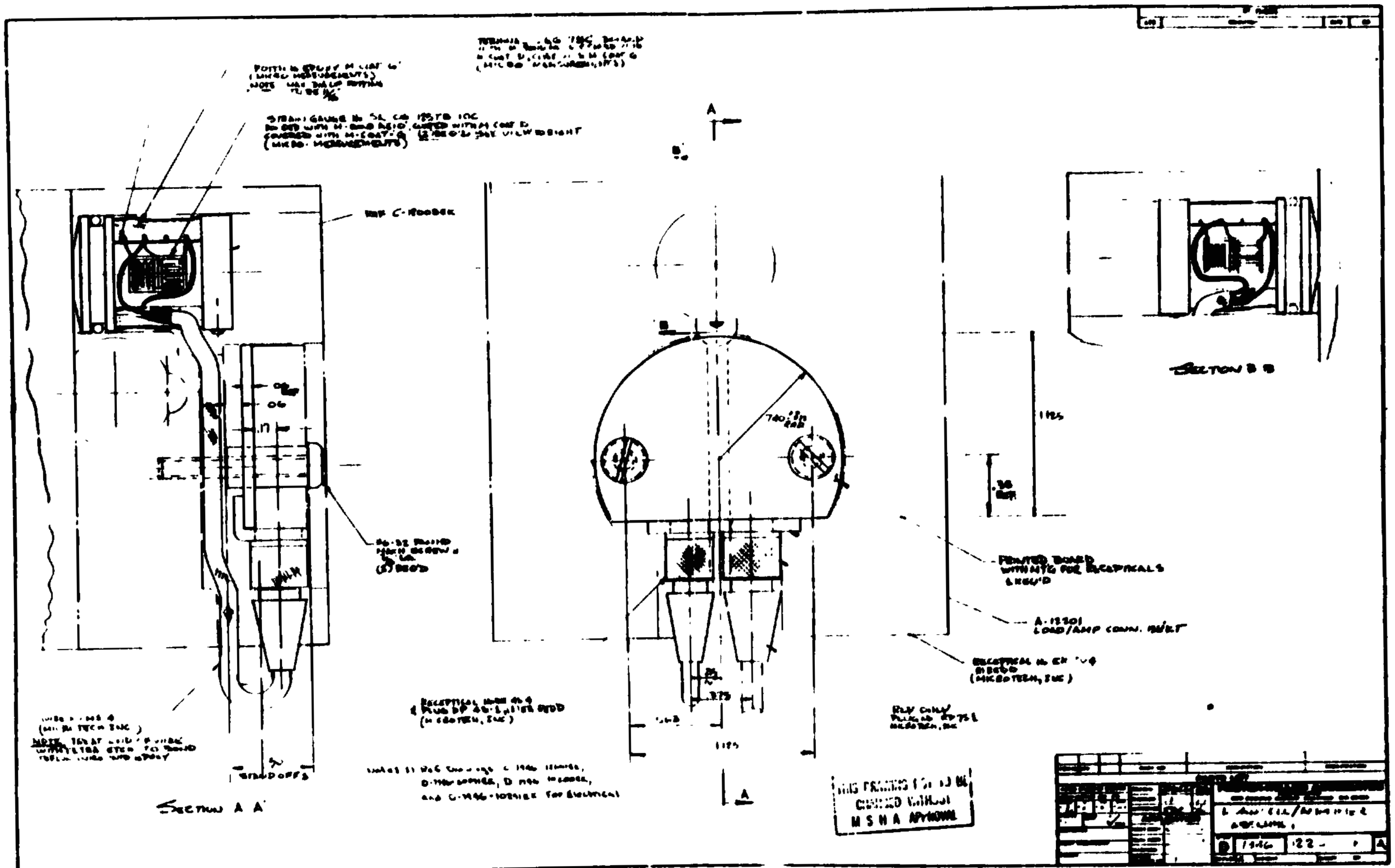


Figure 20. - Load cell/amplifier assembly.

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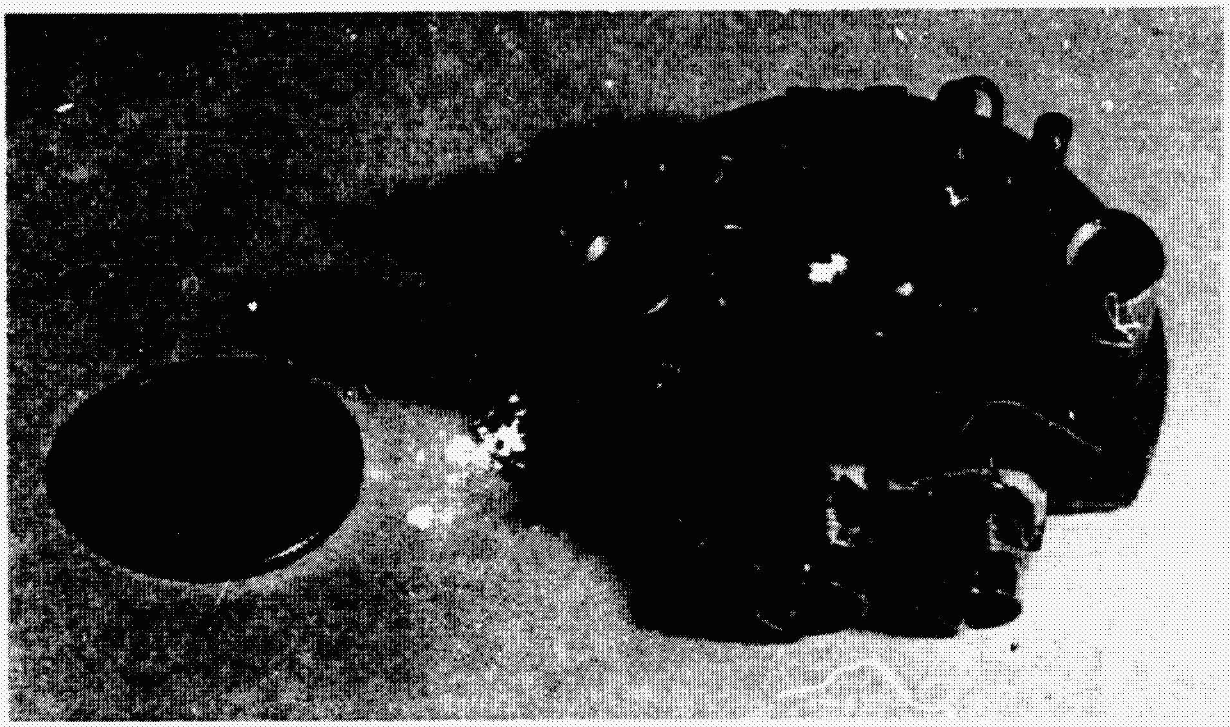

Figure 21. - Preamplifier.

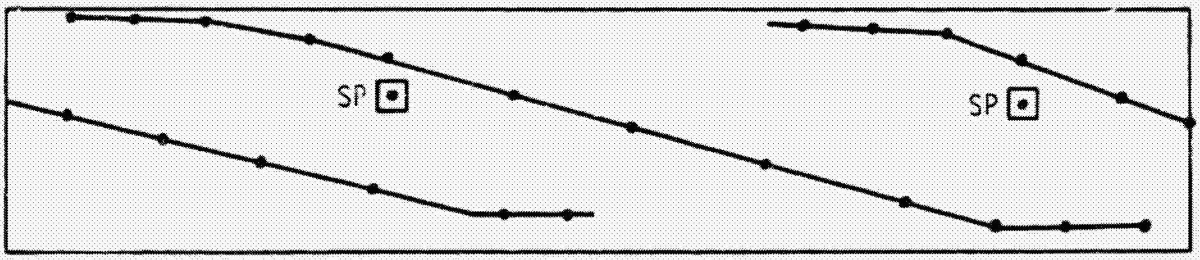

Figure 22. - Pick lacing (example).

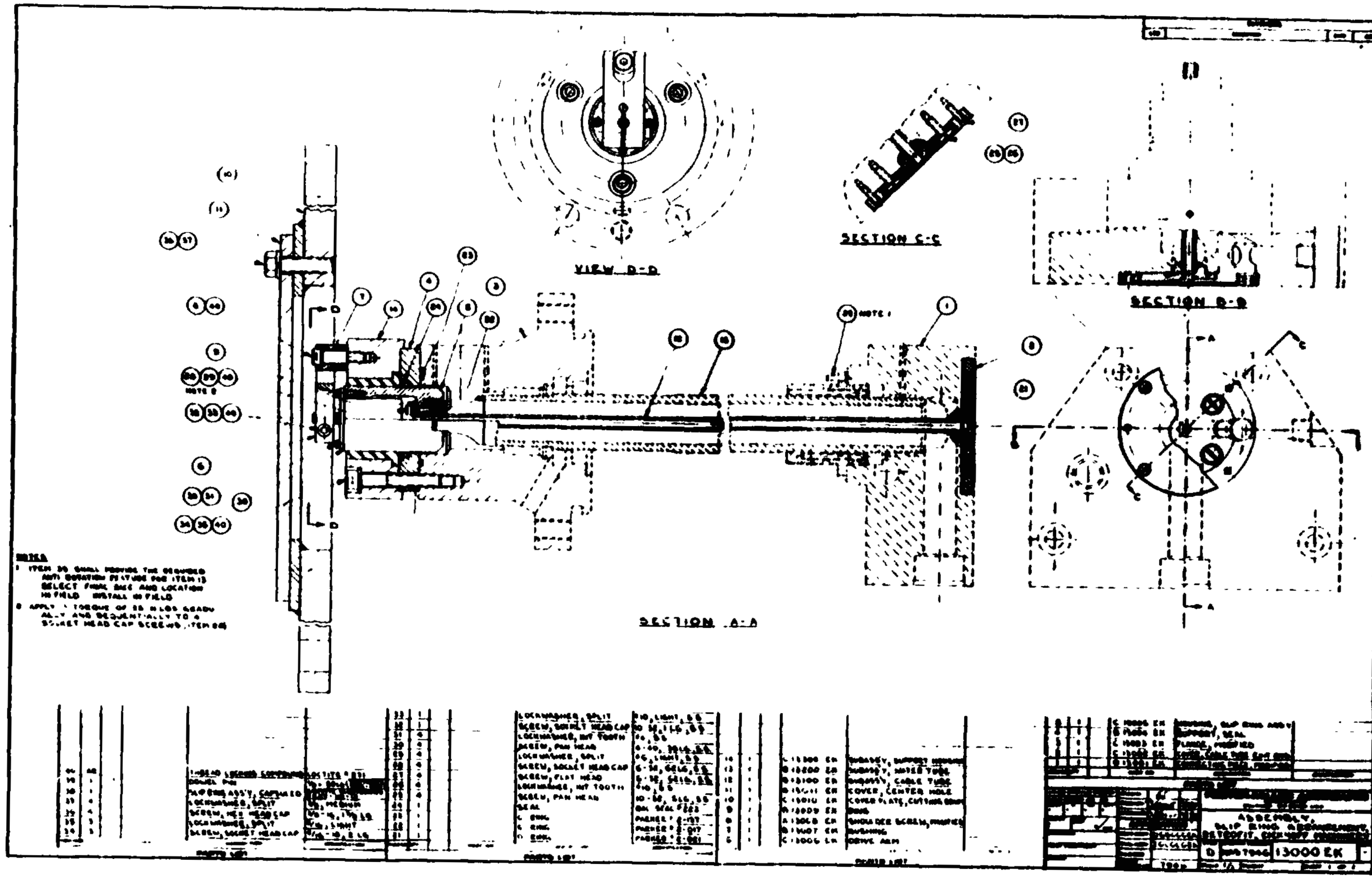

Figure 23. - Assembly, slip ring arrangement retrofit, Eickhoff machinery.

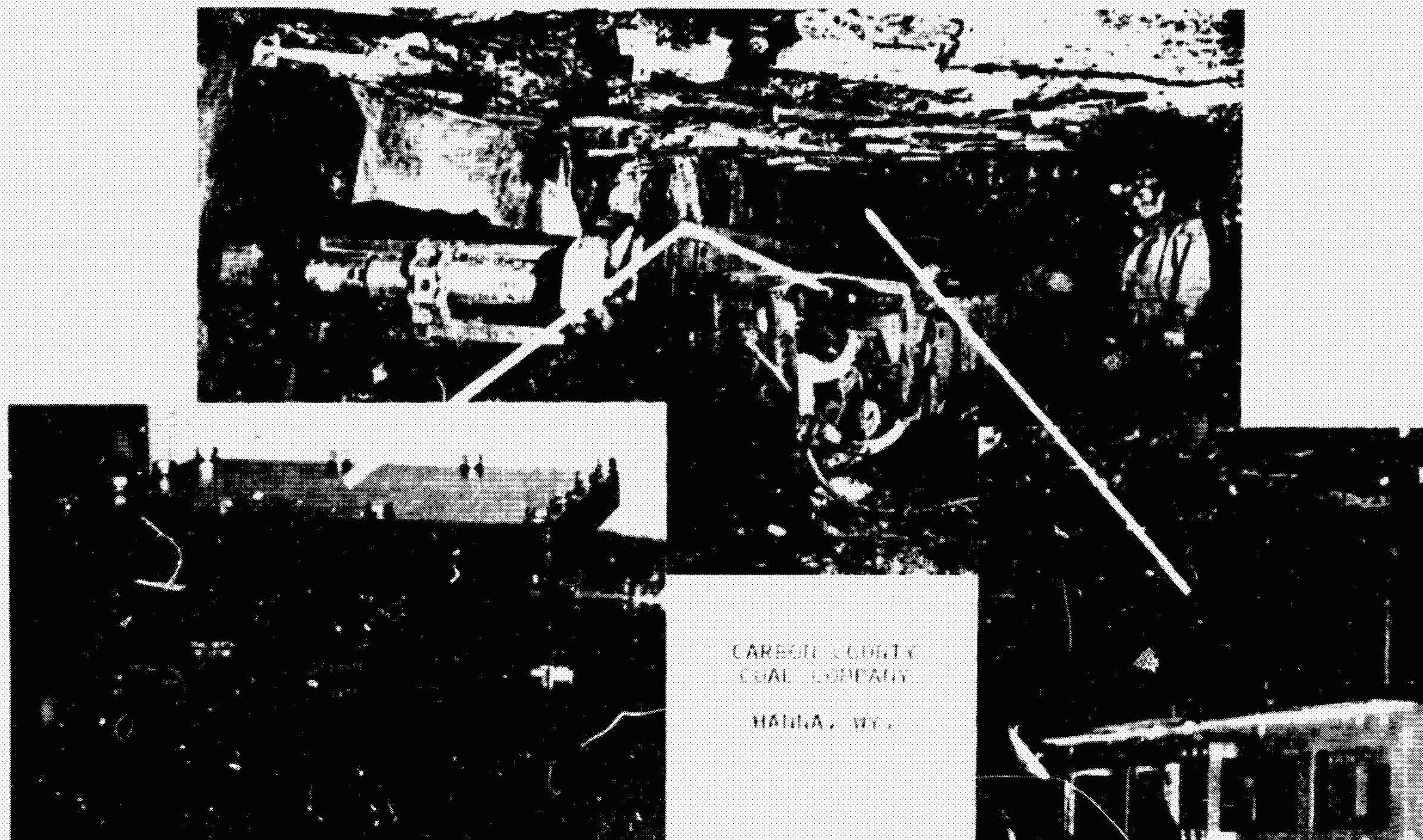

Figure 24. - Natural background sensor.

The control algorithm is designed to take one of three possible actions:

1. If the count is too high, it directs the lead drum down.

2. If the count is too low, it directs the drum to rise.

3. If the count is within some acceptable band, control output is inhibited.

The NBS is effective when it is desirable to leave coal on the roof in a thickness range of 0 to 30 in.

The maximum coal thickness through which the NBS can successfully sense the coal/roof interface is dependent on a number of factors. The primary ones are:

1. Surface area of the sodium iodide crystal

2. The K^{40} content of the overlying strata.

3. The attenuation properties of the particular seam.

The NBS developed for the VCS utilized a 4 × 8 in. crystal and typically has a coal thickness range of 1 to 20 in. The sensor has the advantage over the "active source" nucleonic backscatter sensor of not having to be mounted extremely close to the mine roof. In the case of the Old Ben test, the sensor was mounted *on the machine body just behind the lead drum range arm.*

The power input to the NBS was +12 Vdc and the output signal was typically in terms of pulses which were counted and read by the VCS controller.

4.6 CONTROLLER

4.6.1 System Description

The VCS system is controlled by a microprocessor and its associated electronics. The electronics are housed in an explosion-proof enclosure as shown in Figure 25. The microprocessor and electronics are implemented within a STD BUS structure on a number of printed circuit boards. The sensors for the system provide inputs to the controller. Voltage and current limiting barriers are used to interface the sensors, described earlier in this Section, to the electronics. The barriers keep voltages and currents at intrinsically safe levels in the cables connecting the sensors to the controller.

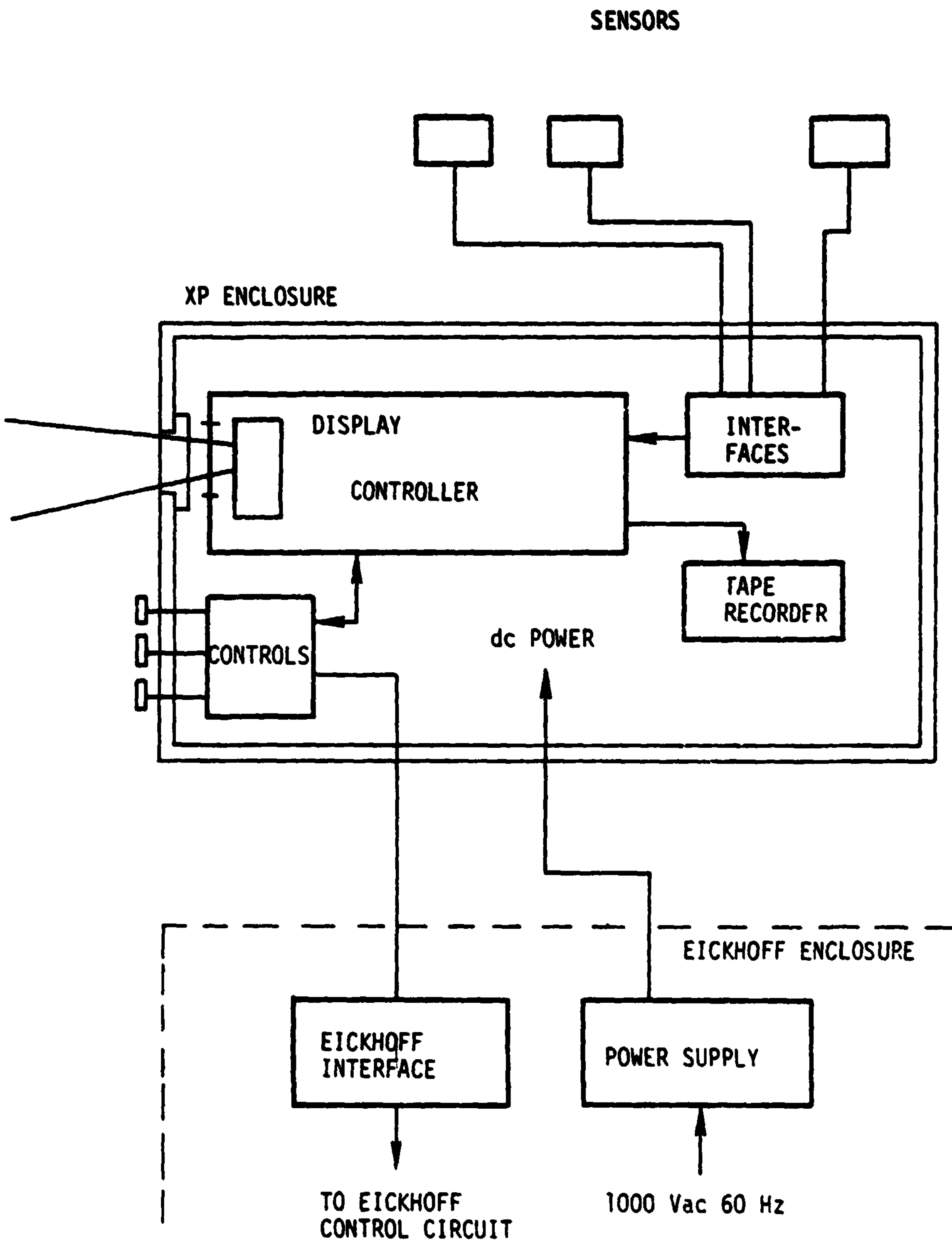

Figure 25. - System diagram.

Front panel controls allow access to the microprocessor memory and are used to start and stop the program. A tape recorder is included to record input data from the sensors for up to 8 hr of operation in a mine.

The Eickhoff Interface converts the controller output signals to levels compatible with the Eickhoff 300L shearer. The power supply converts 1000 Vac into the dc voltages required by the system.

A detailed system diagram is shown in Figure 26.

4.6.2 Circuit Board Description

The circuitry for the system operates under microprocessor control on the STD BUS. The bus structure simplifies the interconnection between boards. A mother board in a card cage has 28 connectors on 0.5 in. centers. Each connector has 56 pins. Each pin is connected via the mother board to all the other connectors. Any board can be placed in any slot in the card cage and no special backplane wiring is required. The system can be expanded or simplified at any time.

CPU

The microprocessor used is the 8085 in a 7801 CPU board made by Pro-Log. The CPU uses a 320 ns clock. Memory on the CPU includes 4K bytes of Random Access Memory (RAM) and 8K bytes of Erasable Programmable Read Only Memory (EPROM). The RAM is used by the stack and for scratch pad use while the EPROM is used for program storage.

EPROM/UART

Additional EPROM (10K bytes) is provided on a combination board made by Mostek. Their EPROM/UART Board (MK77753), in addition to EPROM, has a UART (Universal Asynchronous Receiver Transmitter) to provide a serial interface for either RS232 or 4.20 ma current loop.

CMOS RAM Board

Nonvolatile data storage is obtained from an 8K byte CMOS static RAM board made by Enterprise Systems (Model 10701). An on-board battery provides several weeks of data-retention even if the shearer power is turned off.

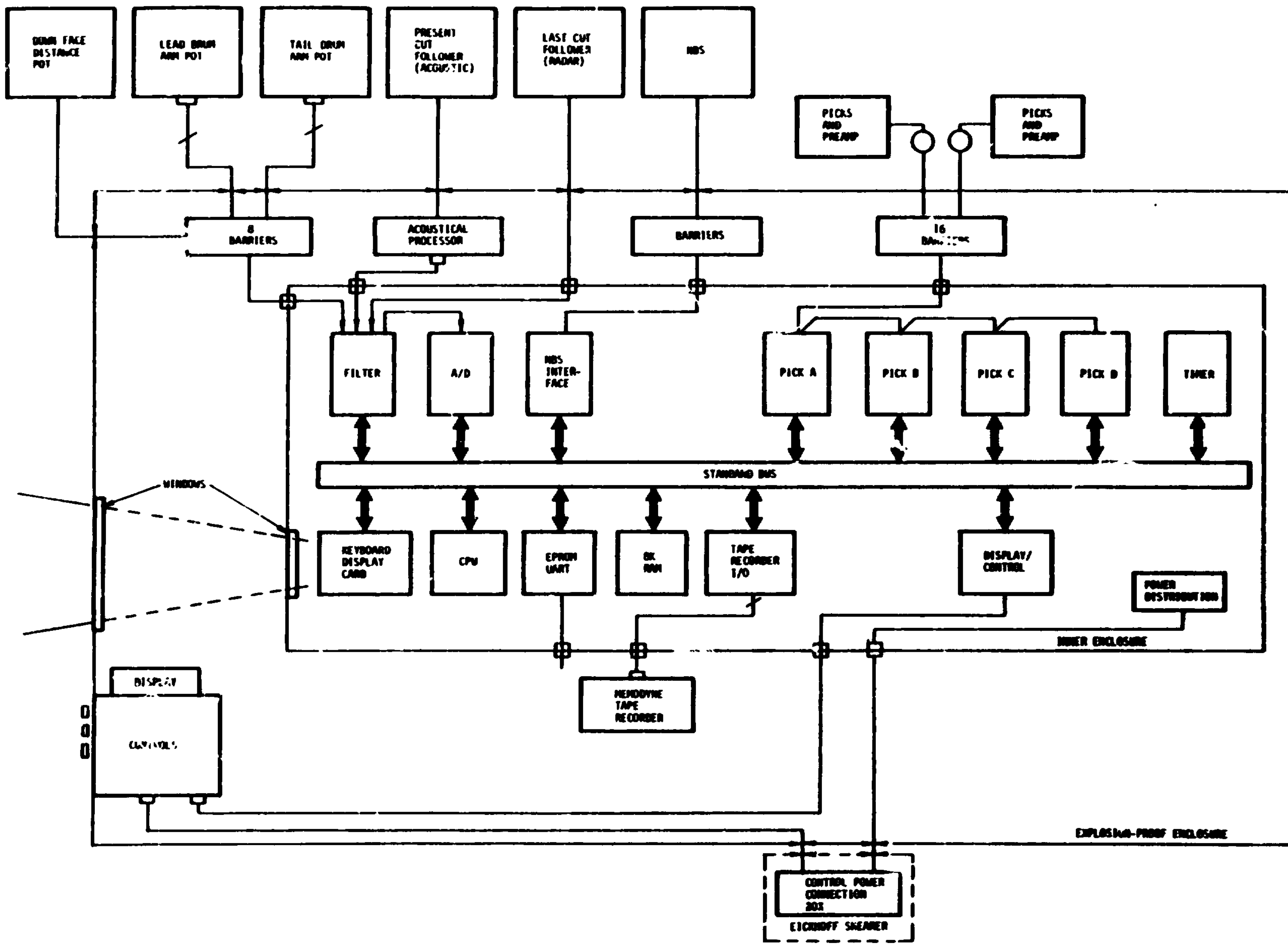

Figure 26. - Detailed system diagram.

Keyboard Display Board

This board is positioned at one end of the card cage opposite a window in the water-proof inner enclosure. A window in the explosion-proof box makes it possible to see the display when all covers are in place. When the unit is being serviced aboveground at a mine or in a laboratory, a 25 key keyboard on the card is used to interrogate memory and to change values in RAM. This board (the Prolog 7303) is compatible with a resident monitor in EPROM on the CPU board. The board also contains eight individual LED displays which are available as status or trouble lights.

Pick Processor

The pick processor subsystem contains two picks spaced 180 deg apart on the lead drum with preamplifiers mounted in the pick blocks. The preamplifiers boost the millivolt load cell signals with a gain of 100 before the signals pass through the slip rings. The slip rings provide power to the preamps and bring the output signals back to the controller. Intrinsically safe barriers are used to isolate the intrinsically safe preamps from the circuitry in the inner enclosure. A pick processor circuit board is required for each sensitized pick.

The circuit for the pick processor was developed by General Electric. The design is basically unchanged except for:

1. A modification to gate out all but the first 30 to 50 deg of the pick signal.

2. An instrumentation amplifier was added to reduce common mode noise.

3. Sync pulses from the slip rings improve timing. In the original General Electric circuit the timing pulses were developed from the signal.

4. The digital output of the circuit interfaces with the STD BUS (see Figure 27).

FUNCTIONAL CIRCUIT DESCRIPTION

The differential input signal enters the pick processor board in an instrumentation amplifier with a gain of 10. The amplifier eliminates common mode noise. A low pass filter eliminates high frequency noise in the signal.

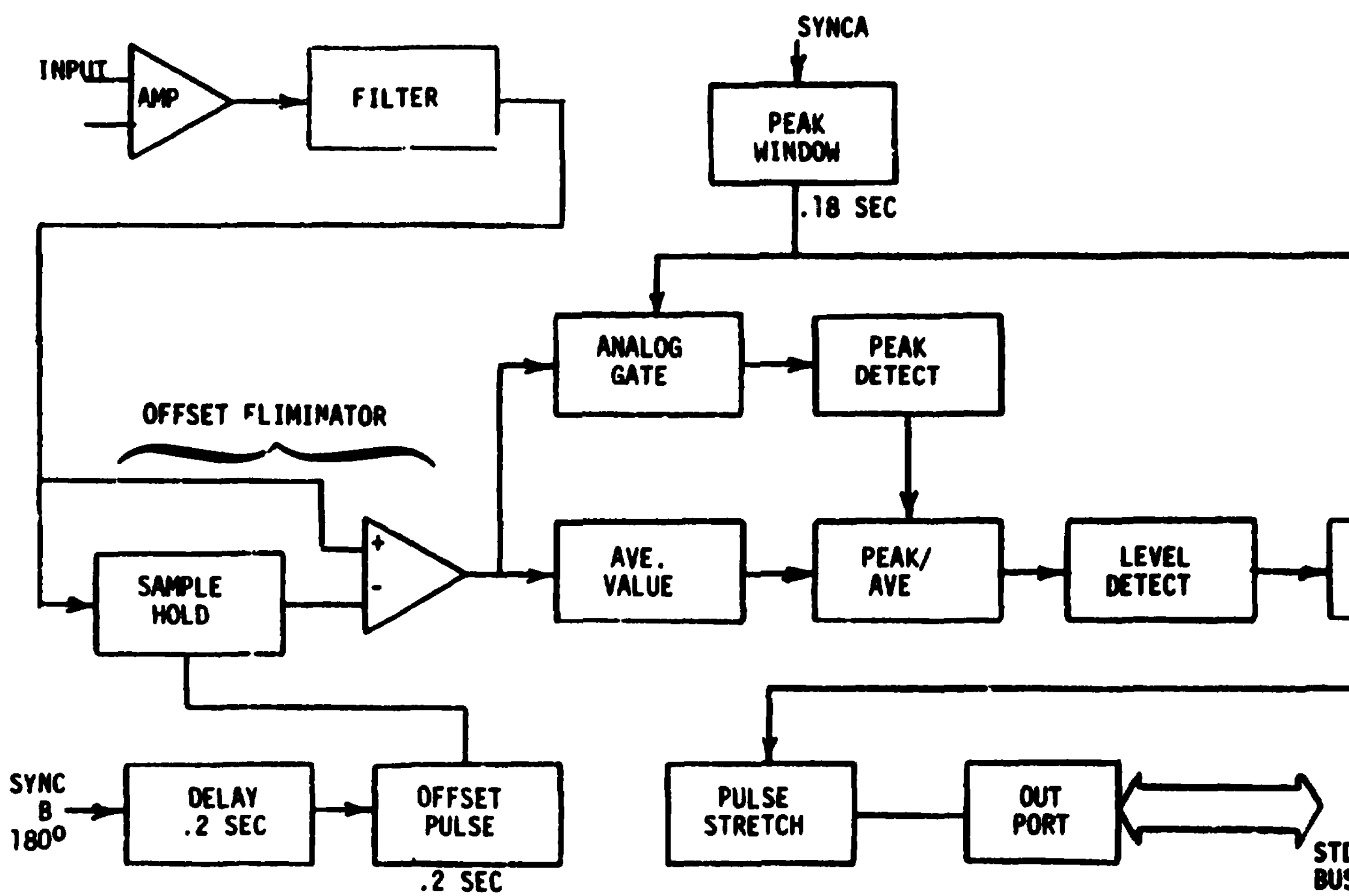

Figure 27. - Pick processor.

The output of the load cell often has considerable offset due to preloading of the cell to improve sensitivity. An offset eliminator reduces the offset. The operation of this circuit can be explained with the aid of Figure 28. The Sync B timing pulse from the slip rings triggers a 200 msec delay one-shot. The trailing edge of the one shot triggers another 200 msec one-shot which is used for the gating pulse of a sample and hold I.C. The pick signal is sampled when the pick is not cutting but instead is in air. The only signal present during the sample interval is due to offset. The value of offset measured is held for a complete revolution of the drum before being sampled again. The output of the sample and hold is fed to an operational amplifier where it is subtracted from the pick signal. The output of the operational amplifier is free of offset.

Sync A is used as a trigger for the Peak Window one-shot (180 msec). The Peak Window coincides with the rock induced spike at the leading edge of the Pick signal. The output of the offset eliminator is gated by the Peak Window and directed into a Peak/Average circuit. The outputs of the analog gate are fed to a peak detector as well as an average value circuit. These two signals are the inputs to an analog divider. The output of the analog divider is the peak/average pulse. If the peak/average ratio is high enough (that is, 2.0) the level detector detects "rock". If the "rock" indication occurs during the Peak Window, it is gated into a pulse stretcher and to an input port where it is processed by the STD BUS.

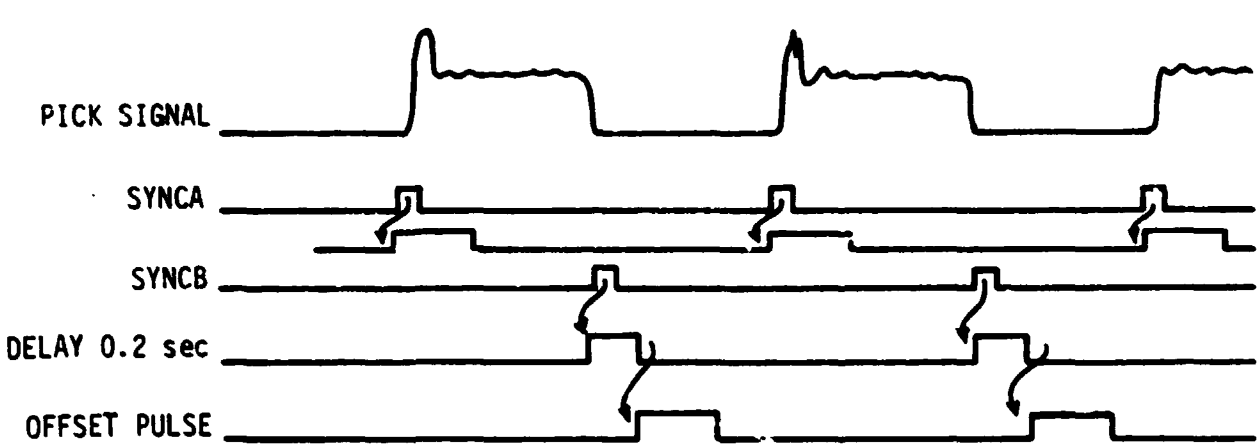

Figure 28. - Pick processor timing.

Filter Board

The filter board is simply a printed circuit board with a low pass filter for each of five differential analog signals from the sensors.

The 3-dBa breakpoint for the filter (see Figure 29) is 6.3 Hz. The output of the filter is connected via a ribbon cable to the analog-to-digital (A/D) converter board. The filter is differential to allow low-frequency common mode signals not rejected by the filter to be eliminated in the A/D converter. A break frequency of 6 Hz was chosen to provide attenuation of 60 Hz noise yet be greater than twice the sampling frequency of 1 Hz.

Analog-to-Digital Converter

The A/D converter board takes the differential signals from the sensors and converts them to a digital form for use by the microcomputer. The board used is a Data Translation Model DT2724. The board will accept 16 single-ended inputs or 8 differential inputs. The board operates from +5 and ±12V power supplies. The board has a wide range analog input capability of 10 mV full scale to 5V full scale.

In the VCS system only 5 of the 8 differential channels are being used. Jumpers on the board set the full scale voltage at 5V.

Natural Background Sensor Interface Board

The purpose of the Natural Background Sensor (NBS) Interface is to accumulate counts from the NBS in a counter and on

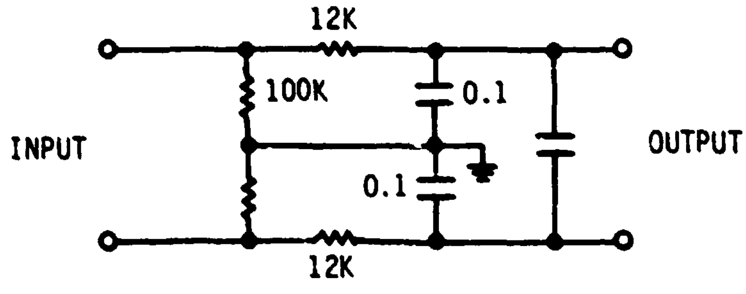

Figure 29. - Filter.

command from the microprocessor transfer the count into the microprocessor. The counts are transferred once per second but the way the data is used is strictly a function of software. For example, the data can be used to calculate a running average over the last N seconds. If N = 10, then once per second the last 10 readings would be totalled and divided by 10. If the average needed to be taken over a longer time the modification would only be in software.

A functional diagram of the NBS interface is given in Figure 30. Input counts from the NBS enter the board and are counted in a 12-bit counter made up of three 4029 CMOS counters. After 1 sec a command from the microprocessor causes the data to be latched into two 74LS374 octal latches. The counter is immediately reset to avoid missing a count. The count is then transferred from the latch to the microprocessor as two bytes.

A self-test capability is built into the board. By sending an *IN SELFTEST PORT* command the signal source will be an on-board oscillator. The oscillator generates 230 to 300 pulses/sec. The pulse width is 50 μsec.

On command from the microprocessor the board will send +12V *CAL COMMAND* to the NBS to activate the calibration oscillator within the NBS. A look *CALPOT* is also included on the NBS interface board to control the frequency of the NBS calibration oscillator.

The interconnections between the NBS interface board and the NBS sensor are shown in Figure 31. The zener diodes, resistors, and fuse in the +12V line is a "barrier" to ensure that the current and voltage remain low and the NBS remains intrinsically safe

In the event that a short-circuit occurs at the NBS, the 12-Ω resistor(s) will limit the current. If a power supply fails and the +12V line rises to 115 Vac the zener diodes will limit the voltage at the NBS. Voltage will be dropped across the 12-Ω resistor until the fuse blows. Commercially built barriers are used for the signal and CAL lines.

4.6.3 Tape Recorder

The tape recorder is used to store test data for an 8-hr period. The tape recorder used in the system is a Memodyne Model 203 incremental recorder. It is a low-power unit using CMOS circuitry and draws a maximum of only 200 mA when operating the stepper motor to advance the tape. The unit operates at

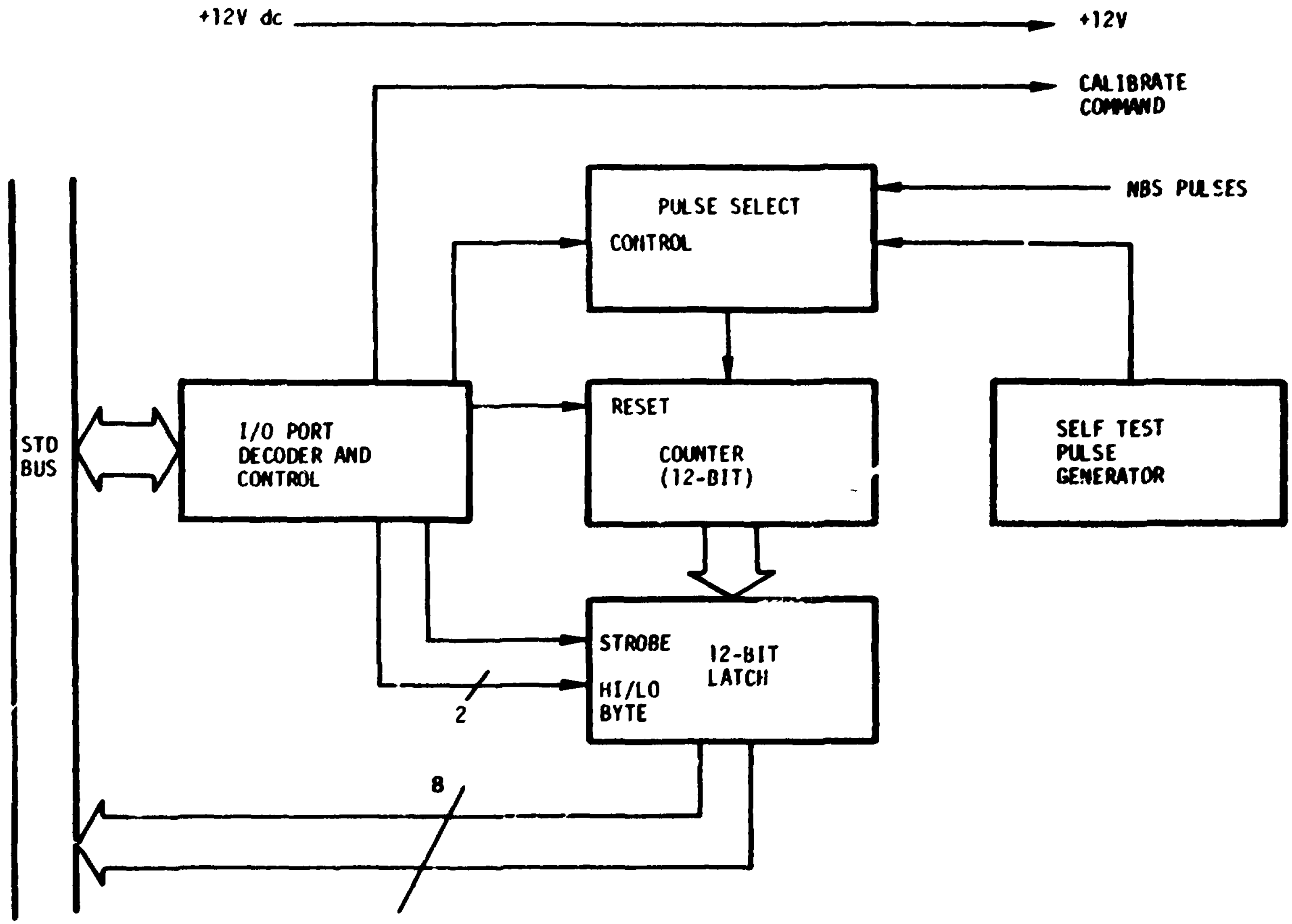

Figure 30. - NBS interface board.

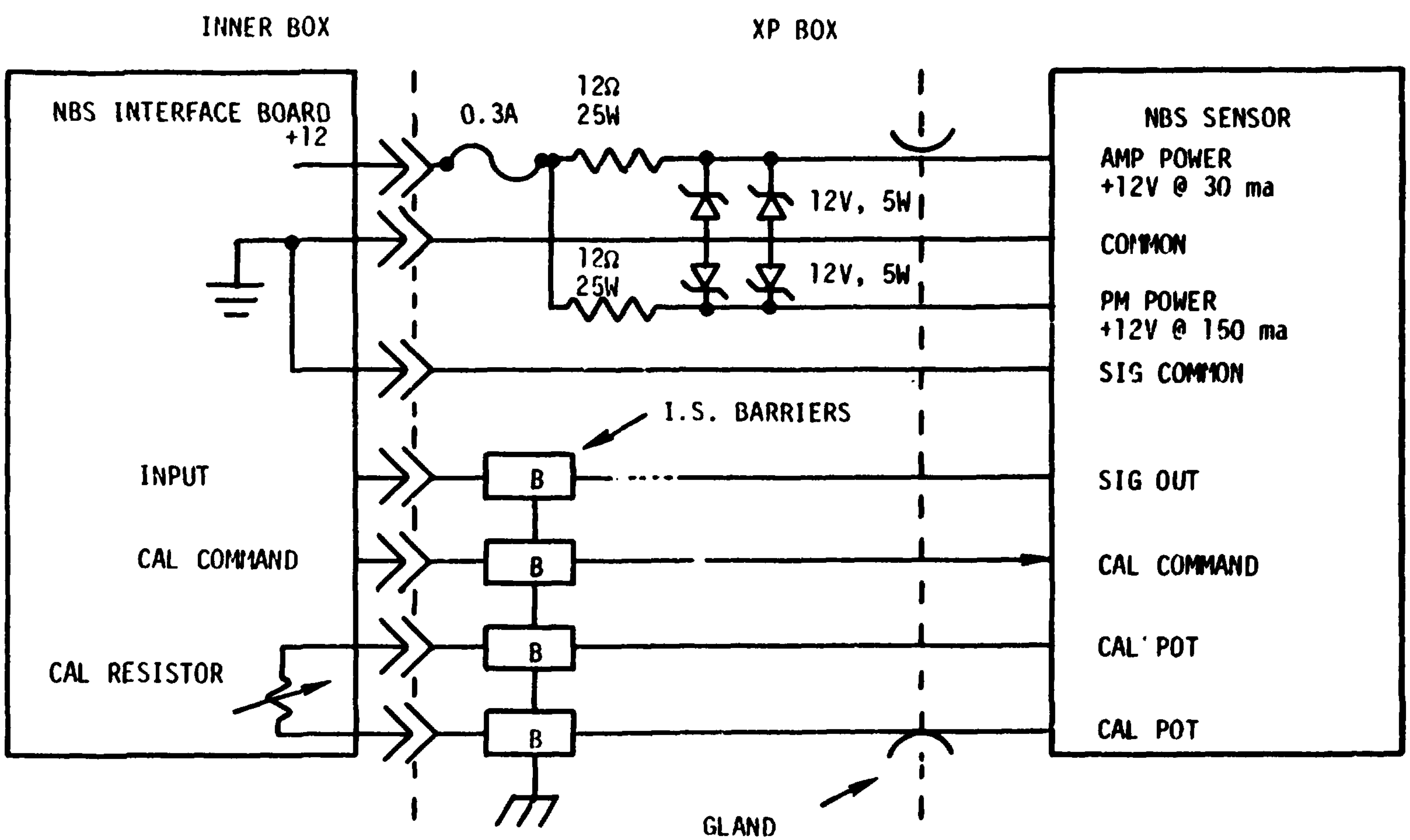

Figure 31. - Natural background sensor (NBS) interface.

180 bits/sec. It uses 300-ft Phillips cassettes and can store 1.76 Mbits.

In operation the recorder will store up to ten 16-bit words every second. Three passes down a 500-ft face can be recorded before having to change the tape. The recorded tapes must be removed and read above ground.

A Memodyne M80 Reader is used to transfer the tape data via an RS232 interface to the HP9825 for data reduction and plotting.

Tape Recorder Interface Board

This board is basically a digital input/output (I/O) port. It decodes and latches a 16-bit output port for data, a 4-bit output port for tape recorder control, and a 4-bit input port for status information. Figure 32 is a functional block diagram of the board.

Data is transferred from the microcomputer to the tape recorder by first sending the 16-bit data to the 16-bit data port. The high order byte of data is latched into port 09 and the low order byte is latched into port 08. A sequence of two output commands are then sent to the control port 0A to cause the *START* output to go low and then high. The resulting pulse starts the Memodyne Model 208 tape recorder. The tape recorder then loads the 16-bit data word into a register. The data is transmitted to the tape a bit at a time (see Figure 33). After the 16 data bits are on the tape, two dummy or gap bits are put on the tape to separate the data words. After 64 words of data have been transmitted from the microcomputer to the tape recorder, the recorder automatically puts an End of File (EOF) gap on the tape. The next data word sent is therefore the first word of the next file.

Timer Board

The purpose of the timer board (Figure 34) is to provide interrupts at precise intervals. Pulses are generated at 1-sec intervals to initiate data acquisition and at 100 msec to initiate the transfer of a 16-bit word of data to the tape recorder. The tape recorder requires 90 msec to move each word onto tape.

The timer board uses an Intel 8253-5 timer chip. This device contains three independent counters. The standard decoder

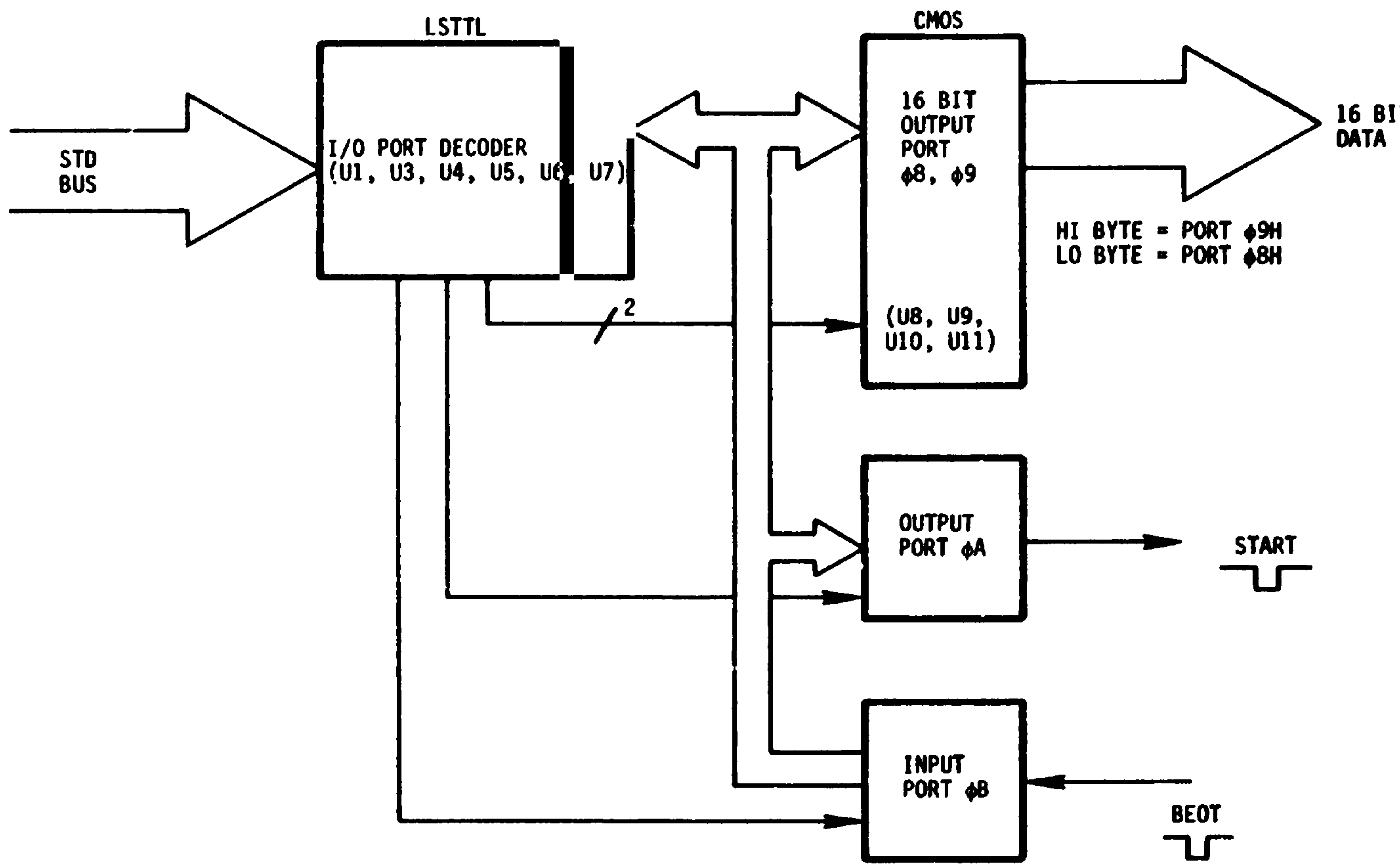

Figure 32. - Tape recorder interface.

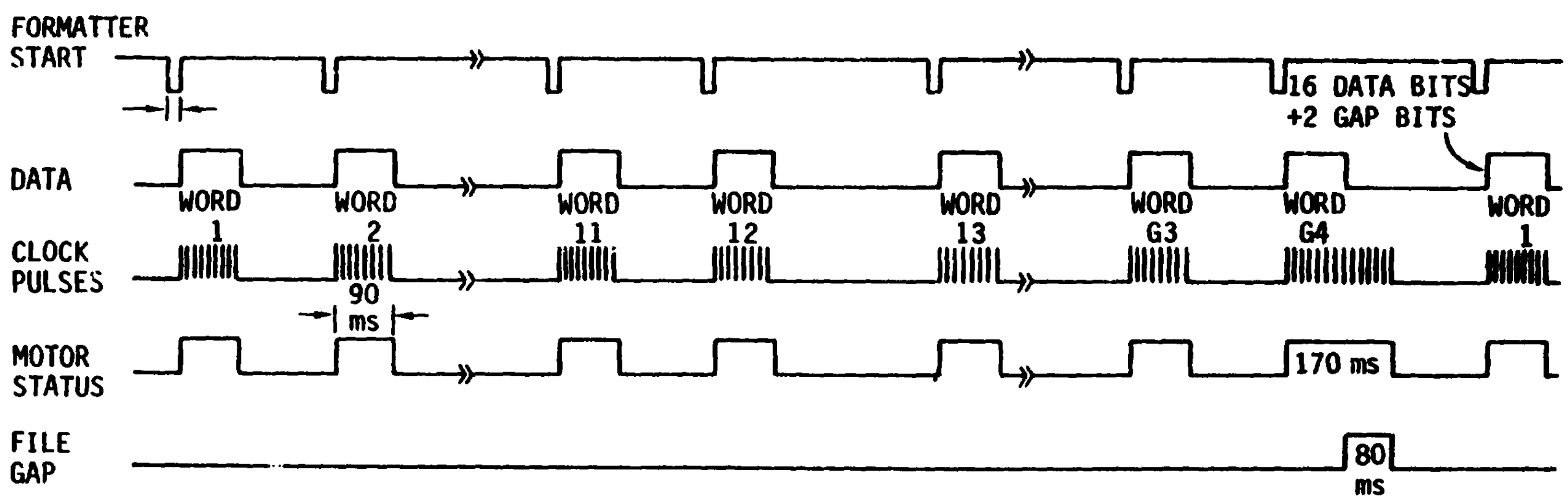

Figure 33. - Tape recorder timing diagram.

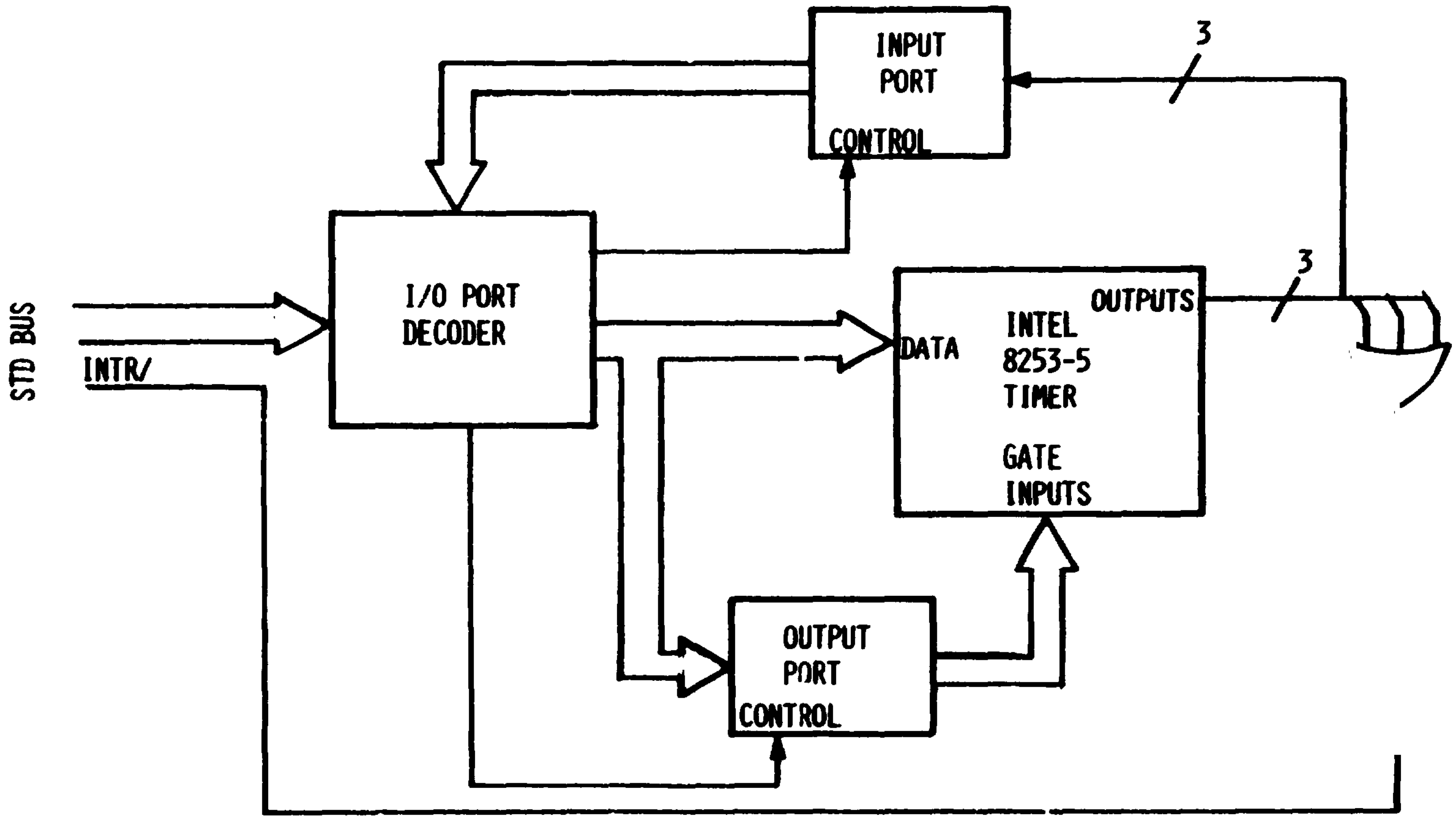

Figure 34. - Timer.

circuitry composed of U3, U4, U5, U6, and U7 provide decoding of input and output ports.

The data buss is buffered and provides the data inputs to the timer chip. Three separate gate inputs allow the three counters to be enabled or disabled independently. A combination of the I/O port decoder circuitry and six control lines into the chip provide access to four data ports within the chip. Each of the three counters is initialized by first outputting a control byte to control port 23. The control byte contains a code for counter 1, 2, or 3, most or least significant byte code, and a code for mode of operation. The least significant byte of the desired count is transmitted to output port 20. Another byte is sent to the control port to point to the most significant byte of the desired count. In this manner all three counters are programmed.

The counters are programmed to provide output pulses at 1 msec, 90 msec, and 1 sec. The 1-msec output is used as the clock for the 90-msec and 1-sec counters. The 90-msec and 1-sec outputs are ored together and used as an interrupt. Once interrupted the microprocessor reads Input Port 24 to determine which counter caused the interrupt.

4.6.4 Eickhoff Interface

The Eickhoff interface is the relay logic interfacing the VCS controller to the solenoids in the Eickhoff 300L shearer. The solenoids actuate hydraulic valves controlling the position of the ranging arms. The two operating conditions are automatic (ranging arms under VCS control) and manual (ranging arms under operator control). A requirement imposed by Old Ben was that the operator could regain control instantly at any time by operating the ranging arm controls on the shearer or remotely by radio control. The Eickhoff schematics were examined in detail and a point in the ranging arm control circuit was found (terminal 17) that is at 39 Vdc unless the operator activates any one of his controls. Figure 35 shows a simplified version of the Eickhoff circuitry and how the manual to automatic switch-over takes place.

A latching relay is used to hold the system in automatic mode. The source of voltage for the latching action is Terminal 1X5-17 of the Eickhoff circuit on drawing No. 10872C2. If any ranging arm control is activated, the relay will drop out and the operator will have control. Two latching relays K1 and K2 were used for redundancy to guard against a relay sticking in the latched position. A warning horn is activated for 3 sec by a

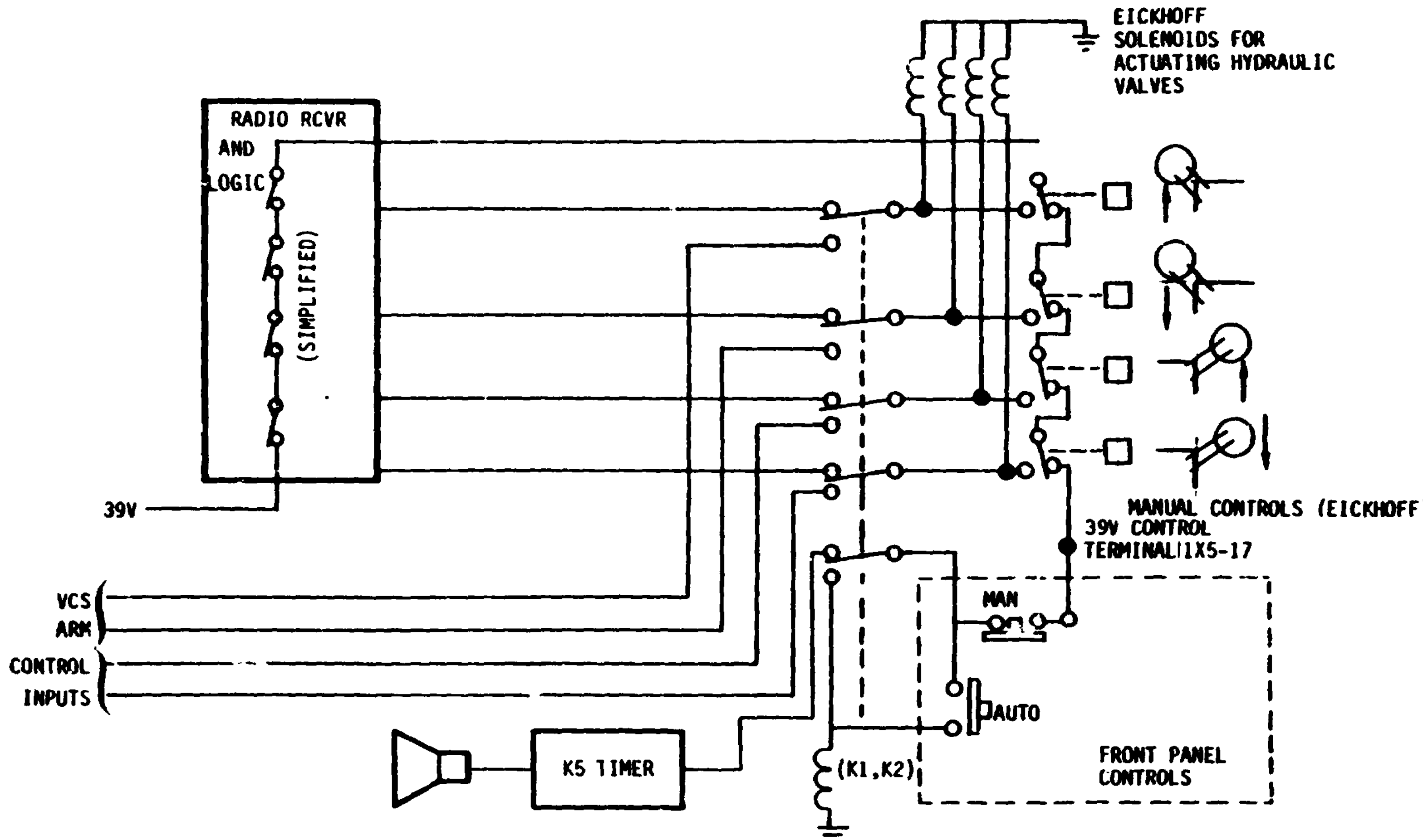

Figure 35. - Eickhoff interface diagram.

timer relay K5 whenever control changes from automatic to manual. This feature alerts the operator to the fact that he must control the machine.

4.6.5 Power Supply

The power supply for the VCS system utilizes 975 Vac from the shearer power and converts it to ±5V and ±12V. The power supply is shown in Figure 36. Fuses F1 and F2 limit the input current to 0.5A. Transformer T1 is a ferroresonant voltage regulating transformer that drops the mine power to 115V. A ferroresonant transformer was used to circumvent the poor line regulation existing in some mines. A factor of those improvements in line regulation is typical for ferroresonant transformers. A Corcom 10R6 line filter is used to eliminate high-frequency noise and transients on the 115 Vac line. An ON/OFF capability is provided by solid state relays K3 and K4 which switch both sides of the 115 Vac line.

Switching power supplies were used to minimize size and power dissipation. Small size was needed because of the small volume available for the power supply and Eickhoff interface circuitry within the radio compartment of the Eickhoff machine. The input of each power supply was fused. All power supplies have current and voltage limiting internally. The ground side (or common) for all power supply is tied together at a terminal strip inside the electronics inner enclosure.

The worst case current and power requirements for the various components of the system are given in Tables 3 and 4. It should be noted that the design of the power supply was based on the assumption that two radar units would be used. This had a large impact on the power supply design since the radars consume one-half of the total system power. The system configuration finalized for use at Old Ben Mine used acoustic followers rather than radars and the total system dc power consumed was only 55W.

4.6.6 Front Panel Controls and Display

One of the major considerations in designing controls for an explosion-proof box is to minimize the number of controls. The through-cover actuators are big and complicate the packaging of a given system. Figure 37 shows the orientation of the controls and displays on the front panel. The following controls were considered a minimum number required for normal operation and to do microcomputer debug procedures:

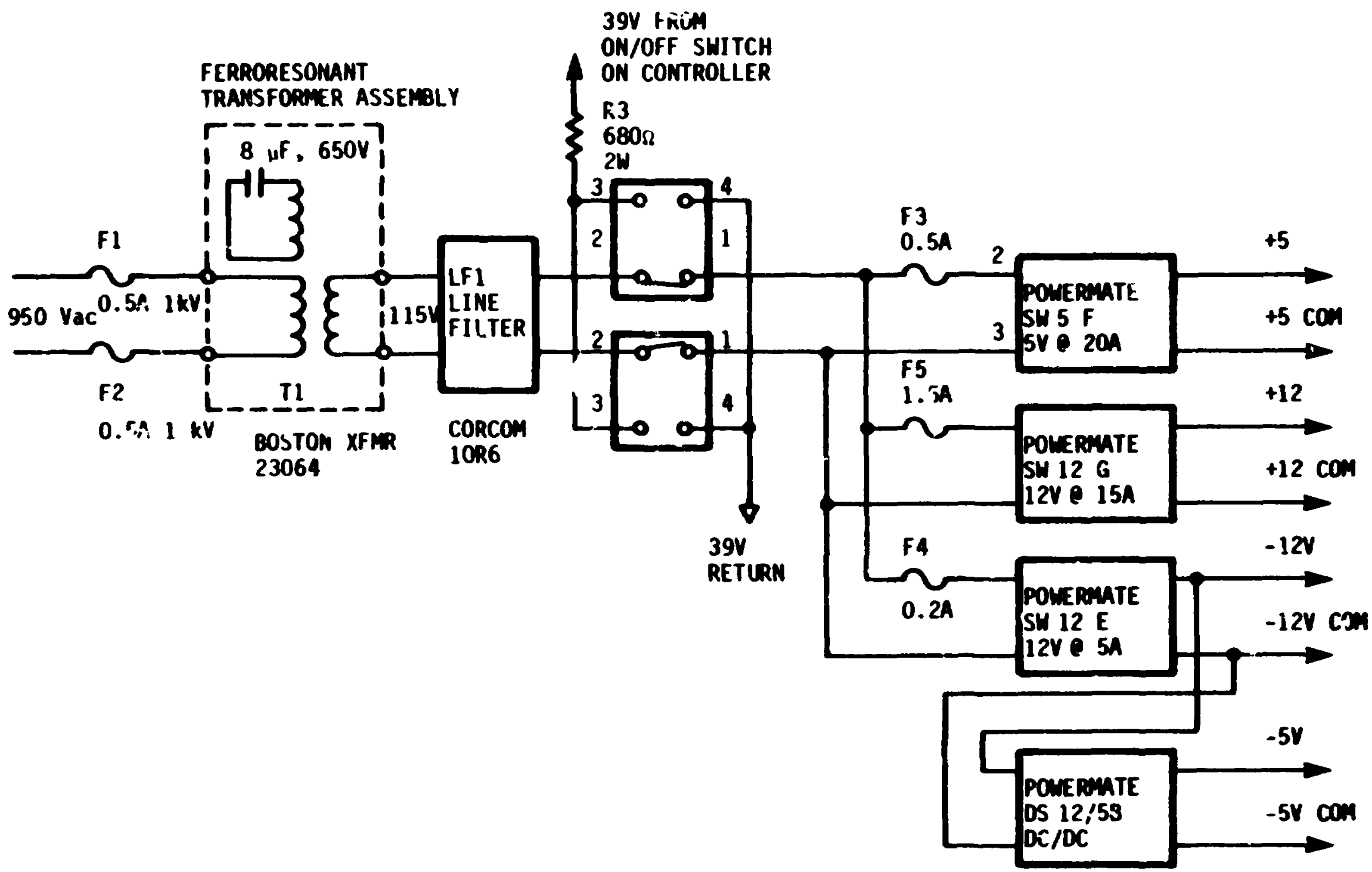

Figure 36. - Power supply.

TABLE 3. - VCS CURRENT REQUIREMENTS AS A FUNCTION OF VOLTAGE

	Current in Amps			
	+5V	+12V	-12V	-5V
MP system				
CPU card	1.400			
Keyboard/display	0.600			
EPROM/vart	1.200	0.050	0.035	
A/D card	0.500	0.075	0.075	
RAM card with 8K	0.177			
Input signals				
Radar (2)	0.430	5.200	0.080	0.180
Or acoustic sensor (2)		0.5	0.5	
Picks and amplifiers		0.120	0.120	
NBS and signal cond.		0.250		
Custom I/O boards				
4 pick cond. boards		0.210	0.210	
CID input board	0.265			
Tape recorder board	0.265			
Arm control and status display	0.365			
Output devices				
Tape recorder	0.100	0.120		
Optical interface for arm control	0.050			
Status indicator lights	0.080	0.120		
TOTALS With two radars	5.697	6.145	0.520	0.180
With two acoustics	5.267	1.195	0.94	

TABLE 4. - VCS POWER REQUIREMENTS

MP system	Power consumption (Watts)
CPU card	7.0
Keyboard/display	3.0
EPROM/vart	7.02
A/D card	4.3
RAM card with 8K	0.89
	22.21
Custom I/O boards	
Timer	1.325
Pick cond. boards (4)	5.04
CID input board	1.325
Tape input board	1.325
Arm control and status display board	1.825
	10.84
Input signals	
Radar (2)	66.41
Acoustic sensor (2)	- (If used, 12)
Picks and pre-amps	2.88
NBS and signal cond.	3.0
	72.29
Output devices	
Tape recorder	1.94
Optical interface for arm control	0.25
Status indicators	1.84
	4.03
System total (with radar followers)	109.37
(with acoustic followers)	54.96

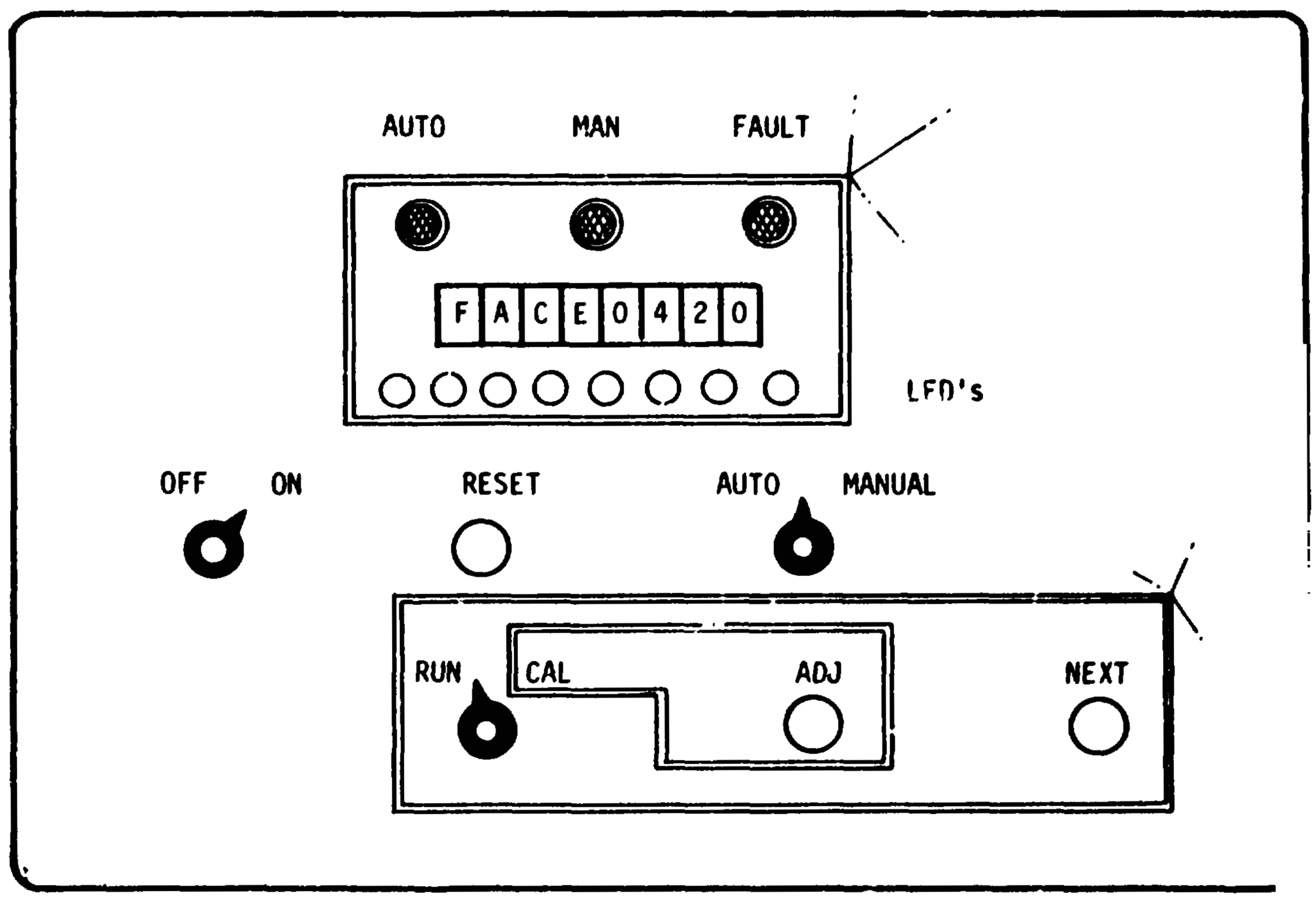

Figure 37. - Front panel.

1. *ON/OFF*

2. *AUTO/MANUAL* switch

3. *RUN/CAL*

- Run position - Enter main routine
- Cal position - Enables the *ADJ (ADJUST)* and *NEXT* pushbuttons

4. *NEXT* pushbutton - When pressed sequences through a list of variables the variable name and value is displayed. The variables are altered by pressing the *ADJ* pushbutton.

5. *ADJUST* pushbutton - When pressed increments the variable being displayed.

6. *RESET* pushbutton - General purpose pushbutton whose function varies with the program being run. In general, it is used to terminate a given task.

A window on the side of the explosion-proof enclosure allows indicators inside to be monitored. The following displays are used:

1. *Alphanumeric Display* - An eight-digit display on the keyboard/display card but visible through a set of windows. The display is used to prompt the operator and to display a number of variables, messages, and memory locations.

2. *LED* - Eight LEDs are also a part of the keyboard/ display board. Their use is uncommitted at present. They can be used to display status.

3. *STATUS INDICATORS* - Three LEDs are used to display *AUTO*, *MANUAL* and *FAULT*. The *AUTO* and *MANUAL* displays are obviously to indicate whether the system is in automatic or manual operation. The *FAULT* indicator tells the operator that a problem exists with the system.

4. *DISPLAY/CONTROL BOARD* - The Display/Control board provides a digital I/O interface between the microcomputer and the frontpanel controls as well as the Eickhoff interface.

5. *EICKHOFF INTERFACE AND THE FRONT PANEL* - The Front Panel Interface functional block diagram is shown in Figure 38. The I/O port decoder is identical to the decoder portion of several other boards in the system. It is composed of

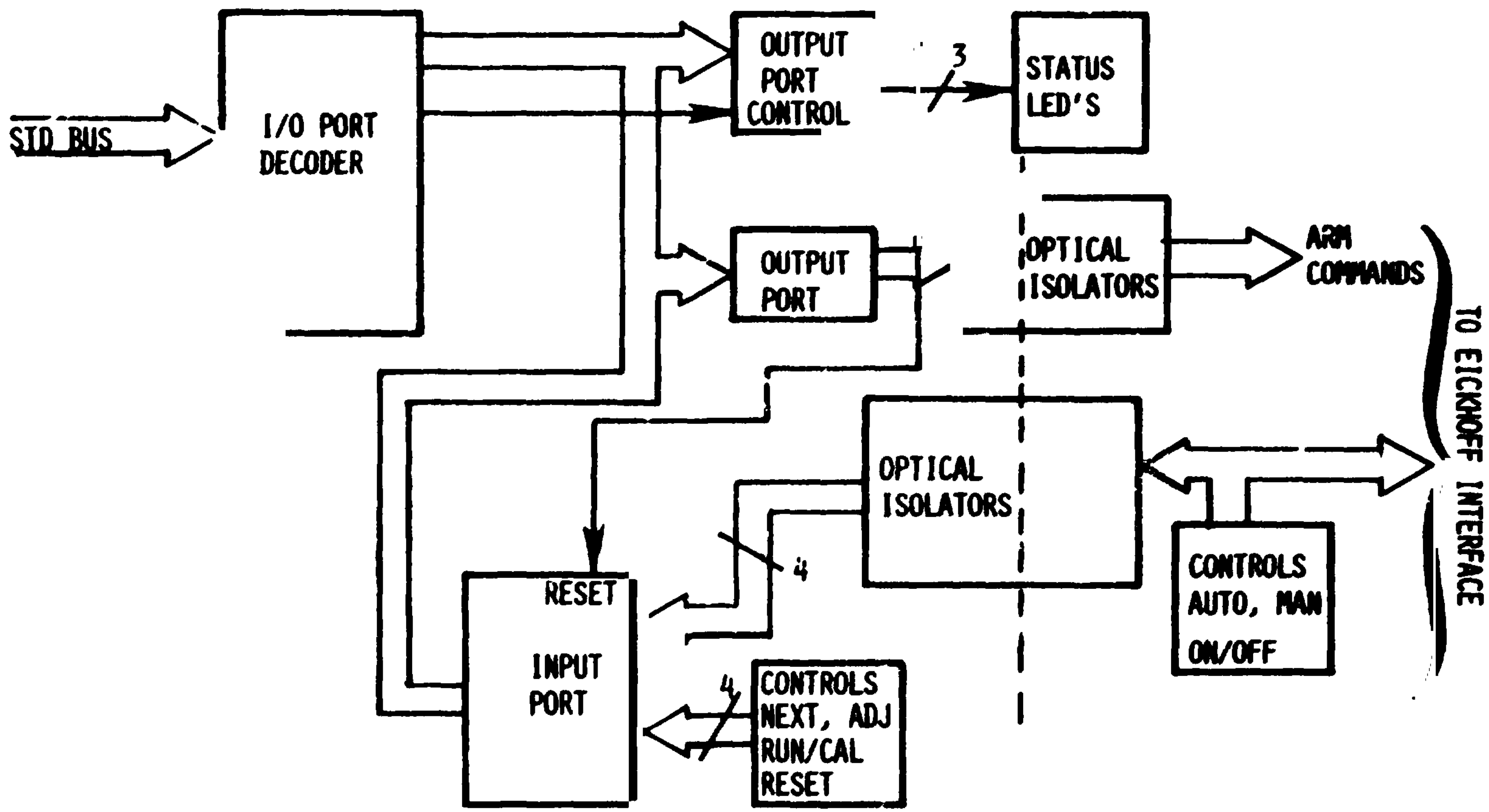

Figure 38. - Front panel interface.

U1 through U7. Input port 04 is composed of U11 and U12. This port is the interface for the front panel switches. The least significant 4 bits of the port are in order of increasing significance *NEXT*, *ADJUST*, *RUN/CAL*, and *RESET*. The upper 4 bits of input port 04 starting with the MSB are *SPARE*, *AUTO*, *39 VOLTS*, *MANUAL*. The optical isolators between the controls and input port 04 prevent noise on the 39-Vdc line from causing problems in the microcomputer.

Output port 06 (U8 and U9) provides the drive for the status LEDs *FAULT*, *AUTO*, and *MANUAL* on bits 3, 2, 1, and 0, respectively. Two other bits (bit 4 and bit 5) of port 06 are used to control a 1.5-sec timer (see Figure 39). The timer acts as a missing pulse detector. The output port 03 for controlling the ranging arms is enabled by gating U14 only if a reset pulse immediately followed by a trigger pulse occurs once per second. If there is a problem in software or system hardware and pulses cease, the timer will time-out after 1.5 sec and control of the drums will be inhibited.

The cross-connected tri-state 74126 buffers (U14) prevent a given drum from being commanded to go up and down simultaneously.

The output of the timer is buffered by U7 (pin 6) and used as a signal to inhibit the latching relay in the Eickhoff interface and return system operation from automatic to manual.

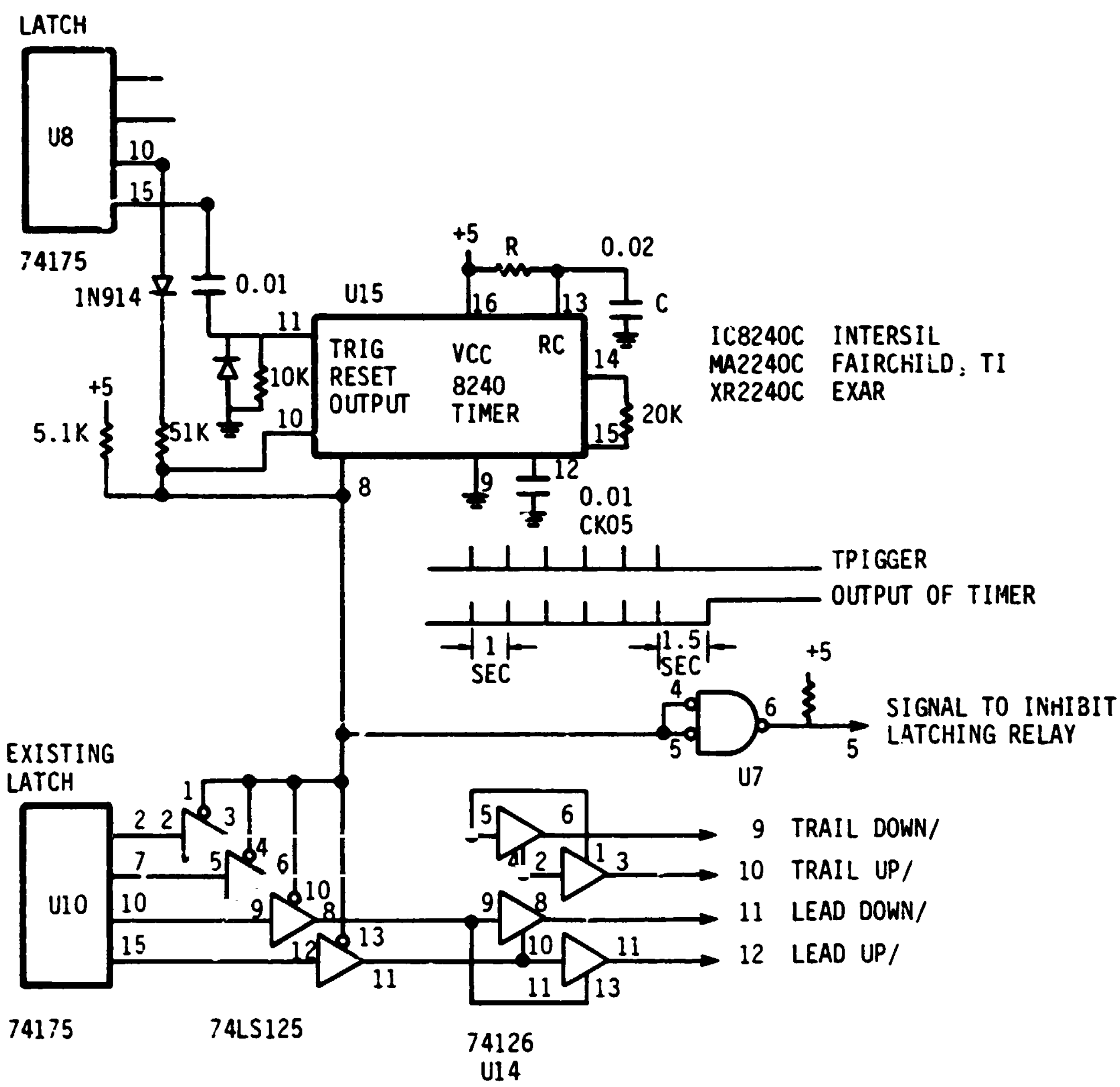

Figure 39. - Missing pulse detector.

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5. BRUCETON MLF TESTING

5.1 BACKGROUND

Prior to the FMA contract MSFC had implemented a control system on the Joy shearer at Bruceton. FMA essentially took over this hardware in place and gradually transformed it into a configuration that was as nearly as possible identical to that which was installed underground at Old Ben Coal. The following paragraphs describe the chronólogical sequence of those testing efforts as the final configuration became available and the culmination of these tests at Bruceton with a formal demonstration of the control system to MSFC in March of 1981.

5.1.1 MSFC System Description

Figure 40 is a block diagram representing the functional characteristics of what will be referred to as the MSFC configuration. Basically the analog signals from the sensors were brought together in a junction box that was physically located on the Joy shearer. Those signals were then transmitted via a 64-in. conductor cable to a trailer that housed an interface box for signal conditioning. The interface box then supplied the Hewlett Packard 9825 data base with the basic sensor information. The 9825 processed the data, generating commands for the front and rear drum control which essentially revised the process through the interface and junction boxes to the electrical solenoids on the Joy. The commands generated were digital pulse signals and defined duration and direction corresponding to the required movement of the drums. It is worth noting that as shown on Figure 40, 115V power was supplied to the junction box for conversion to the voltage requirement of the sensors.

5.1.2 MSFC Hardware/Software Description

Although as shown on Figure 40, the MSFC configuration contains the basic functions required for a control system, there are significant differences in the hardware used in the Old Ben configuration. Therefore, it is probably worth a moment to review the details of the MSFC hardware.

The front and rear drum arm position was obtained from linear potentiometers attached to the shafts of the drum arm hydraulic cylinders. The present and last cut followers used 15 GHz radar and the downface distance measurement device was an extremely accurate encoder used in conjunction with the face alignment system. The sensitized picks at this time incorporated

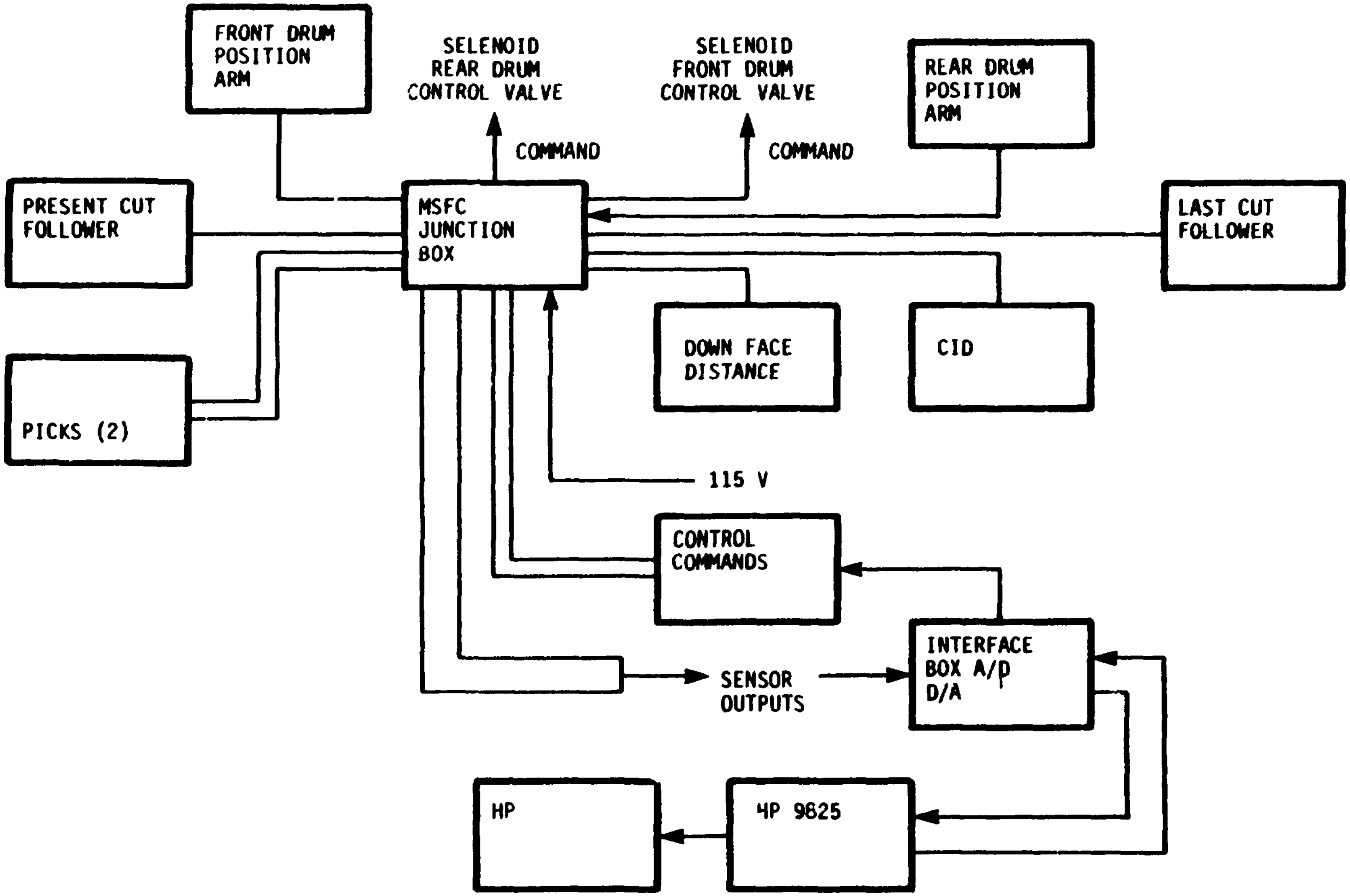

Figure 40. - Diagram of functional characteristics of the MSFC configuration.

an FM link for data transmission with no provision to be incorporated into the control system. There was provision for a CID input but suitable hardware was not yet available.

As previously noted, a junction box was physically located on the shearer while the interface and control hardware was contained in a trailer some 30 ft from the shearer. A Hewlett Packard 9825 desk top computer was used as the control hardware generating control signals for the shearer's electric solenoids that activate the drum arm hydraulics. In addition, a Hewlett Packard plotter was available in the trailer for data reduction and presentation. This was most convenient since all of the sensor information and control signals were available at the 9825 and stored on tape for subsequent analysis.

The software resident on the 9825 was essentially that corresponding to a MODE II or a modified MODE II operation. That is to say that since a CID was not available, MSFC had created software that could be used to control the shearer without CID input. In addition, an extensive plot routine was available for data presentation and analysis.

5.2 FMA DEVELOPMENT AND TESTING PHILOSOPHY

Given that a set of functioning hardware existed at Bruceton, it seemed useful to utilize this hardware thus gaining experience with the Joy machine. This was accomplished by adopting a philosophy of replacing the MSFC components with FMA components as they became available, while continuing to keep the entire system operating at Bruceton. The following paragraphs will describe that process as it occurred.

5.2.1 Old Ben Configuration

At the outset of the preliminary design phase, FMA defined what will be referred to as the Old Ben configuration. The object of the testing at Bruceton was to then substitute components as they became available until FMA could demonstrate the Old Ben configuration at Bruceton. At this point in time, the Old Ben configuration consisted of:

1. Last cut follower - radar or acoustic

2. Present cut follower - radar or acoustic

3. Two sensitized picks - front drum only

4. Downface distance

5. Front and rear drum arm position indicators - potentiometers

6. Natural background sensor

7. Controller

8. Power supplies - interface hardware.

Each of these, with a few exceptions that will be noted, were tested, first as components at FMA, MSFC and finally Bruceton. Those results will be briefly discussed in the next subsection.

5.2.2 Component Test Results

At the beginning of the design work, FMA proposed an alternative to radar as a cut follower. That alternative was an off-the-shelf acoustic distance measuring transducer and associated electronics. This was virtually the first piece of FMA hardware tested on the Joy shearer. The component test results were successful describing a sighting cone angle of 3 deg which was within the needed limits. More importantly, the acoustic unit could be skewed from vertical up to 10 deg when shooting a rough surface target such as coal. The unit was mounted on the Joy shearer as both a last and present cut follower and tested for numerous hours with and without both debris and water. In all cases the acoustic unit has performed successfully.

MSFC supplied FMA with a 15 GHz radar unit which was subsequently redesigned to the 35 GHz range to facilitate packaging. Four 35 GHz units were fabricated and bench tested at Georgia Tech's Radiation Laboratory. Several problems were noted in these tests relating to look angle. It was much too large GIT proposed using a lens to focus the radar beam. A lens was subsequently developed and tested with satisfactory results. When the first units arrived at Bruceton, they were placed in the last cut position to avoid the debris associated with the present cut position.

The upshot of the extensive testing conducted on the radar units is that they were unsuitable for underground application, the primary reason being their intolerance to debris and water. The radar units were not considered as the primary devices for present and last cut followers.

The downface distance device proposed for Old Ben was a multiple turn potentiometer. This device with appropriately different mounting hardware was installed on the Joy shearer much as it was at Old Ben. This unit performed without incident.

The sensitized pick configuration for Old Ben used sliprings as a means of bringing the signal from the pick to the controller. The Joy shearer was retrofitted with the necessary hardware to accommodate the pick leads and sliprings. Both sensitized picks were installed with preamps to minimize noise effects through the sliprings. Both picks were tested repeatedly on the mock longwall face. The sliprings and pick hardware performed without incident during these tests. It should be noted, however, that the ability of the discrimination circuitry to distinguish between rock and coal was never proven. This could in part be attributed to the block of "coalcrete" itself since both the simulated cap and simulated coal were extremely hard.

As previously noted, MSFC had utilized linear potentiometers on the arm hydraulic cylinders to determine arm position relative to the shearer body. Since the Old Ben configuration required rotary pots, this type was used (on the pivot point of the arm) instead of the linear devices. These also performed without incident.

The natural background sensor was never tested at Bruceton because it was impractical to provide a suitable signal at the surface test facility.

The controller and its associated hardware was thoroughly bench tested at FMA and supplied to Bruceton in working order including the software. This particular hardware was tested in the systems tests which will be described in a later subsection.

The power supplies used to convert 115V to logic levels was installed and used at Bruceton during the entirety of the surface tests. One type of power supply failed twice leading to the identification of a bad set of capacitors which were subsequently tested and replaced if necessary in the remaining units. The stepdown transformer required to go from mine power - 1000V to 115V - was not tested at Bruceton since the Joy shearer operated on 460V. As one would expect, the remaining interface hardware was too Old-Ben-specific to be tested at Bruceton.

With the exception of those few previously noted, the components used at Old Ben were tested as a system at Bruceton. The specifics of the Old Ben control system demonstrated formally to NASA MSFC will be discussed in the next subsection.

5.2.3 Final Old Ben Configuration

The final Old Ben configuration tested at Bruceton was as follows:

1. Acoustic last cut follower

2. Acoustic present cut follower

3. Two sensitized picks - front drum

4. Downface distance

5. Front and rear drum arm potentiometers

6. Controller

7. Power supplies (partial).

Figure 41 shows a functional representation of the Old Ben configuration tested at Bruceton. This diagram also shows some of the details of the controller itself such as the filtering, analog to digital conversion, the microprocessor and the real-time tape recording capabilities.

It is worth noting that the Joy arm dynamic response was altered to approximate the Eickhoff shearer used at Old Ben. All of the hardware was mounted on the Joy shearer, although the link between the MSFC junction box and the Hewlett Packard 9825 was maintained in parallel. This was done so that first the convenience of the HP quick turnaround on data could be maintained and second, to verify the tape recording capability in the FMA controller by direct comparison to the HP outlet.

Since the performance of the sensitized picks in the Bruceton coalcrete was questionable, provisions were made in the hardware to supply a simulated "coal"or "rock" signal to the microprocessor on demand so that the entire control algorithm could be thoroughly tested.

Figures 42, 43, 44, and 45 are photos taken of the actual Bruceton sensitized picks, last cut, present cut, and drum potentiometers, respectively. Figure 46 is an overall shot of the shearer showing the downface distance sensor, the controller enclosure and the power supply box.

5.3 OLD BEN DEMONSTRATION TEST

In March of 1981, FMA formally demonstrated the Old Ben Configuration control system to MSFC officials at Bruceton, PA. The following is a discussion of the tests performed, their limitations as well as a presentation and discussion of the test data.

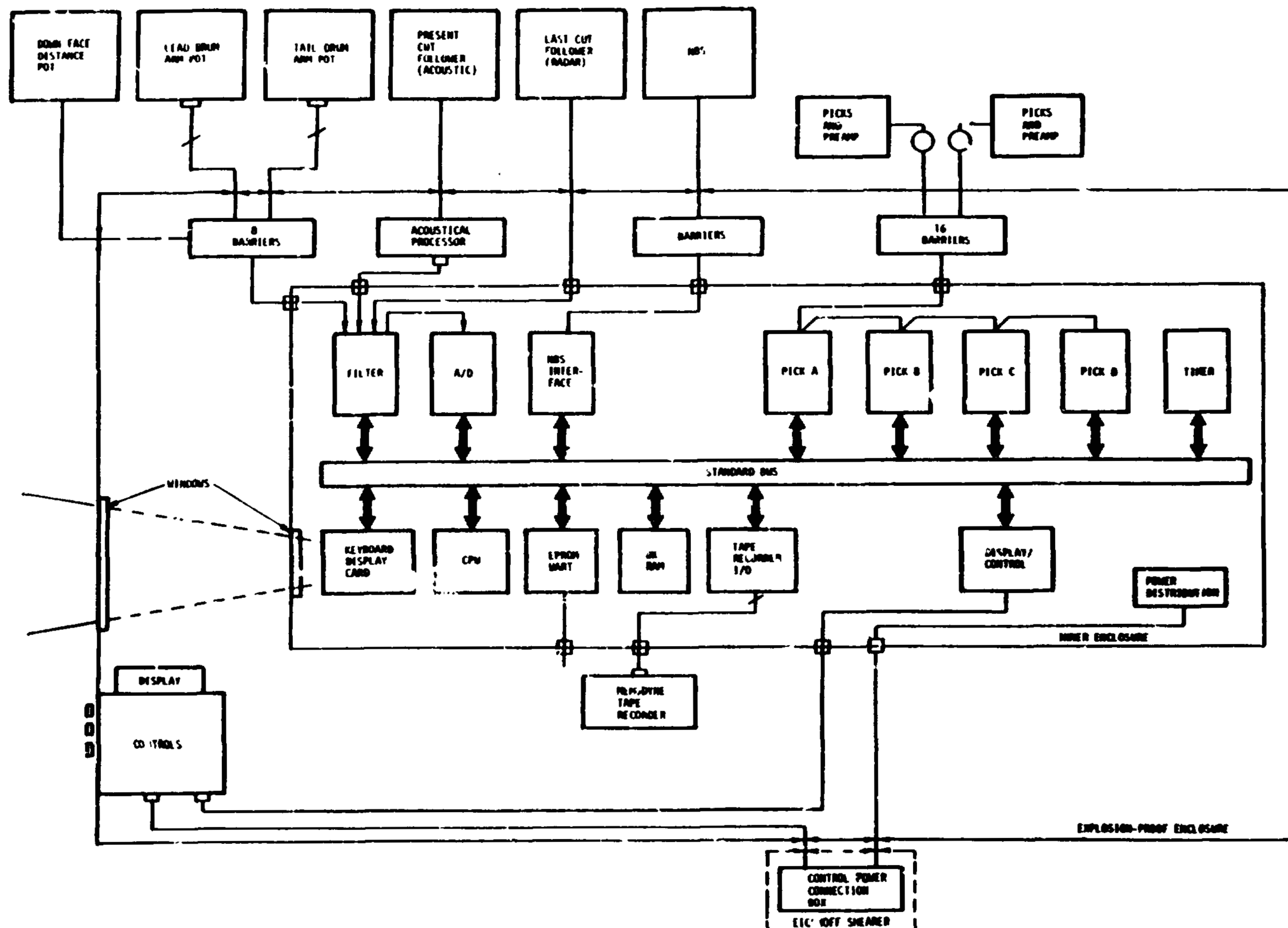

Figure 41. - System functional diagram - Bruceton tests.

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Figure 42. - Bruceton sensitized pick installation.

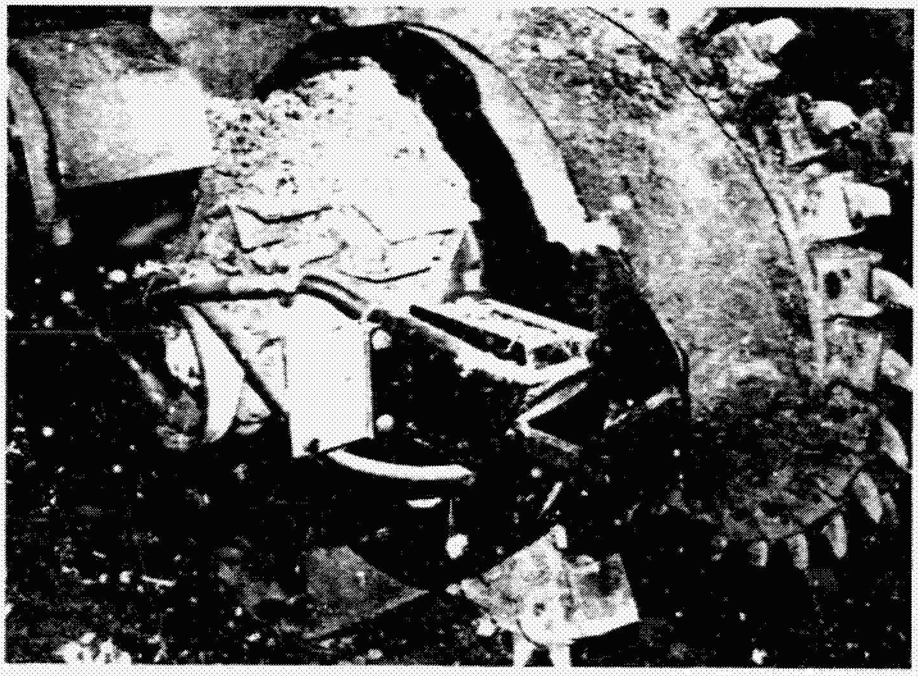

Figure 43. - Bruceton last cut acoustic.

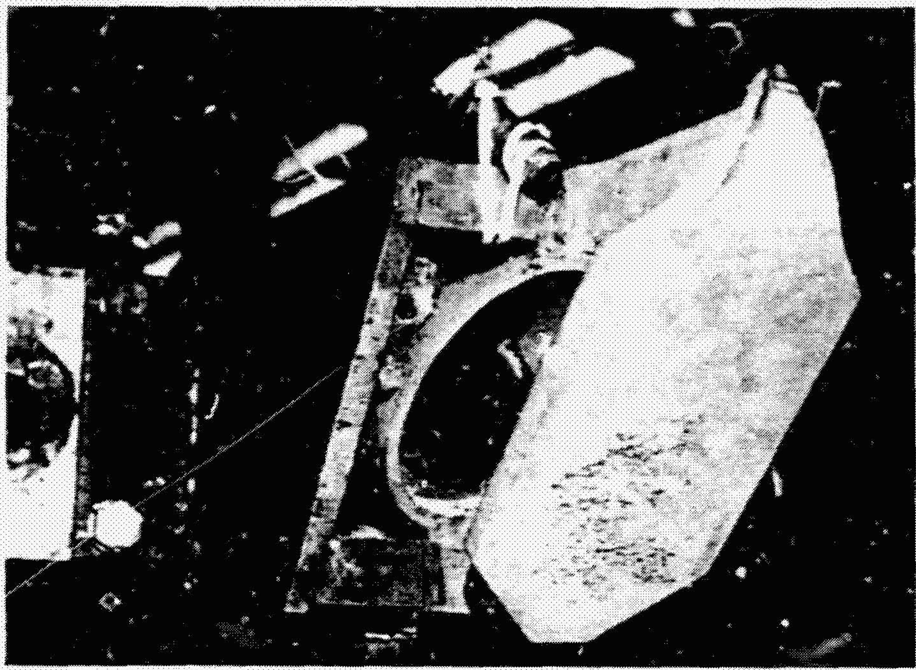

Figure 44. - Bruceton present cut acoustic.

Figure 45. - Bruceton arm potentiometer.

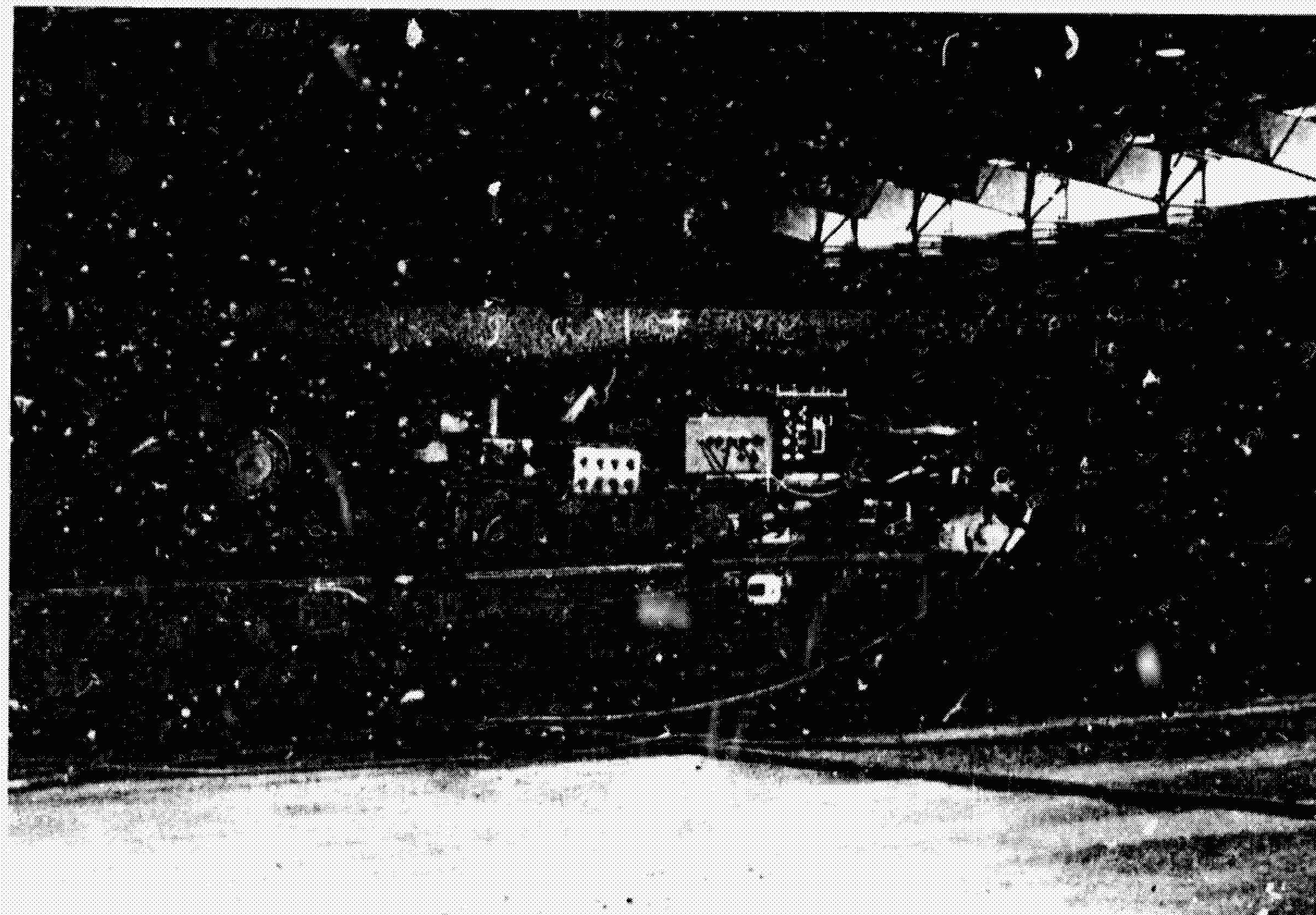

Figure 46. - Bruceton VCS installation.

5.3.1 Test Sequence

All of the testing for the demonstration was conducted as modified MODE I tests, that is to say, real-time front and rear drum control. In addition, FMA did provide other software options for possible situations underground. These included full MODE II software as well as a rear drum slaving routine. The rear drum slaving routine was tested at Bruceton and will be discussed later.

FMA conducted two types of tests, tram and cutting. The tram tests were conducted by tramming the shearer under an extended cap such that the last and present cut fullower had roof profiles to follow. Obviously, it was necessary to set fictitious nominal set points for the front and rear drum so they wouldn't inadvertently plow into the floor or cap. Tram runs served two purposes; first, they conserved the block while allowing a multitude of runs to test the basic control hardware, and second, they allowed much higher tram rates to be tested than was possible while cutting the artificial face. It turned out that the formulation used for the block resulted in an extremely hard material, so hard, in face, the Joy shearer was capable of tramming faster than 5 ft/min while cutting. Old Ben, on the other hand, was expecting to run at between 20 and 25 ft/min along the face. Therefore, it was essential that tram-only tests be conducted at the higher speeds.

For the purposes of the Old Ben demonstration tests to MSFC, FMA conducted a series of tramming tests to demonstrate the effect of speed water sprays, simulated picks, pan line prealignments, simulated shields and rear drum slaving. These tests were followed by a full-web full-face cut under FMA control. The final stages of the testing demonstrated the ability to collect pick data, the FMA tape record capability and some malfunction routines built into the software. The following paragraphs will present the results of those tests and discuss the pertinent findings.

5.3.2 Presentation and Discussion of Data

The Bruceton mock longwall block is a face 80 ft long by approximately 80 in. high. All of the data presented herein is shown as a function of the position on the face to the nearest foot, and as a function of height from the floor in inches. All of these runs were documented on video tape and are available on request through MTIS.

Tram Tests

Figures 47 and 48 shown the results of a tram test using acoustic followers for control only. This test was conducted at slow speed approximately 14 ft/min and did not use simulated picks. Figure 47 shows the comparison between the last cut follower readings and the position of the front drum. As may be noted, the correlation is very good showing a slight averaging effect as the front drum tracks the last cut readings. It is worth noting that the front drum is not activated at the 0 ft point to insure that the last cut follower is receiving a good signal. Therefore as the diagram shows, the drum is a few feet under the cap at the start of the tram test.

Figure 48 shows the rear drum position as it follows the present cut readings. A slight averaging effect is also noted here. It is worth noting that the averaging effect is a result of a lot of work relating to the dead band of the control system. Prior to these, extensive tests were conducted to define an optimum practical dead band that allowed sufficient response yet limited the wear and tear on the shearer hydraulics. These as well as the rest of the tests were conducted with a ±1/2 in. dead band.

Figures 49 and 50 are the front and rear drum plots for a similar run at moderate speed, 25 ft/min. Comparisons back to Figures 47 and 48 show a degree of averaging has occurred on both the present and last cut follower output. This then shows a more consistent dynamic behavior with the drum position as the effect of the dead band is lessened by the increased tram speed. In both cases, however, the correlation between requested and actual position is quite good.

Figure 51 and 52 show the front and rear drum position for a high speed tram test, 38 ft/min. This is about as fast as the Joy shearer can tram. Comparisons back to the slower speed tests show an increased averaging effect brought about by the high speeds. It is worth noting that at no time did either drum begin to deviate substantially from the required position. This indicates a suitable behavior even at the extreme speeds.

Figures 53 and 54 show a slow (17 ft/min) speed tram run using water sprays on the face of the acoustic sensors. In the underground environment, water sprays may be necessary to stop a buildup on the face of the unit. Comparisons back to Figure 47 and 48 show very little effect of water sprays, certainly nothing of significance. It is worth noting that the speed control on the shearer was not precise enough to control the hardware with any greater accuracy than ±3 ft/min.

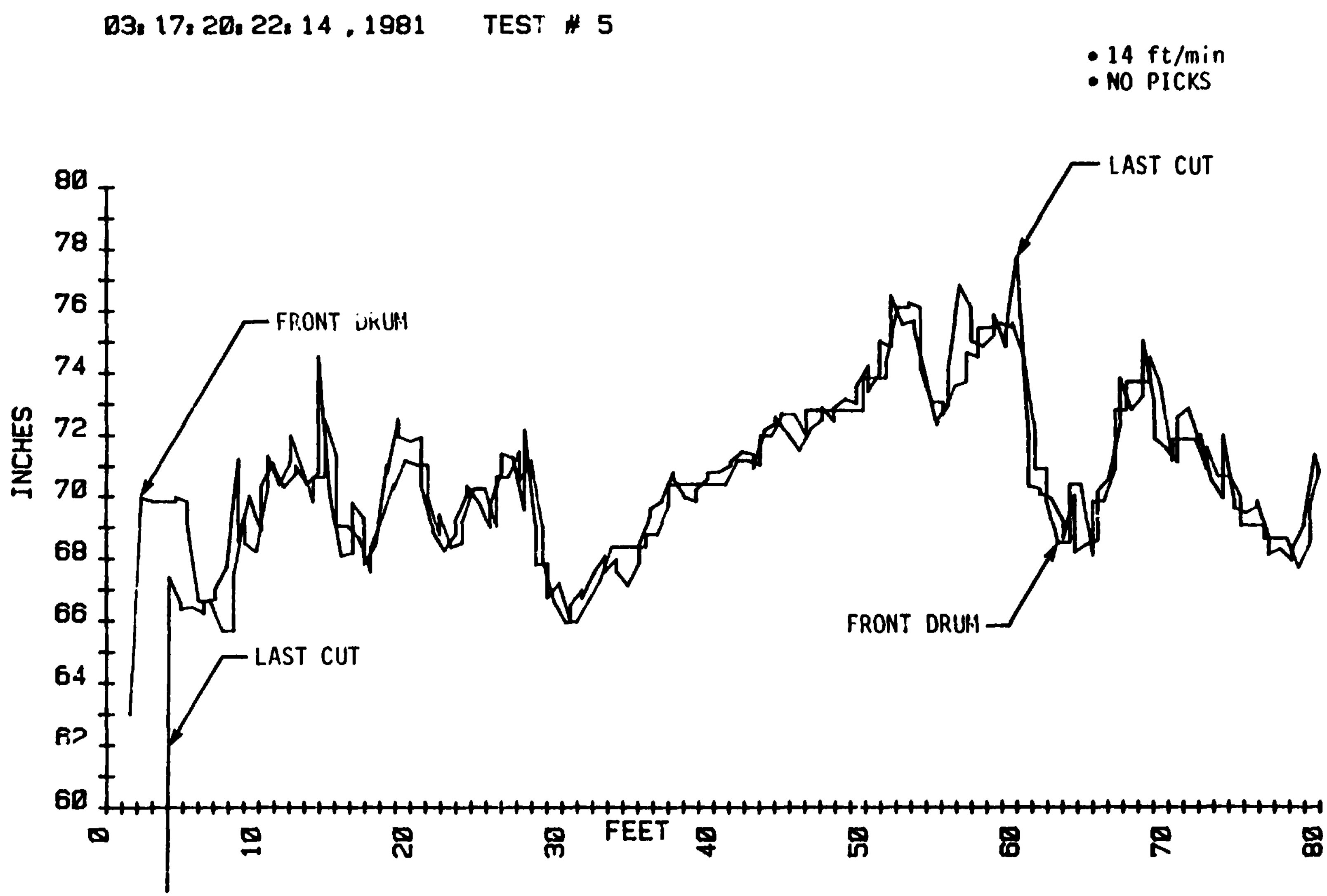

Figure 47. - Front drum with last cut - slow speed.

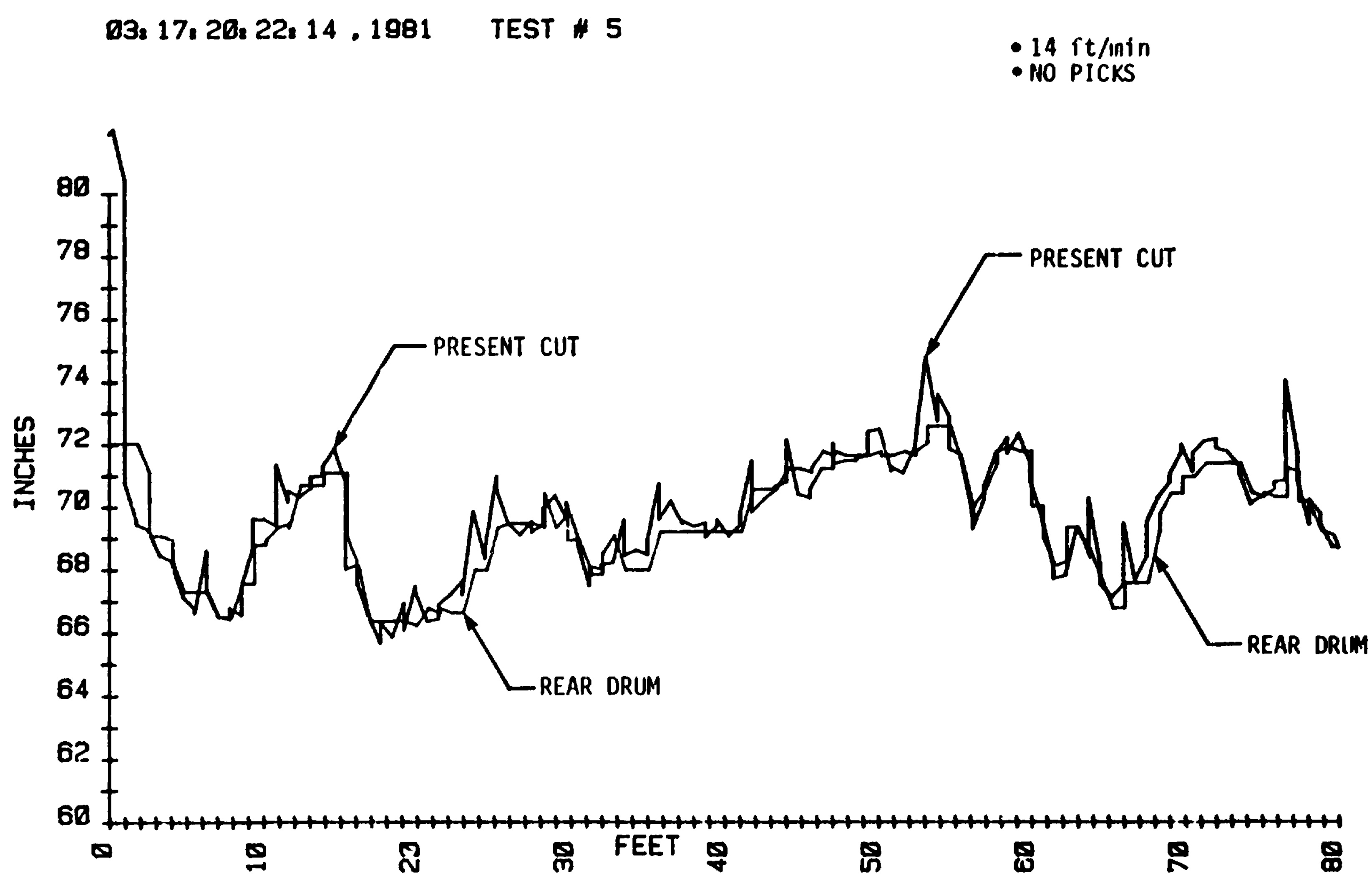

Figure 48. - Rear drum with present cut - slow speed.

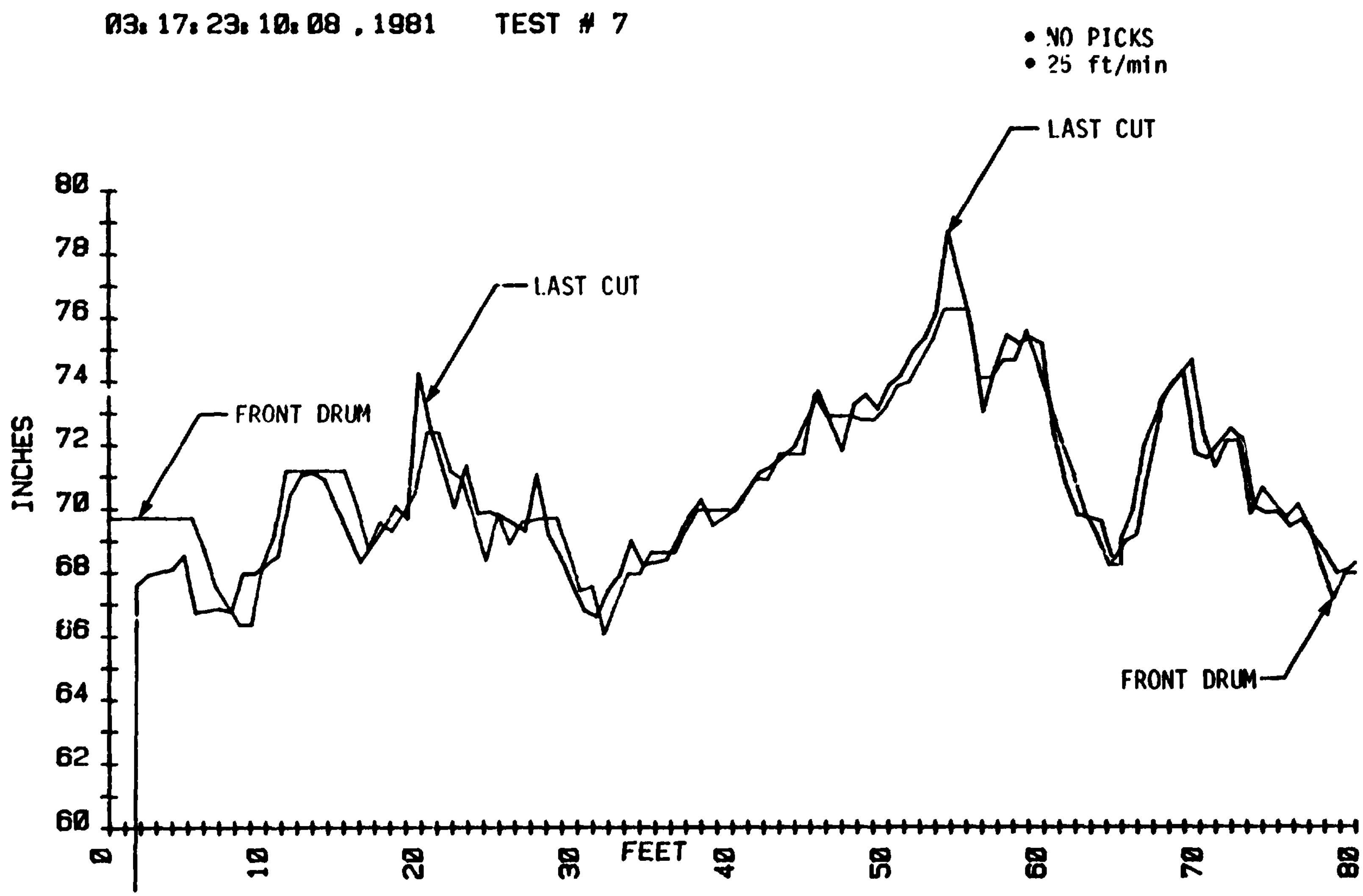

Figure 49. - Front drum with last cut - medium speed.

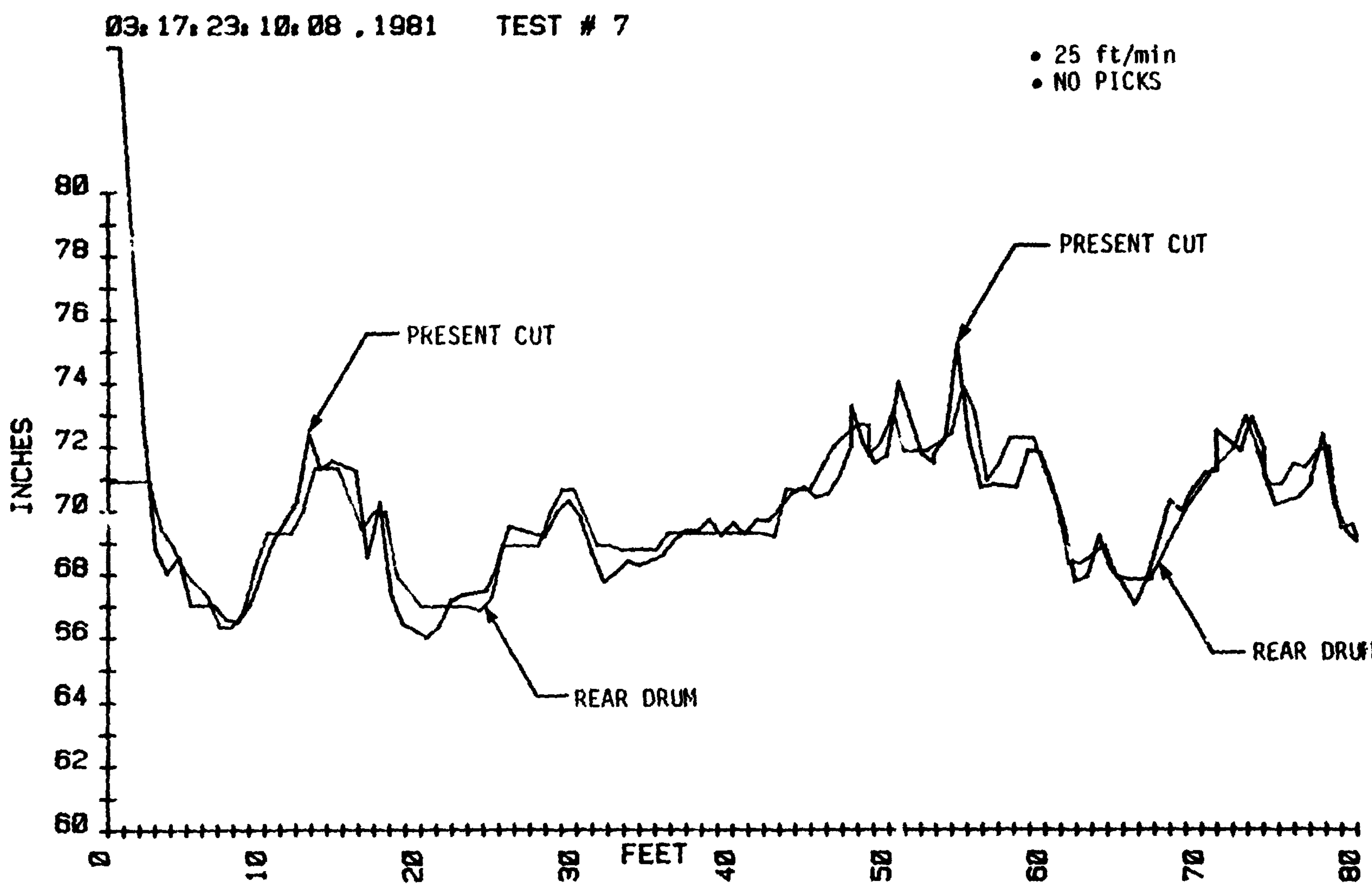

Figure 50. - Rear drum with present cut - medium speed.

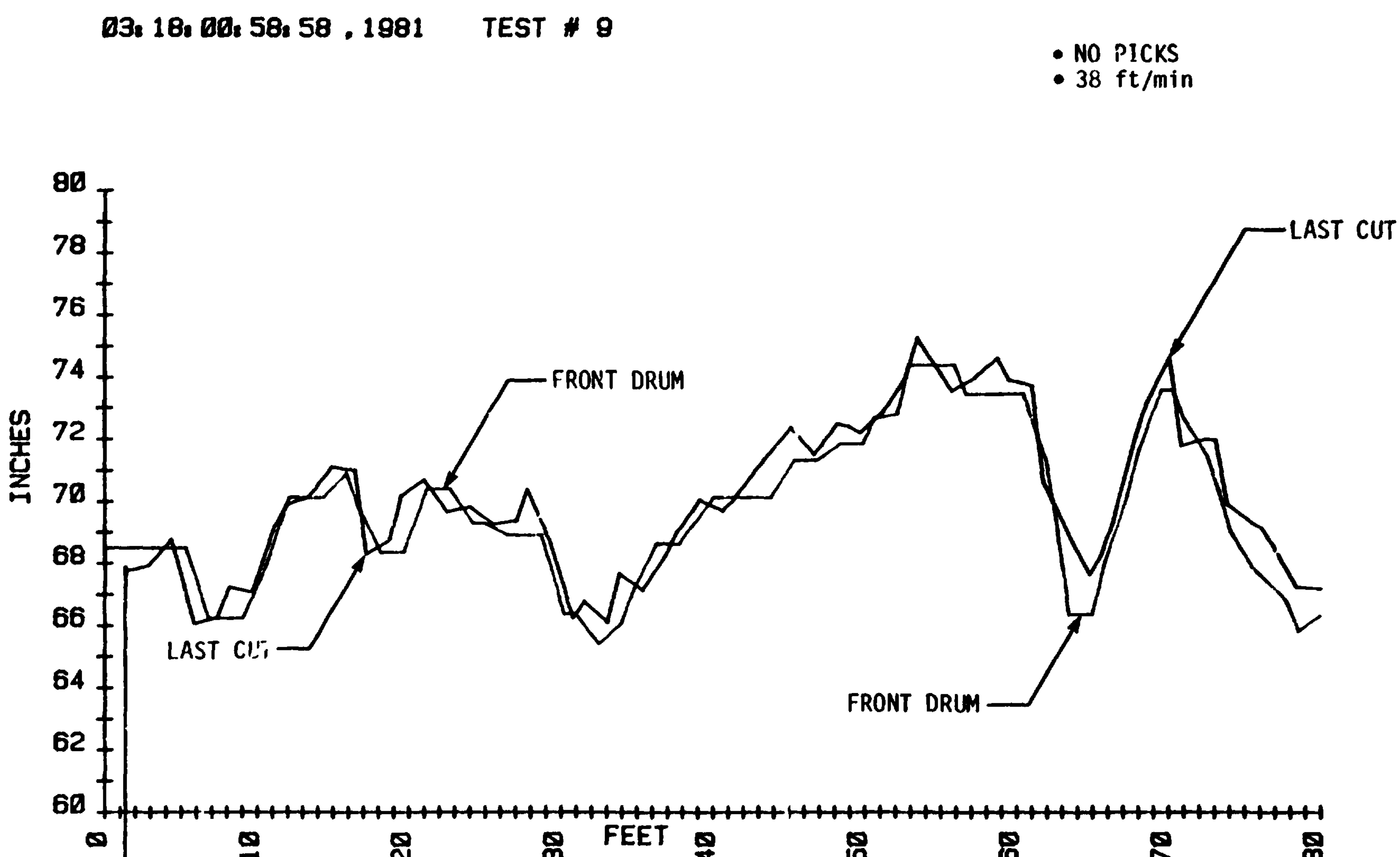

Figure 51. - Front drum with present cut - high speed.

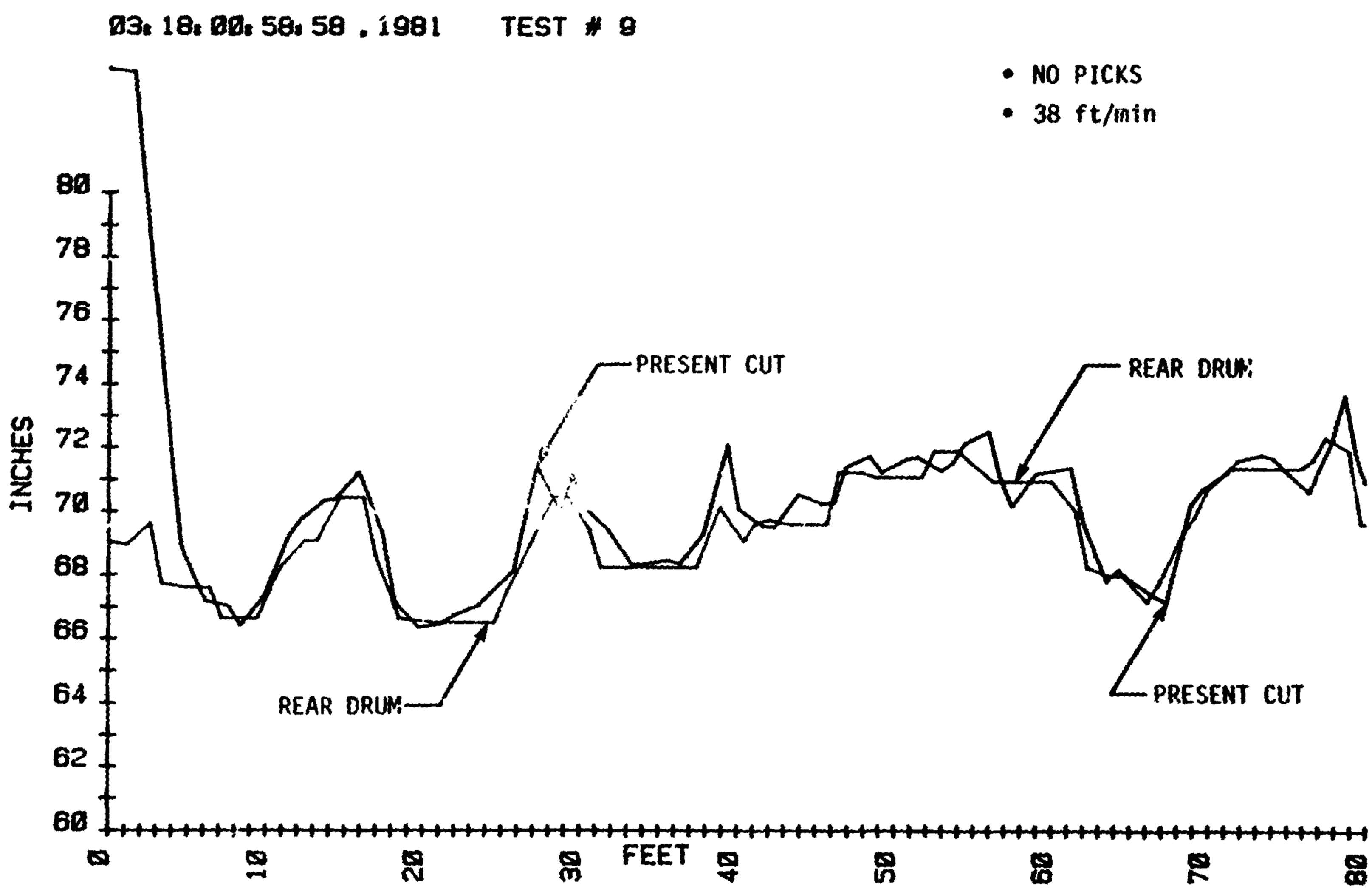

Figure 52. - Rear drum with present cut - high speed.

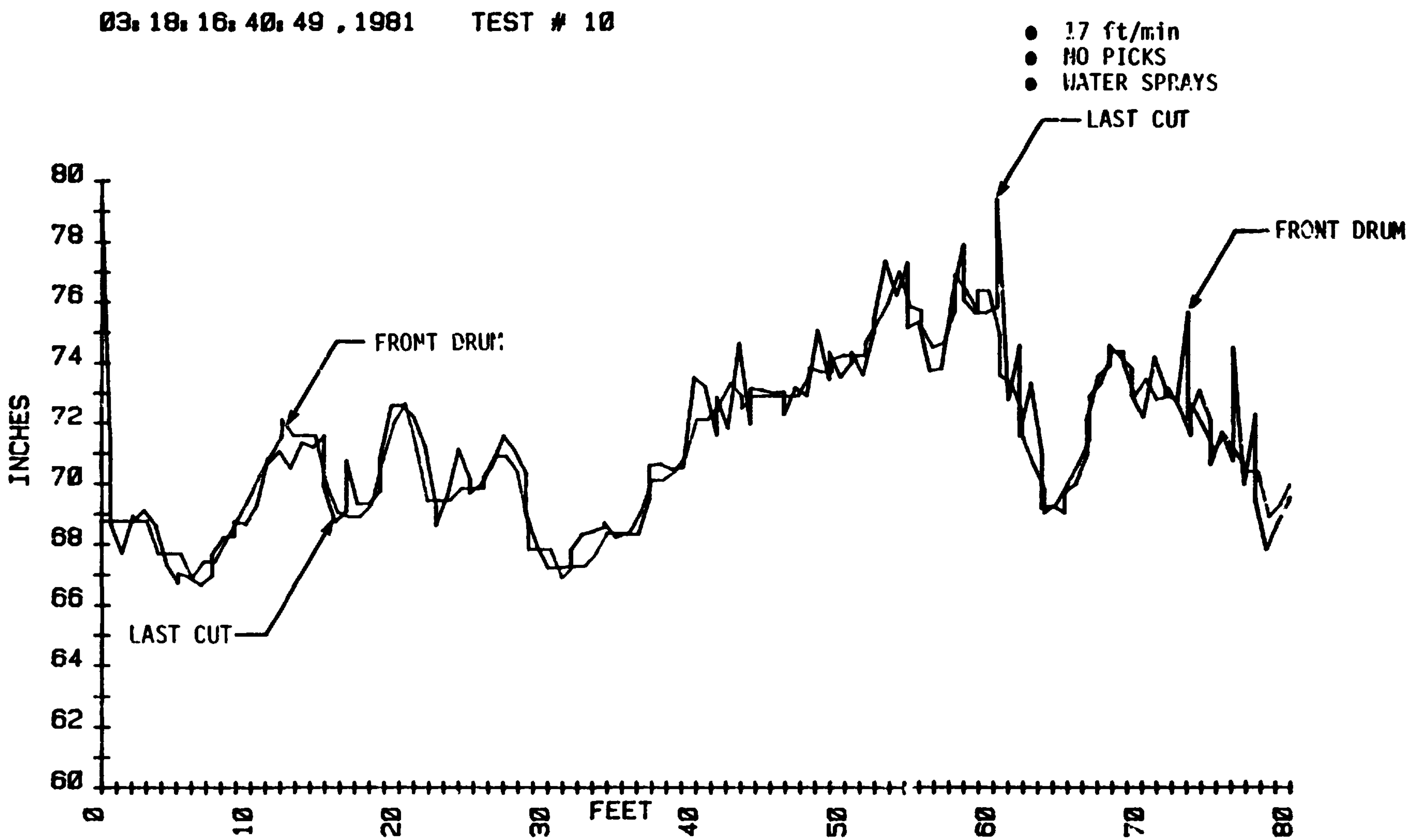

Figure 53. - Front drum with last cut - water sprays.

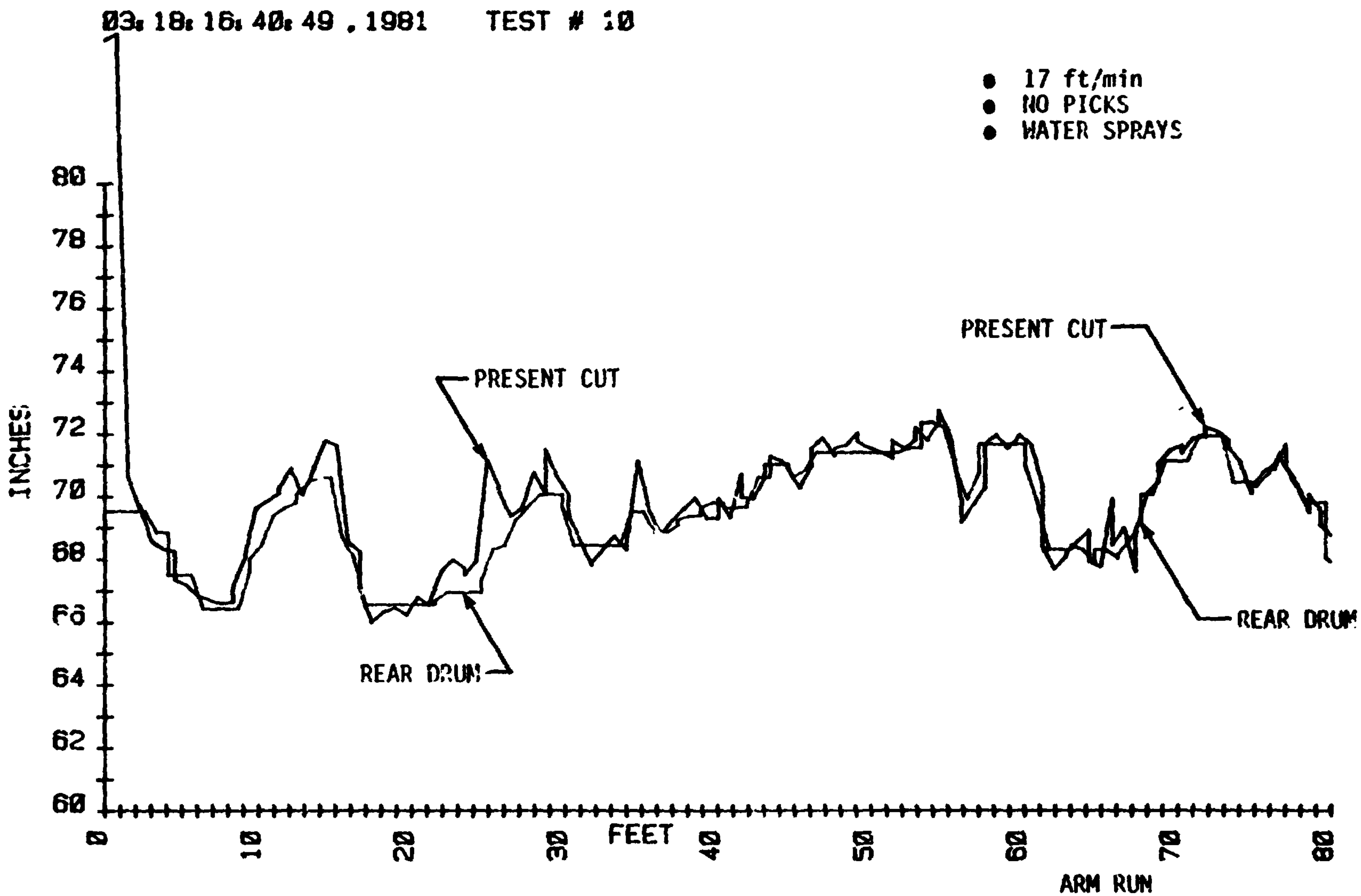

Figure 54. - Rear drum with present cut - water sprays.

Figure 55 shows the front drum results of a tram test using the simulated sensitized pick signals. As discussed elsewhere in this report, the basic MODE II front drum control algorithm requires that the front drum respond to a "rock" or "coal" pick signal by commanding *DOWN* or *UP*, respectively, to the limit of the last cut follower setting. In this case, the last cut follower limit was set at 2 in. As may be seen on the plot, the simulated pick signal was alternated between "rock" and "coal" every 10 ft of face travel. As seen in the 10 to 20-ft position, the picks are reporting coal which requires the front drum to move up but not exceed the 2-in. distance from the last cut. At 20 ft the signal is reversed to rock requiring the drum to descend but not beyond the 2-in. delta. This sequence is repeated across the face showing good tracking capability and a functioning control algorithm.

Figures 55 and 56 show a slow speed tram test with a 4-in. vertical misalignment in the pan line and the effect of a simulated shield tip.

The 4-in. vertical pan line misalignment was achieved by putting a 4 × 4 under the pan line at the 35-ft mark on the face. The 4 × 4 in place is shown in Figure 57.

The simulated shield tip was created by fabricating a plywood 4-ft wide model of a tip and covering the surface with stainless steel sheet to simulate the acoustic return characteristics of an actual shield. A photo of this simulated tip is shown in Figure 58.

Figure 55 shows the front drum results of this test. These separate curves are superimposed to see the effect of the vertical misalignment. The first curve is the last cut reading from Figure 47 which was a tram test at the same speed without misalignment or a shield tip. The other two curves are the last cut reading and the front drum position with the 4 × 4 in place. As may be seen between the 40 and 50-ft mark, the effect of the misalignment shows up clearly. It is worth noting that the effect on the front drum will not be seen until the shoes of the shearer body begin to rise, hence, the 6-ft delay in the plot. It does show proper behavior by the control system.

Further down the face at the 62-ft mark, FMA placed the simulated shield 6-in. from the front drum. As may be seen in Figure 54, there is virtually no difference in the last cut readings when compared with the Figure 47 readings. Hence, the acoustic follower should be able to see into the 6-in. gap at Old Ben Coal.

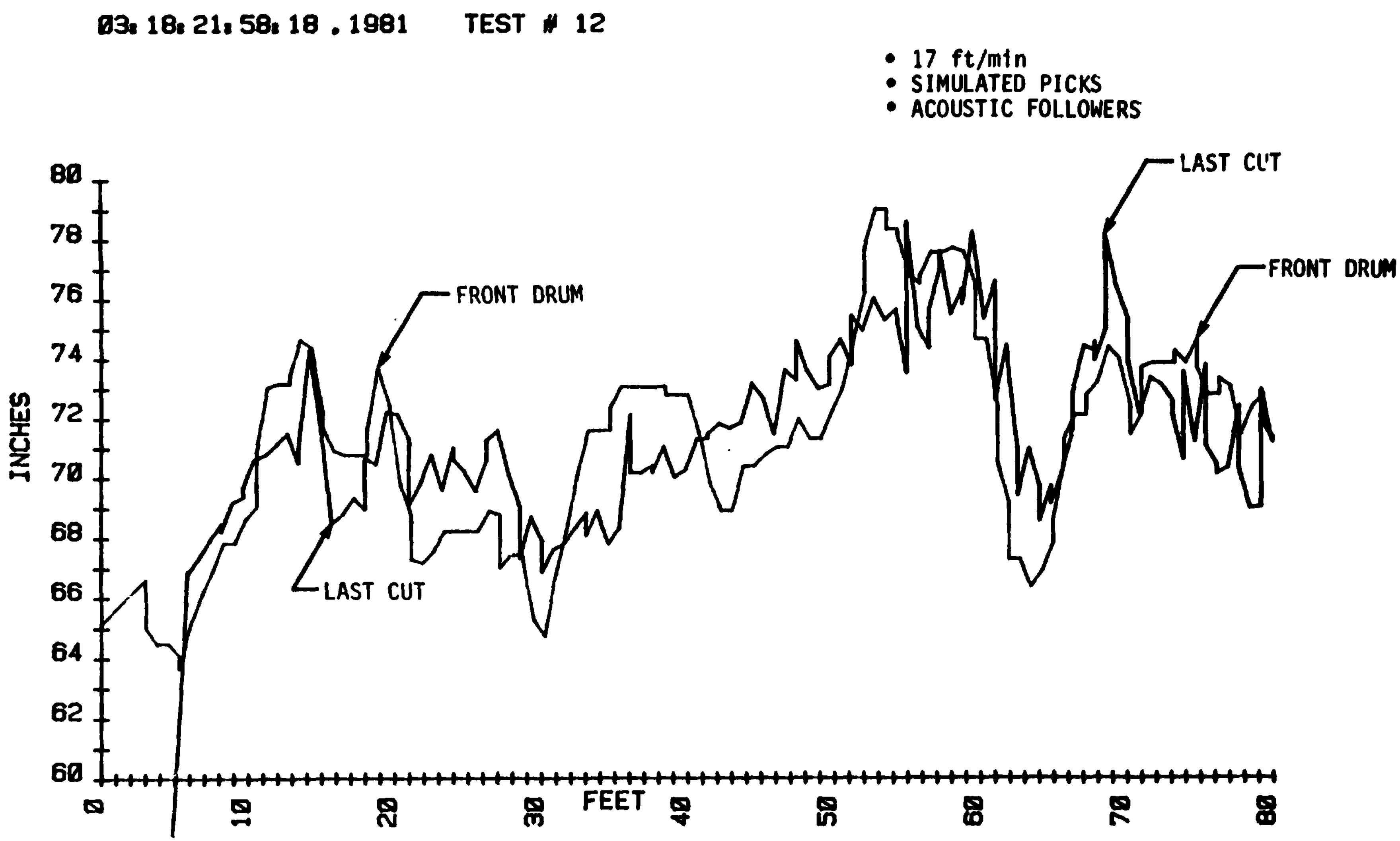

Figure 55. - Front drum with simulated picks.

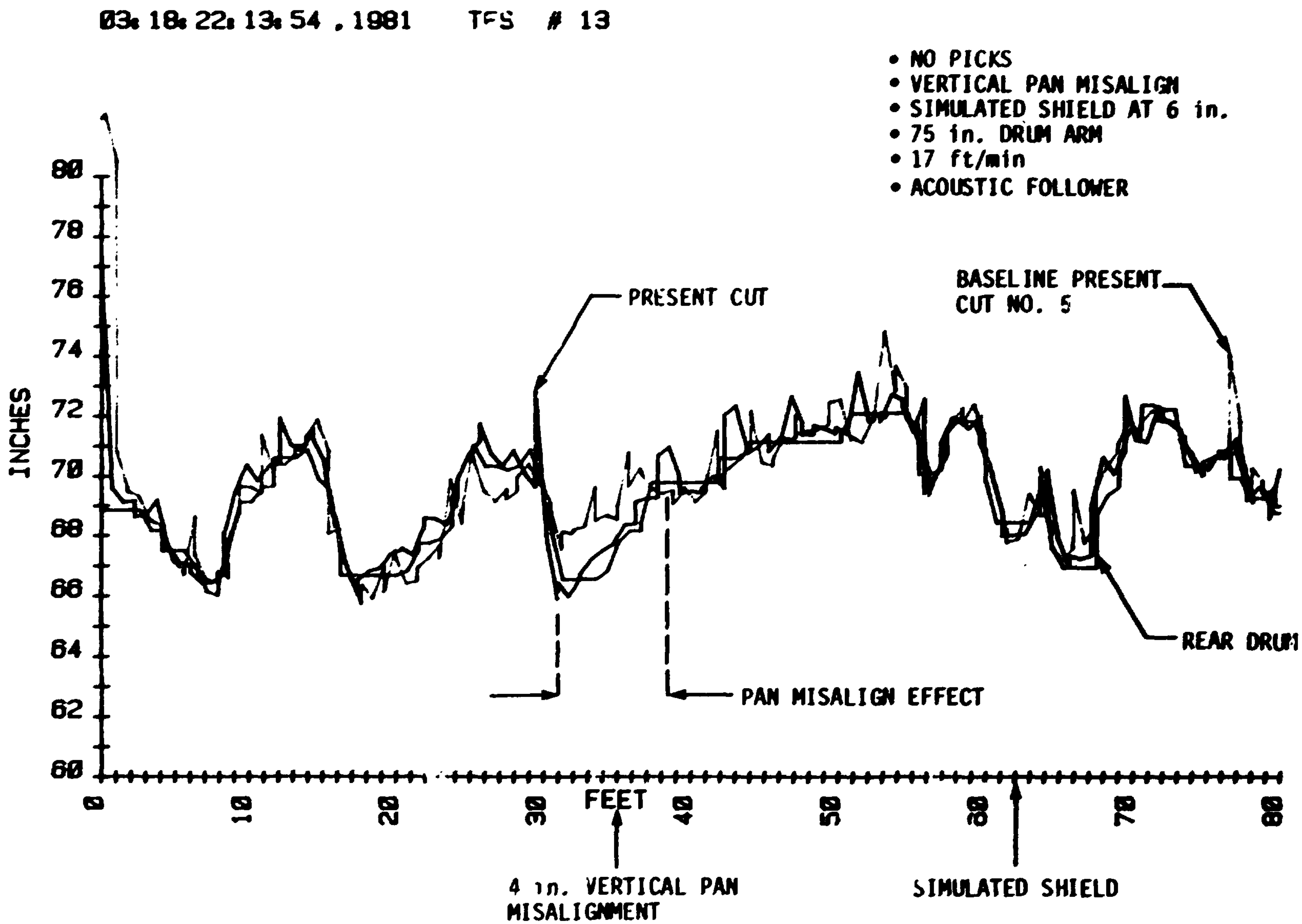

Figure 56. - Front drum with 4-in. perturbation.

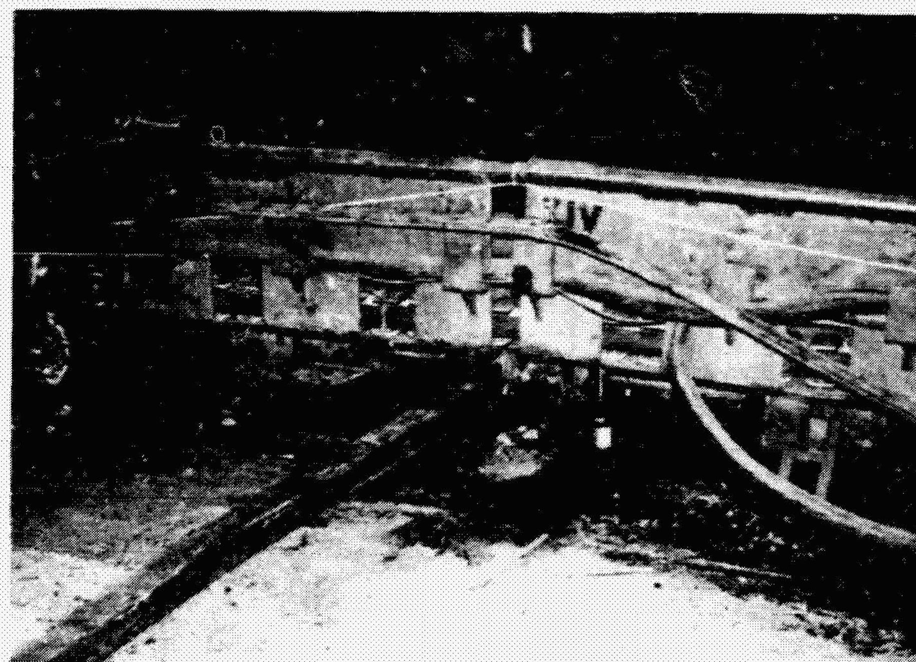

Figure 57. - Pen line 4-in. pertubation.

Figure 58. - Simulated shield.

Figure 56 shows the same results for the rear drum. Once again the spatial shift in the misalignment is due to the distances between the drum center line and shearer body shoes - again, proper behavior, delay, etc.

Figure 59 shows the results of a tram test to verify that the rear drum could nearly be slaved to the position of the front drum. This was a proposed back-up for Old Ben should we encounter multiple sensor failures. All that is needed to accomplish this are the front and rear arm pots or the present cut follower. In this case, the rear drum is slaved through the arm potentiometer. The slightly different response characteristics were due to a faulty rear drum hydraulic valve which was stuck for a period in the 15 to 20-ft face position range. However, the rest of the tests show conclusively that rear drum slaving can be accomplished with VCS.

System Cutting Test

Figures 60 and 61 present the results of a 1/2 face cutting test under FMA control. Acoustic followers with full water sprays and simulated sensitized pick commands were used. Unfortunately, the simulated coal block was so hard that tram speeds of only 5 ft/min were obtainable. This is the reason for the strange appearances of these plots. The 5 ft/min tram speed is an average. During the actual function the shearer lurches rather than trams at these extremely slow speeds. Therefore, with the second repeat rate of the controller, it is possible to get two data points per foot.

Nevertheless, Figure 60 shows the performance of the front drum under simulated pick and last cut control while cutting. There is basically no deviation from the tramming results. Figure 61 shows the performance of the rear drum while cutting, once again, similar to the tramming results. It is worth noting that the horizontal scales of these last two plots have been extended and that the rear drum is in fact 20 ft behind the front drum and hence, the reduced face traverse for the rear.

Static Tests

Among the other tests performed during the demonstration was a series of static tests to show various hardware or software capabilities. The more pertinent of these tests will be described in the following paragraphs.

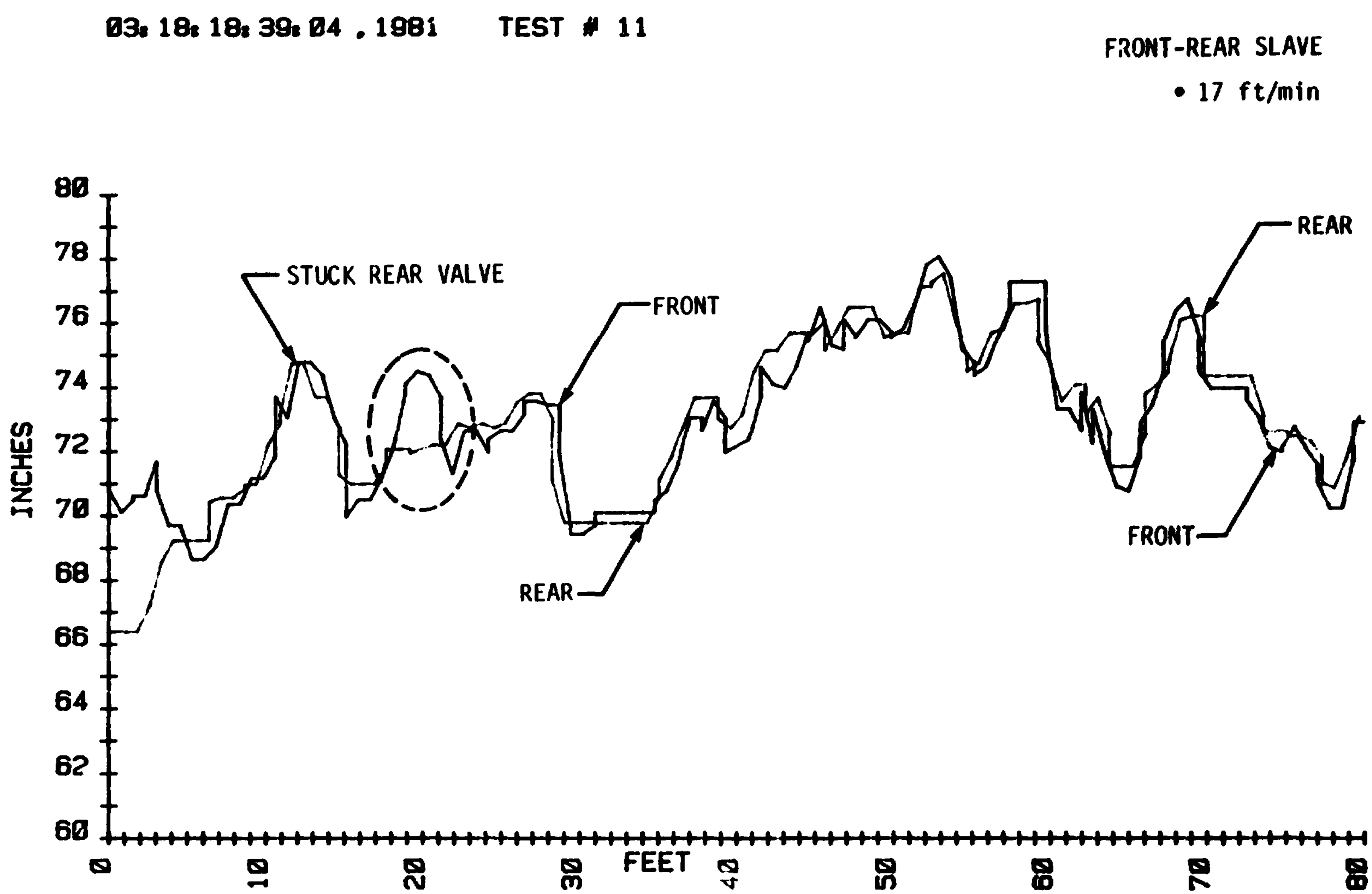

Figure 59. - Rear drum slaving.

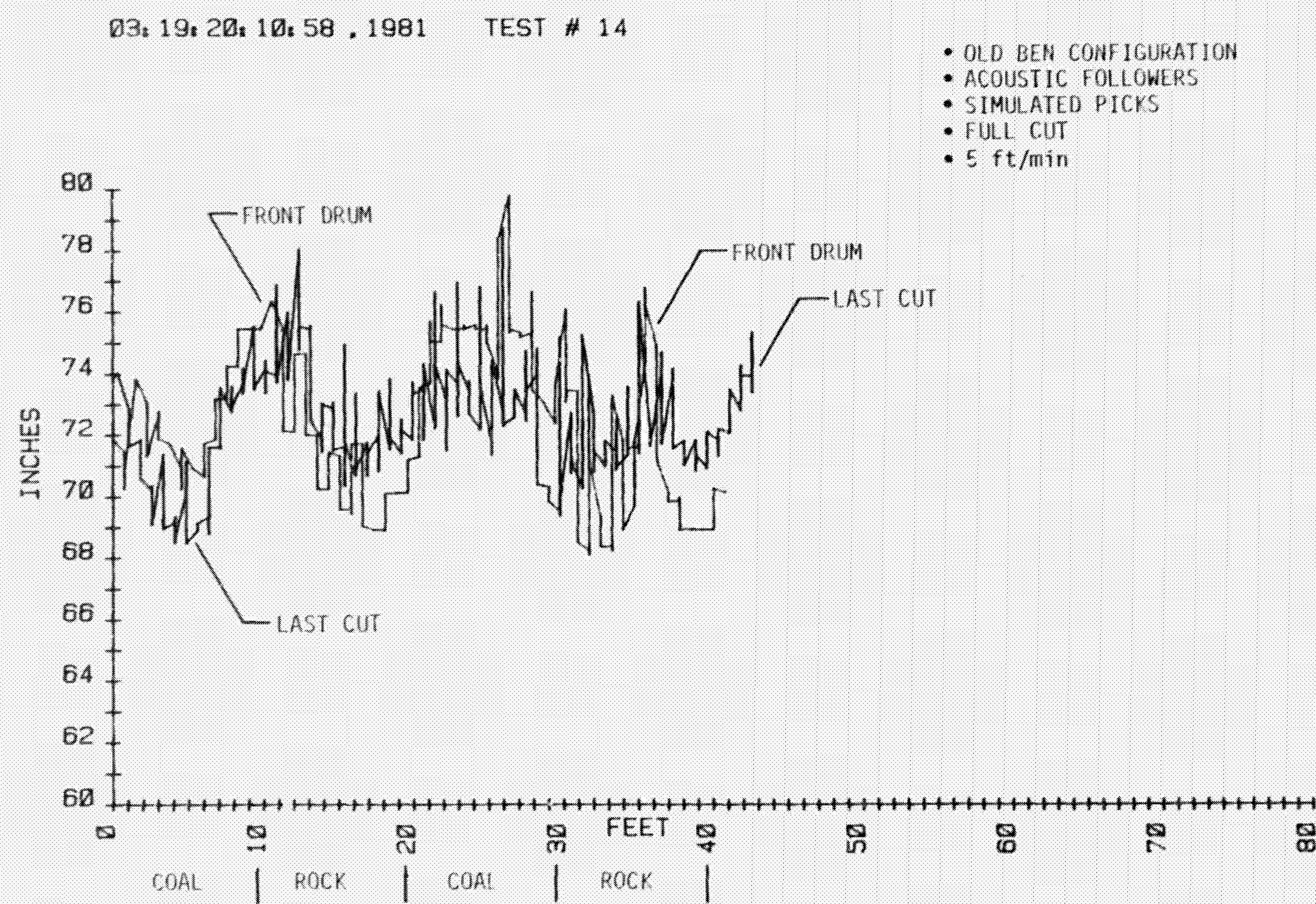

Figure 60. - VCS system test - front.

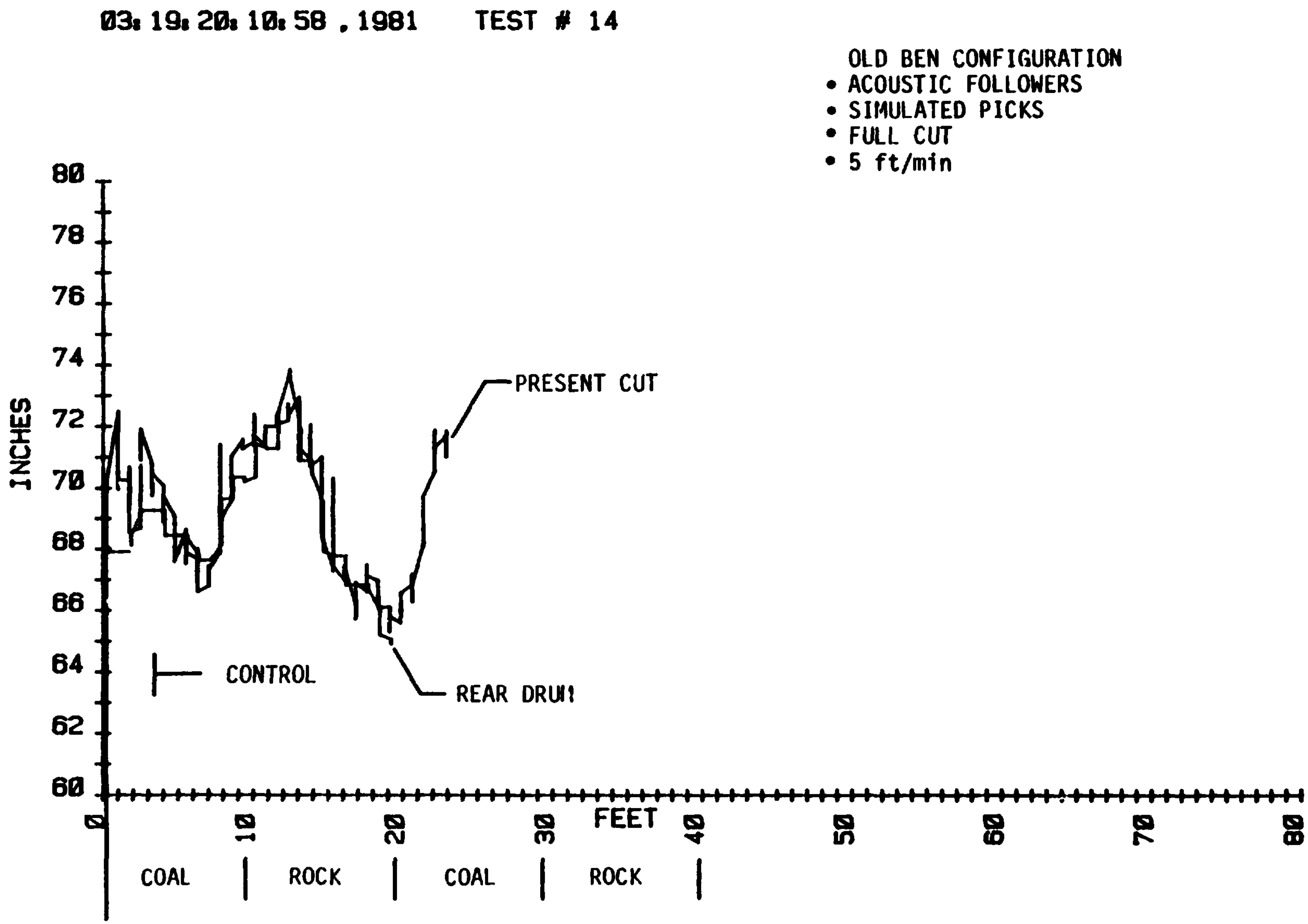

Figure 61. - VCS system test - rear.

The VCS controller is equipped with a memodyne tape recorder for real time data logging on the face. One of the items that can be verified easily is the performance of this unit since it can be compared directly to the HP unit. A run was made using the Memorex and HP in parallel and the results conpared. There was essentially a line to line match. Figure 61 shows a picture of the memodyne hardware used to interface with the HP9825.

During the course of the control algorithm design, it became apparent that should a sensor drop out or give consistantly erroneous readings, the VCS should kick out and return control to the operator. This data quality check was demonstrated at Bruceton by blocking out a cut follower, and allowing the software to perform a reasonableness check. The demonstration was successful with the controller returning to manual operation.

6. FIELD ACTIVITIES AT OLD BEN COAL CO., MINE No. 27, LONGWALL 2, 6/29/81 TO 9/14/81

6.1 INTRODUCTION

Because of the inelasticity of the field test schedule and the simultaneous elasticity of both the MSHA approval process and the UMWA labor action in the second quarter of 1981, the field test duration was compressed to approximately 10 weeks. This notwithstanding, a major effort was made to take advantage of what had been invested in the program to date.

There are three fundamental questions regarding a system of this type which must be answered through "System Testing." These are:

1. Is the whole system operationally feasible?

2. Is it survivable in the working environment?

3. What is the utility of the system to the intended user?

The first question was answered in the course of extensive testing and development at the Bruceton MLF. This activity was discussed in Section 5. The second two questions were to be answered during the underground tests at Old Ben.

Much was accomplished at Mine 27 in terms of reworking the system's physical embodiment to enhance its survivability. Conditions at Mine 27 were considered by all who worked and visited there to be grim. The mine was located at the eastern edge of the Illinois No. 6 basin and as such the seam was thinning out and the roof conditions were variable and somewhat unpredictable. Consequently, the VCS hardware took a real beating during its short stay at Old Ben. Many of the initial sensor configurations were destroyed by roof falls. More often than not, the operators were forced to squeeze the longwall through a minimum cut of about 6 ft, 2 ft of which was rock. Thus the roof supports were always in close proximity to the top of the machine and any VCS hardware that was not well concealed and protected was quickly removed in spite of the size and weight of any attachment.

The subsection which follows is a kind of chronology of our experiences at the mine. A great deal was learned about what to do, and what not to do, in the next Vertical Control system installation. Those painful experiences are committed to record here in the hope that they will not have to be repeated.

6.2 INSTALLATION

After checking out and demonstrating the VCS system at the Bruceton MLF, the controller was removed with its cables intact and shipped to the mine. New sensors, instruments and other equipment were packaged at our Waltham facility and shipped to the mine. These materials were shipped at the end of the UMW strike before the settlement was fully recognized by some of the local organizations in southern Illinois. Consequently, the shipments were destined for the Old Ben central shop rather than the mine itself.

Upon our arrival at Old Ben our materials were located at the central shop and transportation was arranged to the mine. Some materials such as the sensitized picks were dropped off at the shop for installation on the shearer drums while the remainder was taken to the mine and staged in the crosscut nearest the headgate.

6.2.1 Controller Installation

At this time Longwall 2 was being constructed in a setup room. The shields were in, as was the panline, the shearer, the head and tail machinery and the belt line. All that remained to make the longwall operational was the installation of both range arms/drums and pluming of the hydraulic lines associated with the roof support system. Among some of the factors that were noted upon our arrival was that the machine was to cut from right to left while the haulage was to be carried from left to right. This is known at Old Ben as a right-hand face.

This had a significant impact on the experimental VCS in that the main controller enclosure was designed for a left-hand face. A simple explanation of this difficulty is that the tailgate end of the shearer is used as a breaker for all large objects on the conveyer. All material which falls onto the pan to the left of the shearer must be broken until it passes the shearer. If the controller enclosure were to be attached to the tailgate end of the machine, it would become the breaker. Since it was designed to mount this way, an attempt to swap sides would result in either the controls and display facing the face or the controls facing the gob side but upside down and the cables exiting from the bottom of the box rather than the top.

The first option was considered impractical and unsafe in that in order to manipulate the controls, the range arm would have to be raised and the operator would have to get under it between the machine and the face. The second option was thought to have a low survival probability in that the control cables would be placed in an extremely vulnerable position. The obvious solution of reworking the enclosure itself was not considered because this was an MSHA-certified enclosure and any modifications of this magnitude would have to be recertified.

Under the circumstances, the only option available to us was to proceed with the installation but try to protect the enclosure as much as possible. Toward this end a two-piece box was designed and built which would mount onto the machine and within which the VCS enclosure would be housed. This box was fabricated from 1-in. hot rolled steel plate, held together with 1-1/2-in. bolts; the entire assembly was welded to the shearer. This installation is illustrated in Figure 62. Although this larger box would present something of an obstruction to material which loads out over the range arm, the operator agreed to the installation.

No problems were experienced with the protective enclosure; however, we had considerable difficulty with the attachment of

Figure 62. - Controller and protective enclosure.

the box to the machine. The protective enclosure was welded directly to the shear and the welds failed several times. The failures occurred at the interface between the weld material and the Eickhoff casting. The problem was resolved by utilizing a Castolin Eutectic rod No. 2233. These are difficult to obtain and are quite expensive ($20/lb), but worth the price when welding directly to the Eickhoff casting material.

6.2.2 Sensitized Pick Installation

The picks and associated hardware were installed with comparatively little difficulty. This subsystem went in as planned with no significant field modifications required. The picks were installed on the drum as they were in the surface tests, except that they were side-supported rather than radially supported. This proved to be a sound method of mounting. One-inch heavy wall tubing was used to enclose the signal wires until they were safely inside the drum.

A two-by-two angle iron support was installed across the inside diameter of the drum to serve as a protected path, away from prying fingers, so that the wire bundles would not get in the way during hose changes.

Cable routing was an important consideration in all sensor installations. We quickly discovered that if cables were exposed for even a short distance, they would be cut. The sensitized pick cable, after exiting the hub on the gob side of the machine, was brought under the range arm cover, down the range arm, under covers, and into the controller protective enclosure from behind. The only exposure was between the range arm and the controller which was a deep, narrow channel. Material falling into this area had to break to a 2-in. size, thereby representing little threat to the cable and conduit.

6.2.3 Natural Background Sensor

The NBS installation was also straightforward. A simple open-top box was fabricated from 6 × 6 × 1/2 angle iron. This box was mounted on the face side of the machine body in the upper corner on the tailgate end. The NBS, weighing some 200 lb, was set inside the box and the cable was to be routed under the Eickhoff service covers. This mounting remained intact for the duration of our stay at the mine, and can be seen in Figure 63.

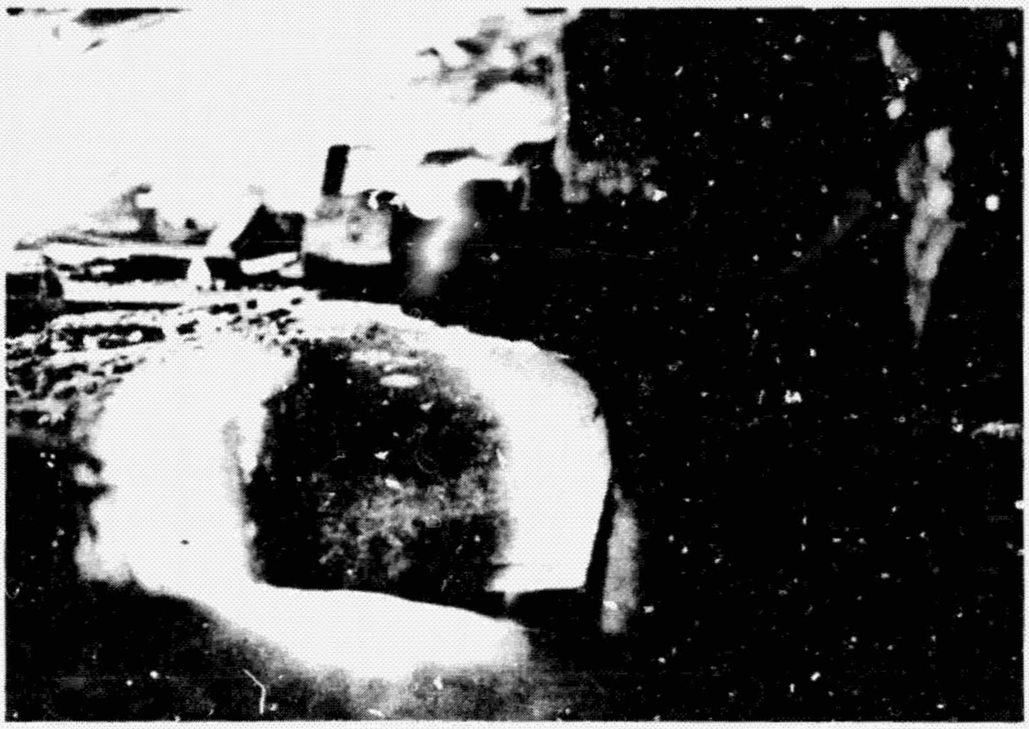

Figure 63. - NBS support bracket.

6.2.4 Last Cut Follower (LCF)

The initial LCF mounting configuration as shown in Figure 64 was designed for both the radar and acoustic cut follower. It was designed to sit in the same place as the cowl arm on a return pass and consequently it was designed to swing toward the gob when contact was made. In discussing operation with the men on the face, it was found that the cowl was swung during the tailgate turnaround and often this was done when the drum was even with the tailpiece. This meant that there would have been no place for the swingout bracket to swing.

The bracket was modified as shown in Figure 65 to mount flush with the range arm cover and hold the sensor inboard such that it just cleared the cowl arm. This installation survived until on one particular pass the crew cut into the floor. With the soft bottom problem it is very important to get the system back up on coal bottoms because the shields sink and loss of the longwall can result. This is done by cutting the floor high on the next pass and pushing the system "uphill." When the machine and pan are on this angle and the tailgate is still straight some interference is experienced between the range arm and the

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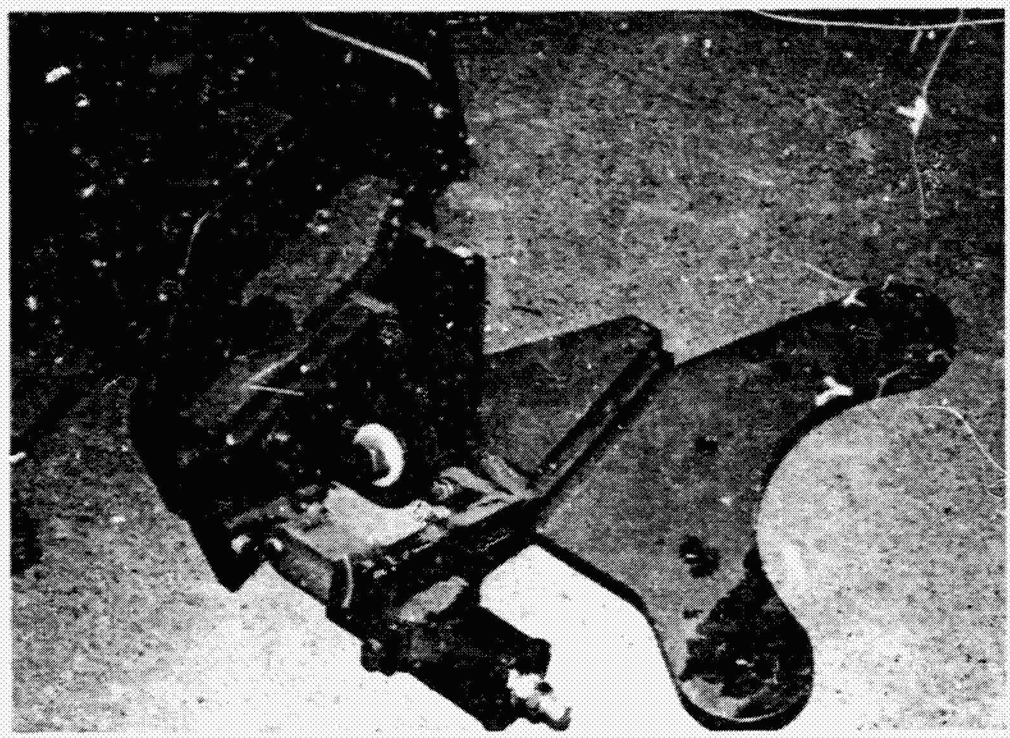

Figure 64. - Last cut follower swing-out bracket.

Figure 65. - First LCF mount modification.

profile plate on the tail piece. In this particular case the seven 16 mm bolts holding both the LCF and the range arm cover were sheared and both pieces were lost.

A final installation was made by directly attaching the sensor to the range arm. This is illustrated in Figure 66. The logic was to reduce to a minimum the bracketry involved and to nest the sensor in the center of the least vulnerable location. This configuration survived for a limited period of time also. Eventually it was removed by a shield that was left too low. Thus, in the final analysis, we have not devised a Last Cut Follower mount configuration which will survive operational conditions for extended periods of time.

6.2.5 Downface Distance Sensor

The Downface Distance Sensor (DFD) assembly was installed as per plan. This is shown in Figure 67. The only problems experienced involved dust and were resolved by gasketing the cover.

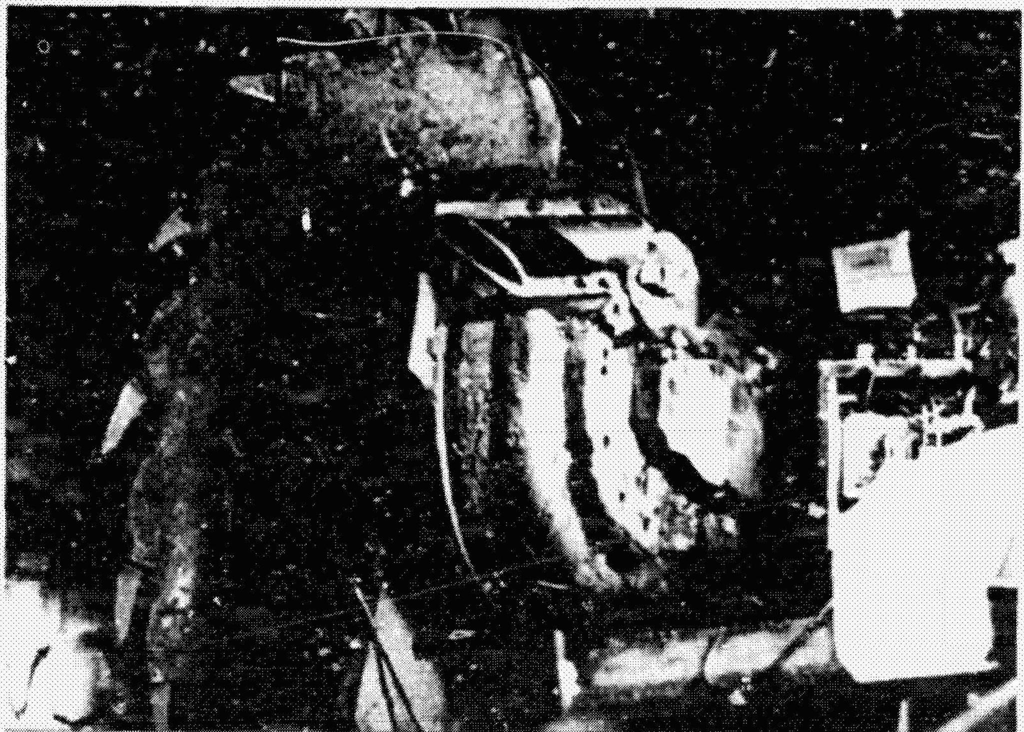

Figure 66. - Second LCF mount modification.

Figure 67. - Downface distance sensor installation.

6.2.6 Arm Potentiometers

The arm pots (2) also were installed per the plans. Although the environment was quite dirty both units survived for the duration. Figure 68 shows one of these units installed with the cover removed.

6.2.7 Present Cut Follower

The cantilevered PCF installation, as described in the drawings, was lost during the first major roof fall. This unit was designed with a shear bolt mounting for just that reason. Considering the roof conditions, however, this shear bolt-type installation was not practical if we were ever to run a test. The PCF mounting was redesigned to be capable of withstanding the several ton pieces of shale which frequently fell between the drums.

Figure 69 is a photograph of this unit under construction. Figure 70 is a schematic diagram of what is shown in the photograph. The photograph requires this explanation because the

Figure 68. - Arm pot installation (tailgate end, cover removed).

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Figure 69. - First PCF modification (under construction).

lighting behind the machine was very poor and the photographer was trying to limit his personal exposure.

A saddle was built which covered the range arm picking up the bolts holding the range arm onto the machine. Longer bolts were substituted to accommodate the 3/4-in. thickness of the saddle. Welded to this saddle were a pair of drilled and topped sensor mounting blocks. Each mounting block was reinforced by a section of 1-in. plate which served both as a gusset and to shield the sensor from direct hits. The bounce plate protruded out from under this protective arrangement just enough to send the signal to the roof and receive the return signal. This arrangement survived for the remainder of our stay at the mine.

6.2.8 Power Supplies

A power conditioning system was required to take the 1000 Vac supplied to the machine and generate ±12 Vdc and +5 Vdc. The configuration of the Eickhoff components in the high-voltage connection box forced us to mount the transformer upside down under the

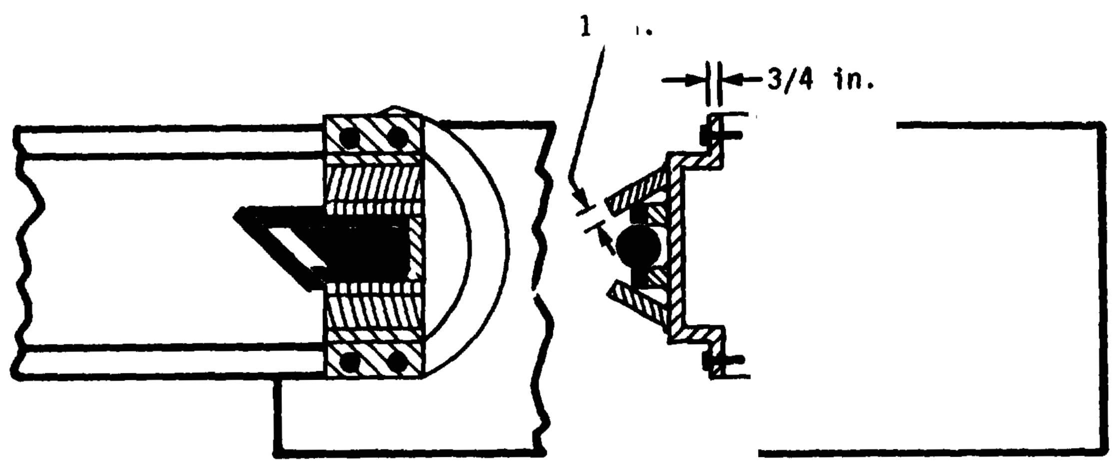

Figure 70. - First PCF modification.

existing hardware. Although this was a difficult installation to effect, once the components were in they functioned perfectly.

One problem we encountered, however, involved fatigue of the transformer legs. After a bout with a limestone slip, the severe machine vibrations apparently caused an accelerated fatigue failure of the transformer legs. Upon investigating a loss of power to the VCS system, we found the transformer loose in the bottom of the connection box. The transformer feet, however, were still bolted securely to the mounting plate.

New, heavier gussetted legs were built and the transformer was remounted to the bottom of the connection box. Both the initial and modified arrangements are shown in Figure 71. The transformer was not mounted to the floor of the box initially because it was thought that some water would collect inside the box. When we experienced the problem (about 1 month after startup of the longwall), we found the box dry. On that basis the transformer was mounted more securely to the bottom of the box.

Also illustrated in Figure 71 are the dc power supplies. Figure 72 is a photograph of the actual installation. In this photo, the top layer of components are the VCS power supplies and failsafe logic while the row below contains the Eickhoff radio remote control recover and control connections.

6.3 EPILOGUE

Once we got the VCS system installed and refined to a point where a majority of the hardware was survivable, the field inspection of the equipment by the Mine Safety and Health Administration (MSHA) was scheduled. This was conducted by Mr. Roland Berryanne on 3 August 1981. The few minor discrepancies noted during the inspection were corrected as were the associated drawings. Shortly thereafter a followup inspection by the local authorities resulted in granting of the final field approval.

Unfortunately, we were approaching the end of our contract and decisions had to be made. The mining conditions on Longwall 2 had deteriorated somewhat and were not conducive to running control system tests. As was described earlier, the coal seam was thinning and roof had to be cut in order to allow advance of the equipment.

It became clear that time spent on Longwall 2 was not productive. A meeting was held on 27 August at Old Ben. Representatives of DOE and NASA travelled to Old Ben to view the VCS installation and witness the deteriorating conditions. A detailed

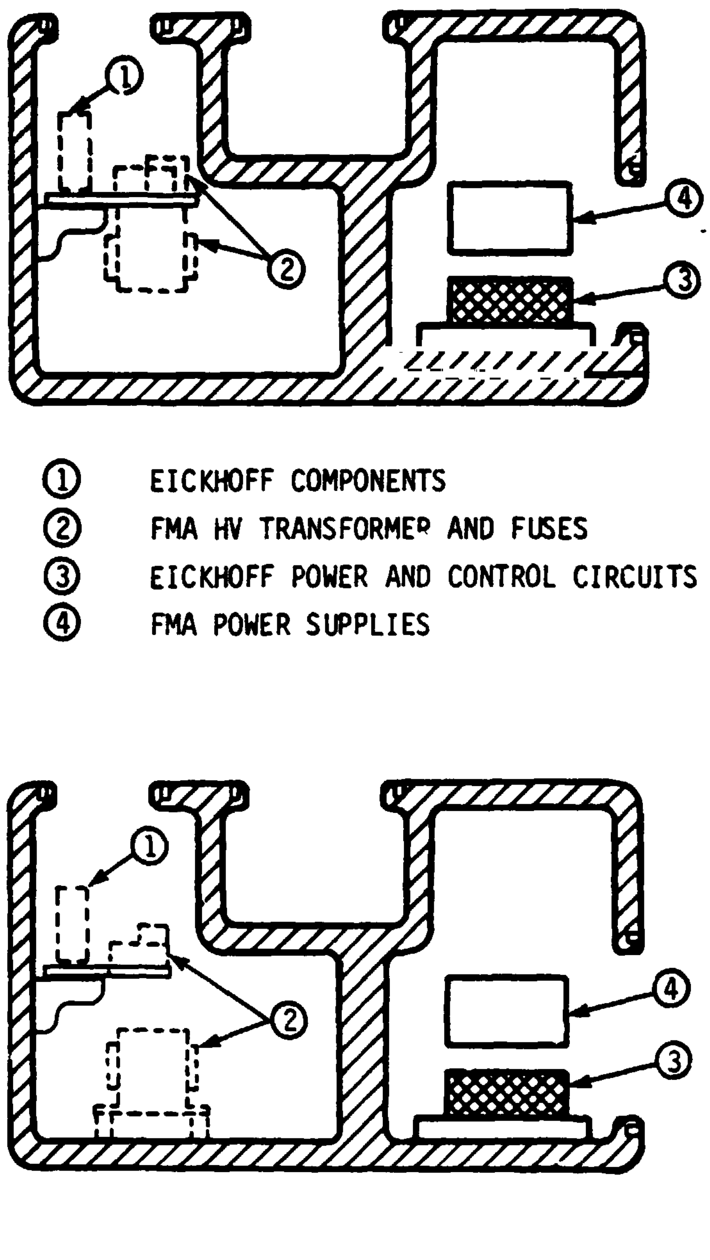

Figure 71. - Power supply locations, sectional view of Eickhoff high-voltage connection box.

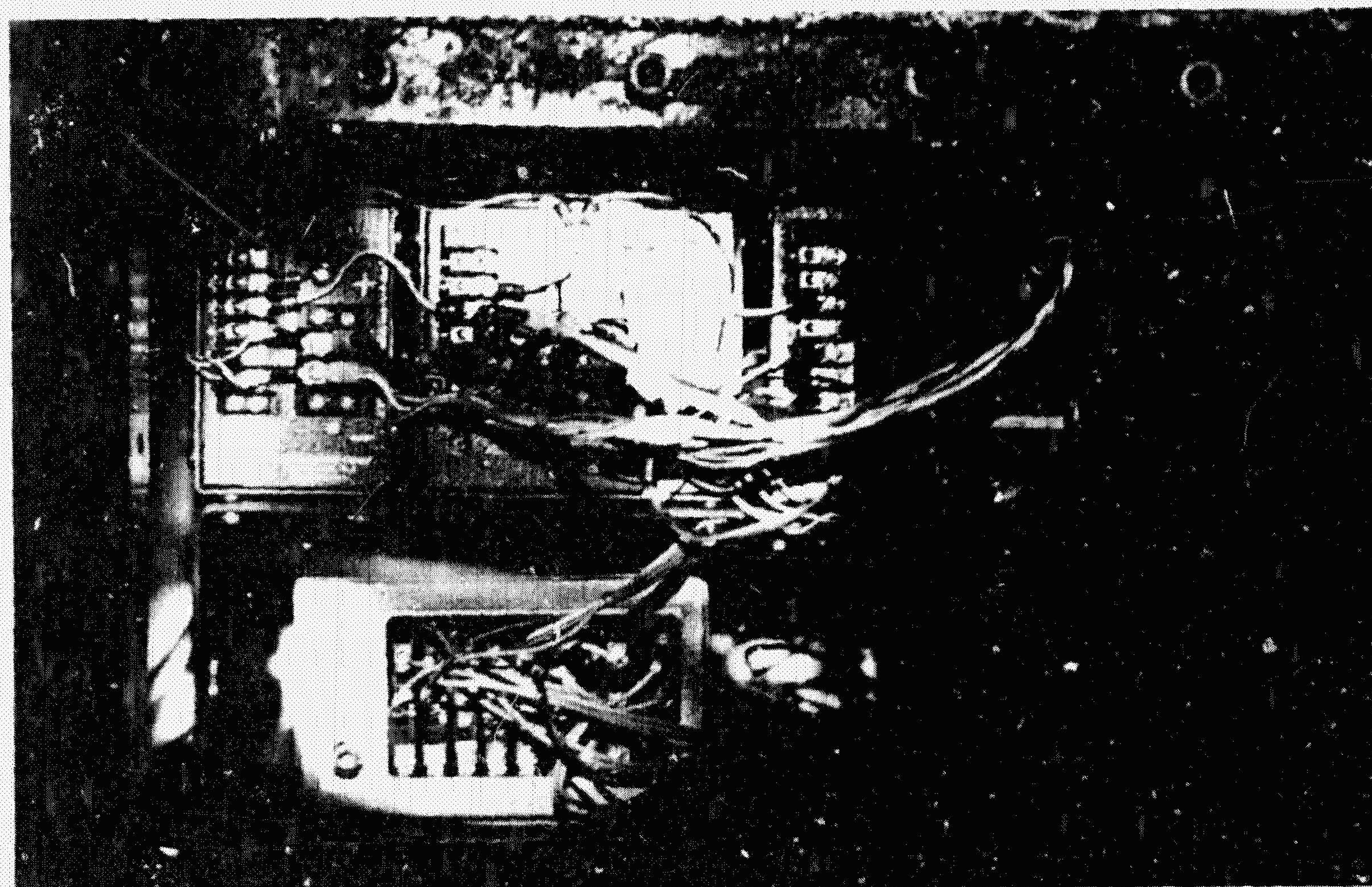

Figure 72. - DC power supplies installed over Eickhoff components.

survey of the edges of the panel was made by walking up the beltline to the head of the panel. There was no clear indication of improving conditions within a reasonable distance from the face. Since this survey did not offer much hope for improving conditions and since there were no predevelopment core drillings it was decided that testing should be abandoned.

The VCS hardware was removed during the next available idle shift, packaged, and returned to our Waltham facility. The controller assembly was opened upon arrival. Aside from exterior damage to the enclosure, all the controller components were dry, clean, and functional.

Although we were unable to operate the automatic control system underground, we did learn quite a bit in a relatively short period of time. Sensors that were well-designed were sorted out from those that required improvements. Those improvements were effected. The system was installed and approved by MSHA. A computer control system was demonstrated to be survivable in the underground environment. All of these factors were not trivial in themselves and result in our now being much closer, technically, to an automatic horizon control for a longwall shearer.

7. MAN-IN-THE-LOOP

When working in an underground mining environment, it is easy to see how portability increases the usefulness of a piece of equipment. Problems of equipment weight and nonportability increase twofold in such an environment. The availability of mine power must also be considered. It was these problems, encountered with VCS, that led to the development of the Adjunct Systems Display Processor (D/P). The D/P was designed to be relatively lightweight and portable and to run off of its own rechargeable battery source. With its own power source running any peripheral sensor equipment, machine-dependent safety approvals can also be avoided. Such a system would lend itself to numerous applications.

7.1 SYSTEM FUNCTIONAL DESCRIPTION

Adjunct Systems Inc. of Huntsville, AL, was chosen to be the subcontractor which would provide a mine-permissible controller/data logger to be used in a "man-in-the-loop" configuration. This controller housed in an approximately 6 × 6 × 8 in. interior dimensioned explosion-proof box, was designed to be as lightweight and portable as possible.

The system was designed to have one eight bit wide digital input port and four differential analog input channels. In the controller configuration, these channels were used to input data from two arm pots, an acoustic sensor acting as a PCF, and DFD sensor. An additional, single-bit, input port was supplied to accept and count pulses from the NBS. The internal handling of these counts was designed to be in accordance with the objective of the NBS to determine coal seam thickness in an effective manner with respect to practical manual control.

The controller was designed to be supplemented with a mine-permissible battery pack for its prime power. The goal here was to run all controller/data logger electronics, the digital data tape recorder, and three output display lights for at least 24 hr off of a single battery charge. The display lights mentioned were chosen to be viewable at a distance of up to 50 ft and were of three different colors. The lights are programmable and can turn on or off in accordance with modifiable software which can accept readings through the various input ports and use those readings in calculations to determine the status of the shearing drum vertical setting with respect to a controlling algorithm.

The indicator lights have programmable pulse rates allowing duty cycles from 5 to 100 percent (continuously on). In the controller configuration, the software will allow indicator activation such that if the shearer drum is out of tolerance low, then one color light appears, in this case green. If the drum is out of tolerance high, then a different color light appears, here, red. If the drum is within tolerance, a yellow light is activated.

The controller subsystem was intended to be capable of updating its display output at rates compatible with man-in-the loop control. It was also intended that this rate should be variable by easily implemented software changes. As a data logger, the system was designed to be capable of storing data from all the input channels and ports with a capacity of up to 130 kbytes. The data logger tape recorder is capable of playing the recorded data back through the system with the following features:

1. The calculator portion of the system can be programmed to reduce and analyze the recorded data.

2. Output, either processed or raw, can be shown on the calculator display.

3. Output, either processed or raw, can be output directly on a printer for the purpose of hard copy.

7.2 HARDWARE DESCRIPTION

Operating as a "man-in-the-loop" controller, the system uses several pieces of Hewlett-Packard equipment. Among these are a HP-41CV calculator, the new HP-IL interface module, the HP-IL converter and the HP-IL digital recorder. These units were selected after Adjunct Systems Inc., had surveyed the marketplace for candidates and found all other contenders notably inferior for the needs. Combining the Hewlett-Packard devices with their own microprocessor subsystem, Adjunct Systems, Inc., packaged the combination in an explosion-proof enclosure with a plexiglass porthole for viewing the calculator display and their own LEDs which signal the coal shearer operator as to what action he should take. The system, under calculator control, samples various sensors mounted on the shearer. Using the sensor signals, it executes mathematical calculations, performs decision-making routines and displays results to the operator.

The calculator CPU interface is performed through the HP 82166A converter module and mass storage of digital data is done with the HP 82161A digital cassette drive. The three Hewlett-Packard devices mentioned above are connected in a daisy chain loop and communicate with each other via a communications protocol controlled by the HP-41CV and HP 82160 HP-IL module. Digital data is supplied to the converter module through two parallel output ports on the CPU board.

The CPU and I/O board design utilized Very Large Scale Integration (VLSI) chips whenever possible to maximize power yet keep the circuit board size small. This approach also kept the design fairly simple. Refer to Figure 73 for a block diagram of the system. The CPU, running at 3 MHz, controls all the peripheral ICs via the control, data, and address lines. The program is stored on one 2 kbyte 2716 type EPROM and 2 kbyte of system scratchpad and stack memory is supplied by two MK4118 type RAMs. All digital input and output is performed using two 8255A Programmable Peripheral Interface ICs. The Pulse Count (PC) input is fed to an 8253 programmable interval timer which is used to count the number of pulses per unit time.

Analog data is read at the outputs of the safety barriers and is routed to a differential eight-channel multiplexer, type DG507C. The differential channel selected by the CPU, via an 8255 output port, is fed to the inputs of a microprocessor-compatible analog-to-digital (A/D) converter type ADC0801.

The nine barriers used to protect the analog input and PC lines were designed and built by Adjunct Systems Inc. The barriers use internal fusing and 6V zener diode shunt protection. They have a series resistance of 890 ohms. Each barrier is potted separately in an epoxy compound.

The originally intended power source for the system had been a Gould battery type PB6270, 6V 27A/hr rechargeable battery. Later additions to the system, such as the acoustic processor electronics, created the need for additional voltage sources. A mine-approved power box, designed for the Face Alignment Monitoring System project, was implemented. This supplied a +12V, -12V, and +6V source. This unit consisted of three batteries housed in separate NEMA enclosures, all housed within an explosion-proof enclosure. Power switching was done via the mine-permissible explosion-proof connector which supplied the power.

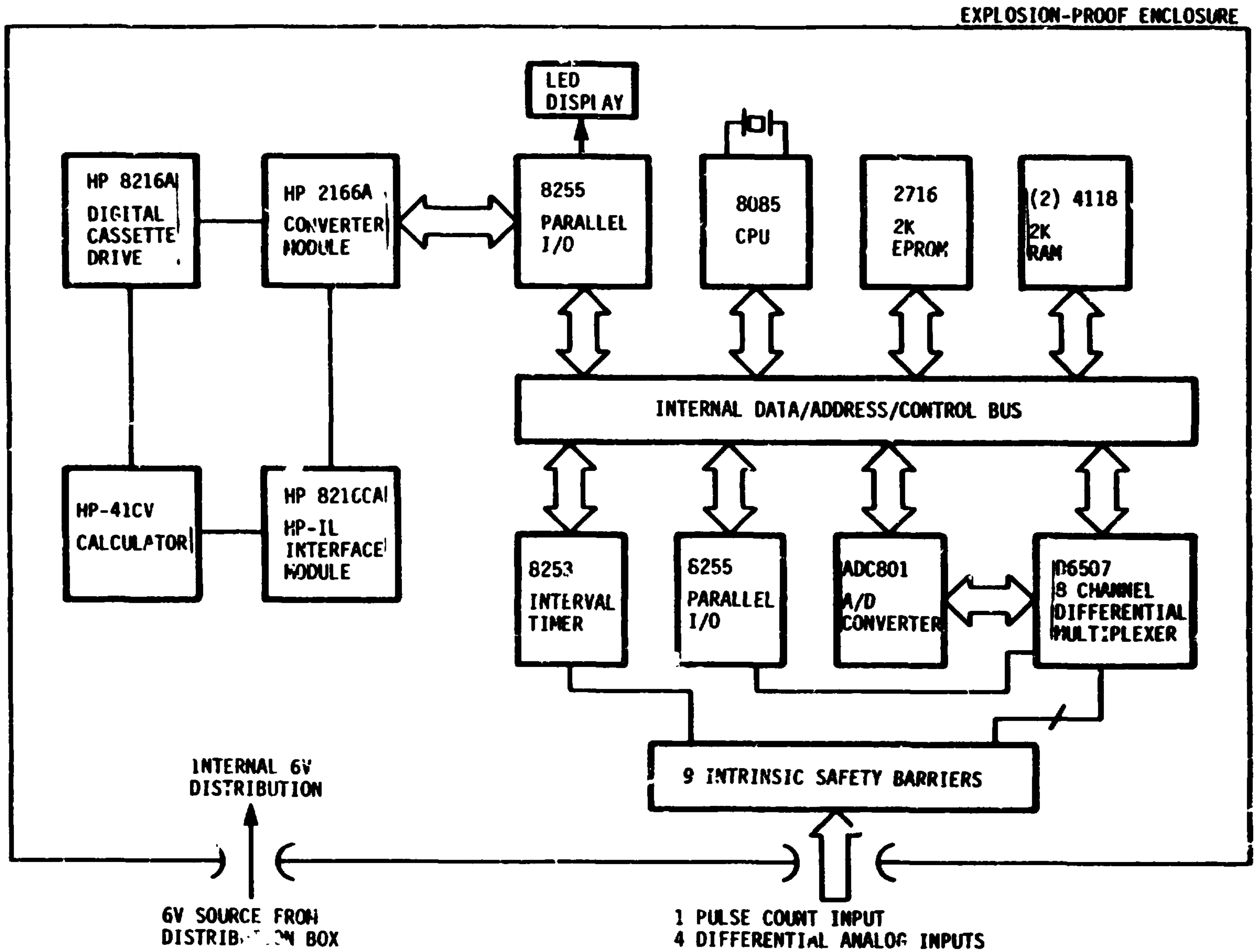

Figure 73. - Display/processor block diagram.

7.3 TESTING AT THE MOCK LONGWALL FACILITY

7.3.1 Introduction

Testing of the man-in-the-loop system was performed at DOEs test facility in Bruceton, PA. Three tests were proposed, each to determine the effect of changing a major operating parameter of the D/P system. Each test would give information necessary for the actual installation and use in the field. The tests were as follows:

1. Determine the effect of sensor delay on the control or cut accuracy of the man-in-the-loop system.

2. With all machine dependent variables held constant (for example, sensor delay, tram speed, roof profile, etc.) determine the effect of increasing the D/P program execution time.

3. Determine the effects on control of a D/P program which provides a visual indication of drum error along with proportional control.

These tests demonstrated the basic feasibility of front drum control using input signals from:

1. A PCF mounted on the shearer body

2. An arm-angle potentiometer mounted on the front range arm

3. An NBS (simulated) mounted near a PCF on the shearer body.

The control algorithms consisted of a comparison between the height from the shearer body to the measured coal/rock interface and the height of the bits in their current cutting position. This algorithm is illustrated in Figure 74. These tests indicated that system response is highly dependent upon how the control signals are interpreted and acted upon by the operator, that is, how much of a correction in drum position is made upon issuance of a particular command.

7.3.2 Testing Constraints and Simulations

In order to conduct these tests in an expeditious manner, it was important to eliminate the requirement of actually cutting the coal block. This was necessary for several reasons: the process of cutting coal, trimming the overhang, and advancing the pan-line is time-consuming and expensive; there are only two passes remaining on the coal block; and the coal block cannot provide the

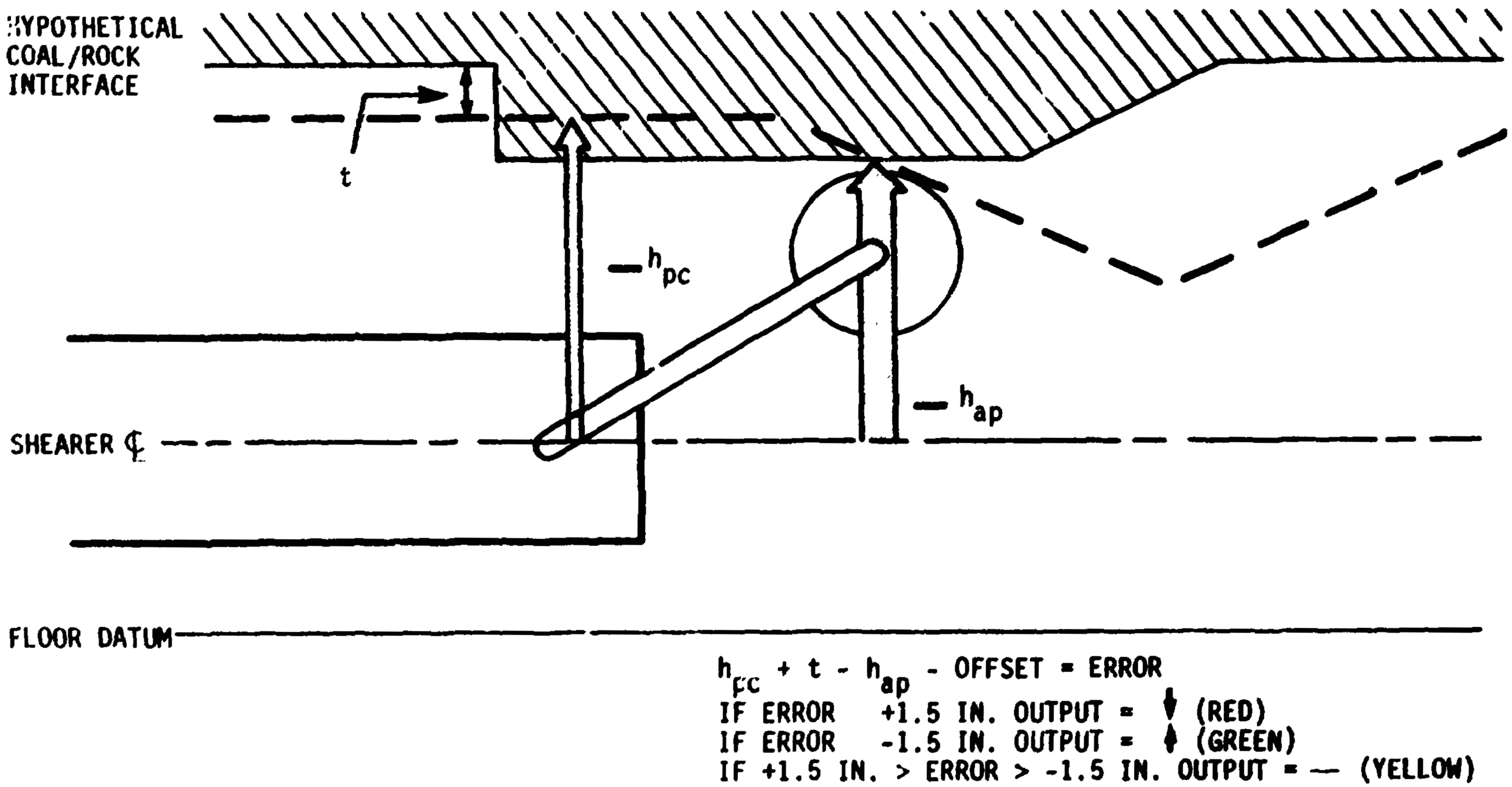

Figure 74. - Man-in-the-loop front drum control algorithm.

necessary gamma radiation needed for the NBS to operate properly. By examination of Figure 74 it can readily be understood that without actual cutting of the coal block there are no roof (hpc) or coal thickness (t) measurements for input into the Adjunct D/P. Given the fact that the VCS microprocessor-based controller was still intact on the machine, this problem was easily overcome. The VCS controller has the capability to store and retrieve data as a function of downface distance. Specifically, what was proposed was to first store in memory a set of numbers representing the hypothetical coal/rock interface as a function of downface distance. In real-time, as the test progresses, the height of the roof that would have been created (as indicated by the arm pot) is sent to memory and positioned in the array as a function of downface distance. Then the values stored previously, which represent height to the roof and remaining coal thickness directly above the points of installation of the cut follower and the natural background sensor, are retrieved and sent to the Adjunct D/P. It will appear to the D/P as though these signals were coming from the sensors in real-time.

7.3.3 NBS and Acoustic Sensor Simulator

In order for the VCS controller to interface with the Adjunct D/P, a special STD BUS compatible board had to be designed and built. The board contained two separate circuits, each which functioned independently of the other. The first circuit, the NBS simulator, would output a pulse train whose frequency was a function of the eight-bit number supplied to it by the CPU. The second circuit, the acoustic sensor simulator, would output an analog voltage that would correspond to the eight-bit word supplied to the circuit. A block diagram of the circuits is shown in Figure 75.

Both circuits interface to the STD BUS through a standard "front-end" decoder/driver configuration. The NBS simulator can be thought of as comprised of three major blocks: a 275 Hz frequency generator; a curve look-up table stored in PROM; and a variable frequency pulse generator. The frequency generator is actually a programmable divider. The frequency output of the divider, in our case 275 Hz, is given by the equation

$$f_{osc} = 1/2 \left(\frac{3.125 \times 10^6}{65,535 - N_s} \right) \qquad (1)$$

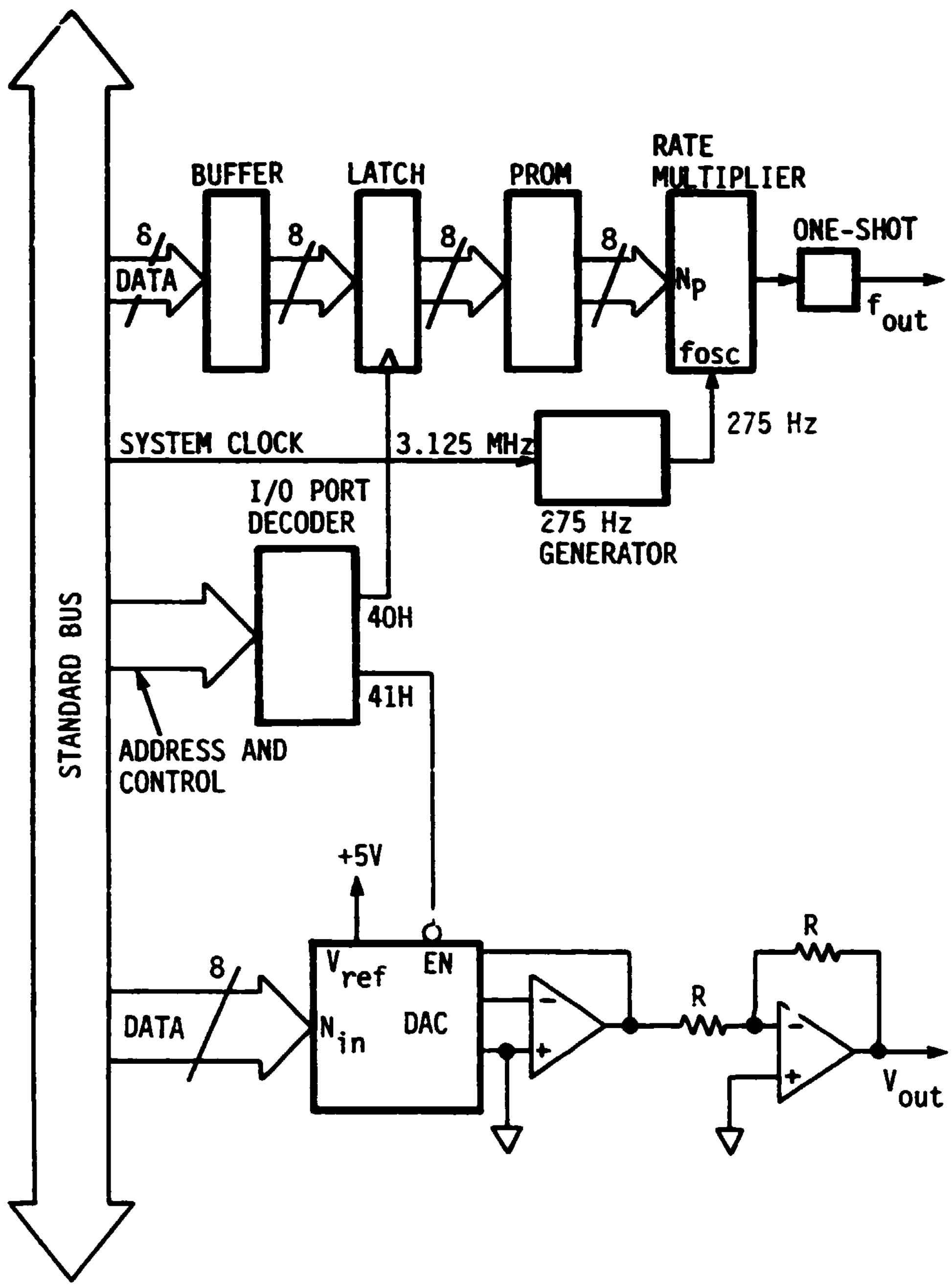

Figure 75. - NBS/acoustic simulator block diagram.

where N_s is a number selectable via D/P switches. The pulse generator circuit is composed of two cascaded four-bit rate multipliers whose output is fed to a one-shot multivibrator. The pulse output frequency of this circuit is given by the equation

$$f_{out} = f_{osc} \frac{N_p}{256} \quad (2)$$

where N_p is the decimal value of the eight-bit word from the look-up table. The look-up table is simply a 2-kbyte, 2716 PROM with a data table stored in it. The digital number supplied to the address inputs of the PROM represents a value for the numbers of inches of coal that is being simulated. The output byte is a number which upon application to equation (2) will yield a pulse count whose frequency is given by the relationship

$$N = C_1 E^{-\mu x} + C_2$$

where N is the number of counts per 8 sec, C_1 is the number of counts at 0 in. of coal, μ is the absorption coefficienct, x is inches of coal, and C_2 is the number of counts for a relatively large number of inches.

The second major circuit on the board is the acoustic simulator. The circuit is simply a digital-to-analog converter (DAC). To simplify design, a 12-bit microprocessor-compatible DAC was used. The output is inverted to obtain 0.0V at full-scale input and 5.0V at minimum input. By controlling the digital input word, the computer can accurately duplicate the output of the Wesmar SLM11B Level Monitor, our acoustic sensor.

7.4 TEST RESULTS

The first test performed was the effect on control by sensor delay. This test would simulate the effect of moving the acoustic sensor towards the rear drum. To perform the tests, the Adjunct D/P was mounted on the Joy shearer and power for the unit was provided from a 6V high-capacity gell-cell rechargeable battery. All signals were provided from the slaved VCS controller as described in subsection 7.3.2. The simulation of sensor delay was performed by a manipulation of data within the VCS controller.

The results of the first test as described in subsection 7.3.1 are shown in Figures 76, 77, and 78. The darkened area on each graph depicts the "dead-band" area within which the controller is satisfied. The band represents the 4 in. of coal to be left after cutting along with a ±1.5 in. tolerance band. The general response as seen from the graphs is good but does suffer from response lag. This lag may be the result of several separate causes: the accuracy of downface distance is defined by ±1 DFD bit, here 1.6 ft; noise in the system introduced errors on all analog channels; and the analog inputs to the system seemed to have relatively low input impedance which caused loading on circuits.

From the graphs we see that as the sensor delay was increased the system delay increased. The system's response, which was found to be approximately 0.2 in./ft for a tram speed of 10 ft/min and a program execution time of 10 sec, was not affected by sensor delay. We can also see that the tendency of the controller was to keep the drum within the band shown. For this configuration, we can conclude that the system works reasonably well.

The results of the second phase of the testing are shown in Figures 79 and 80. Here again, we see that the speed (slope) of the system response is not affected. The most noticeable difference was the extra delay encountered in the response for the 10-sec program execution. It took much longer for the controller to respond to the up-ramp in the 10-sec mode. This demonstrates the fact that program delay adds to system delay.

The final phase of the testing was not fully completed due to time constraints. The program was set up to turn on the display LEDs for different lengths of time depending on the amount of drum error. For errors greater than ±6 in. the display was lit continuously; 4.5 to 6 in., 3 sec; 3 to 4.5 in., 2.5 sec; 1.5 to 3 in., 1.75 sec; and for no error to 1.5 in., 1 sec. The controller, in this mode, was useful only when drum errors greater than 4.5 in. were encountered. Small errors were, in most cases, lost due to noise and inaccuracies in the system. Also, difficulties in distinguishing between a 1.75-sec display and a 2.5-sec display were noticed.

7.5 TESTING AT JIM WALTERS RESOURCES

7.5.1 Introduction

Field testing of the D/P as both a controller and data logger was arranged to be performed at the Jim Walters Mining Research Center mine sites No. 5 and No. 3 in the vicinity of Birmingham, AL. Two separate test efforts were to be performed. The first

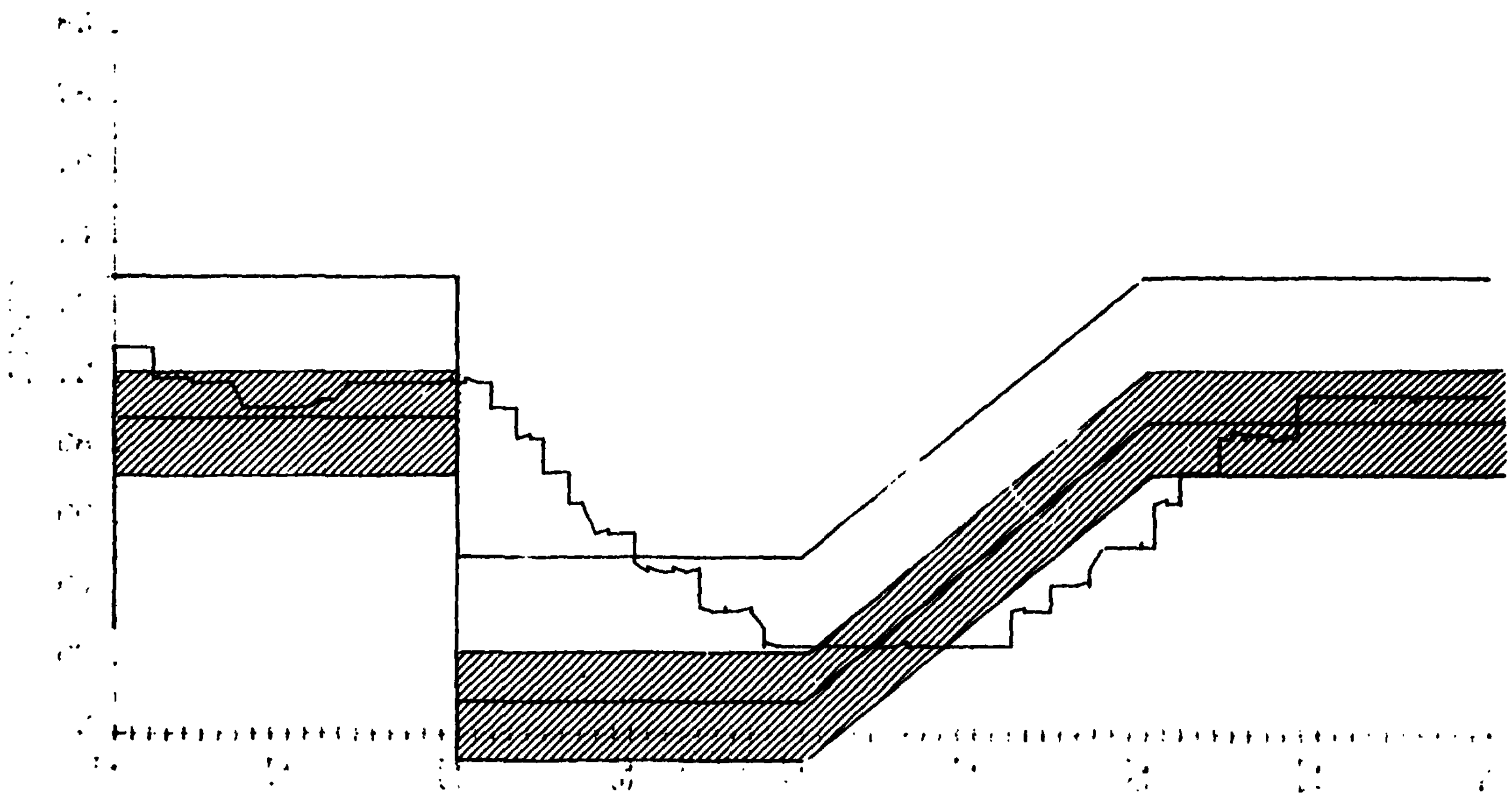

Figure 76. - D/P and prolog simulator 6-in. daily 10-sec program execution (tram = 10 ft/min) - test No. 2.

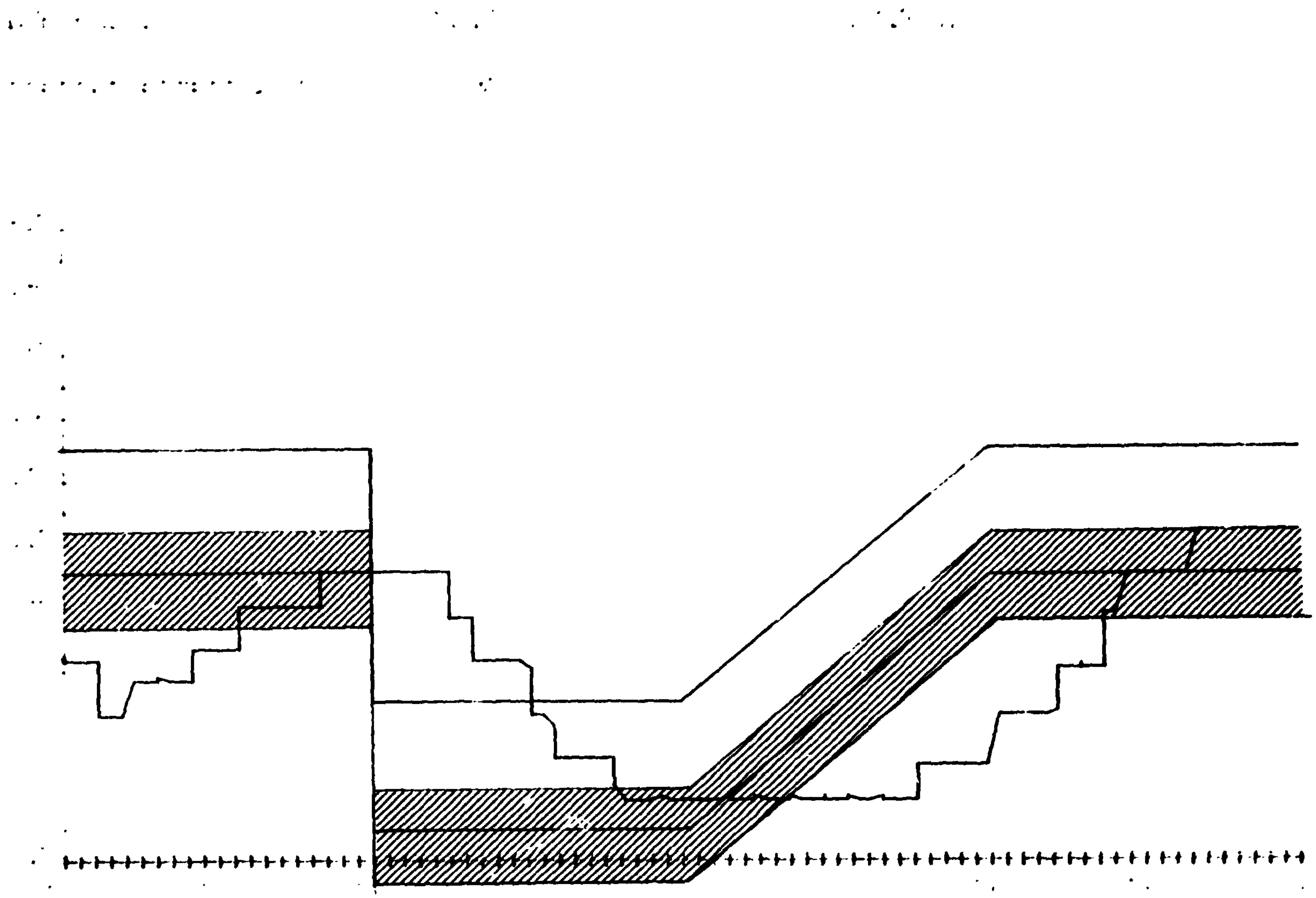

Figure 77. - D/P and prolog simulator 24-in. daily 10-sec program execution (tram = 10 ft/min) test No. 3.

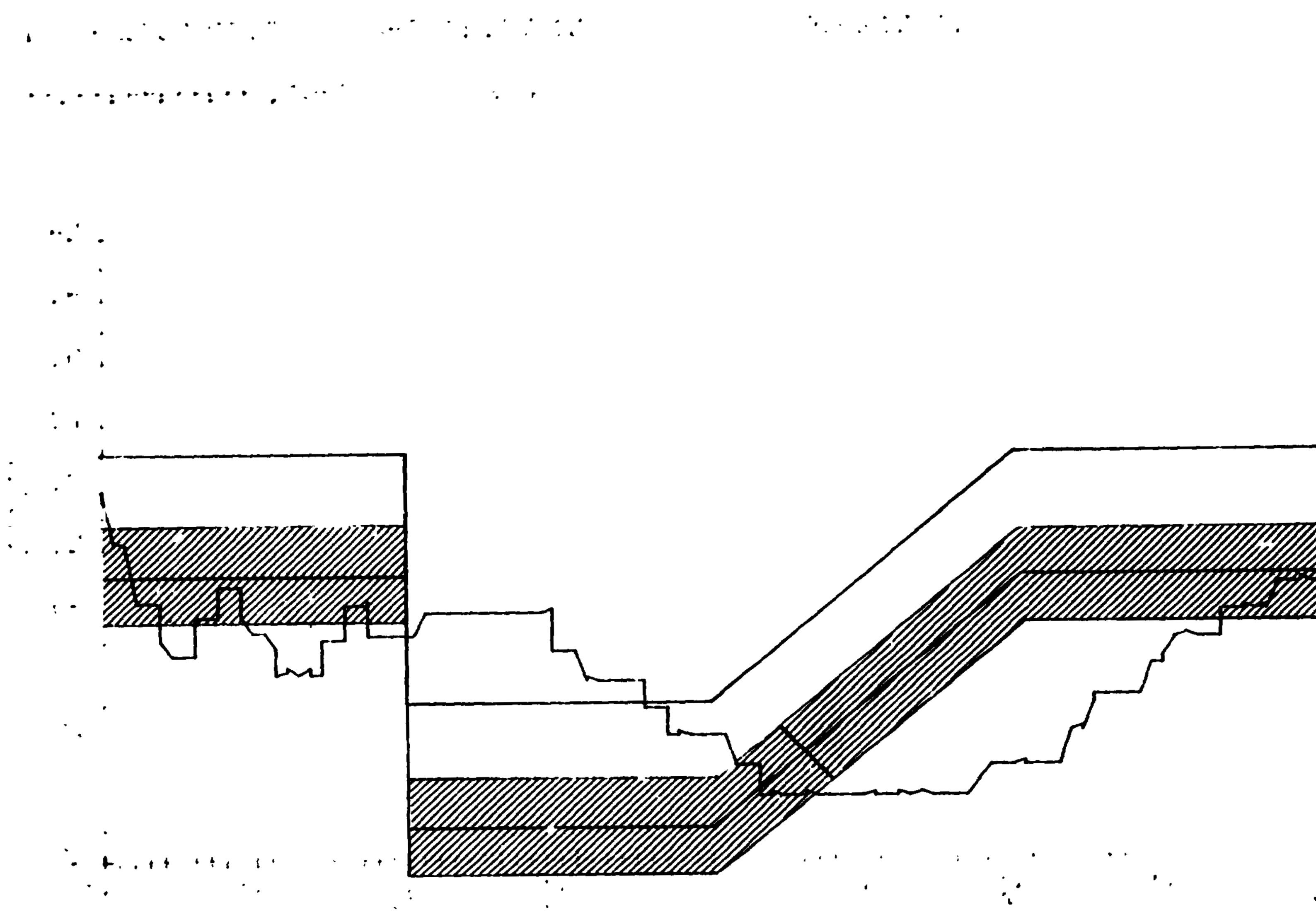

Figure 78. - D/P and prolog simulator 48-in. daily 10-sec program execution (tram = 10 ft/min) - test No. 4.

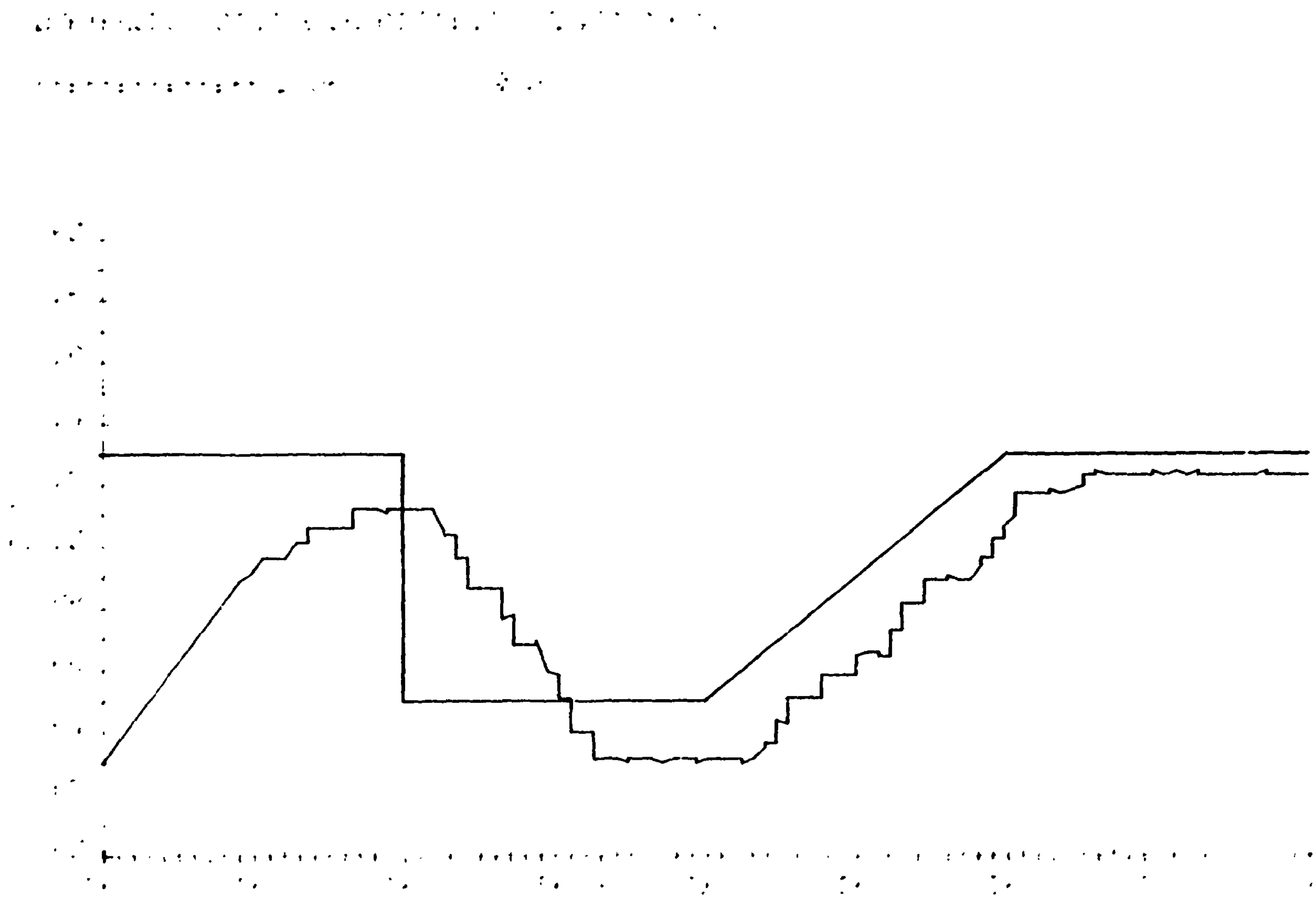

Figure 79. - D/P and prolog simulator 6-in. daily 5.45 sec program execution (tram = 10 ft/min) - test No. 9.

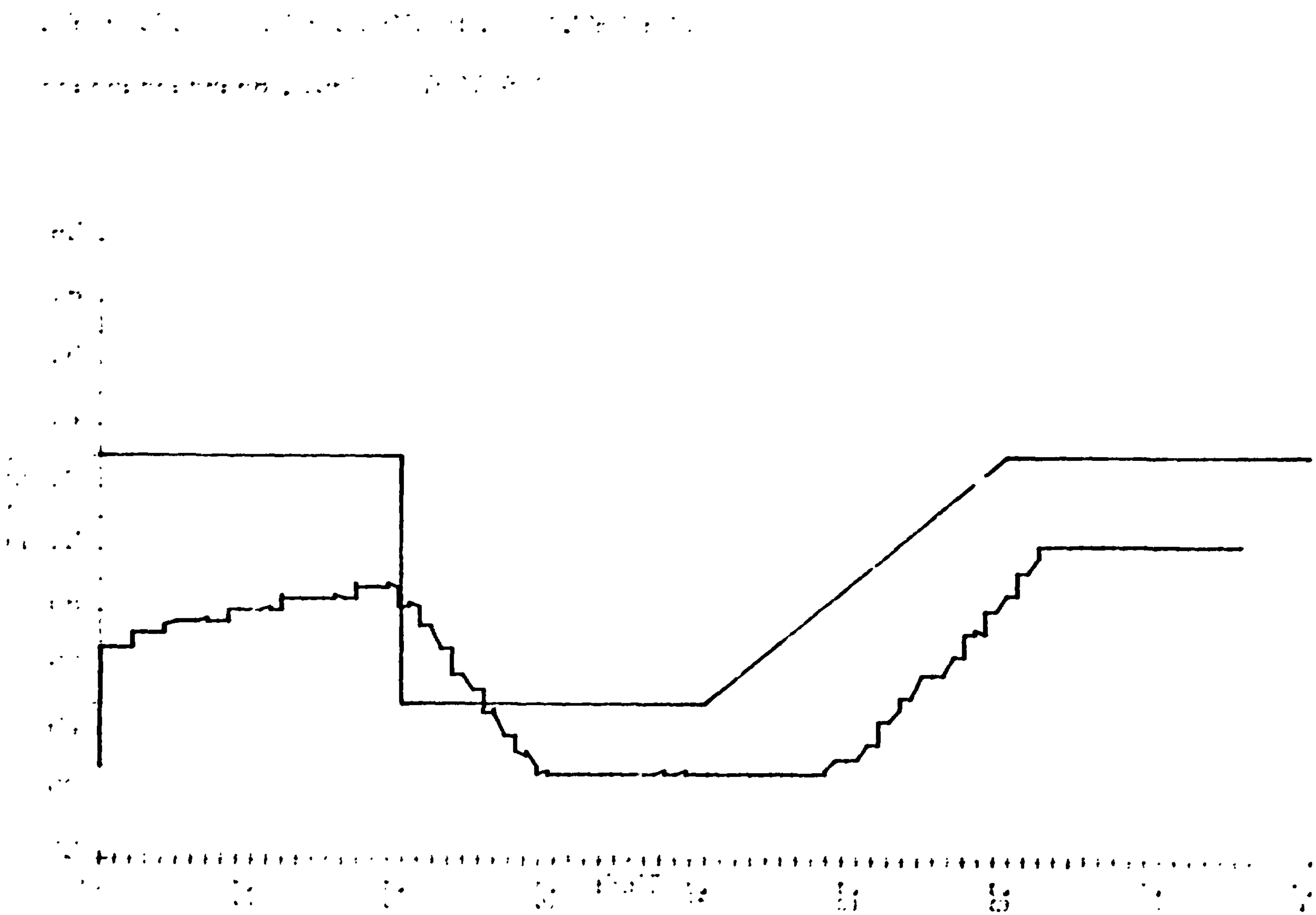

Figure 80. - D/P and prolog simulator 6-in. daily 10-sec program execution (tram = 10 ft/min) - test No. 1.

was to incorporate an acoustic PCF with the Adjunct Systems D/P for the purpose of slaving the position of the rear drum. This was to be accomplished using the information supplied by the cut follower to display to an operator in a man-in-the-loop fashion the desired rear drum control position. The second effort was to exercise the D/P's data logging capacities. Here the D/P was interfaced to a methane monitor data recorder which used a strip chart recorder for permanent records. The D/P was to accept the data seen by the methane sensor and perform statistical analysis on it before storing it permanently.

The controller test, performed at site No. 3, called for the mounting of three separate explosion-proof boxes onto an Anderson-Mavor built shearer: the Adjunct D/P, the Adjunct power distribution box, and the VCS battery box. After closely examining the shearer and the space available for mounting the control package, it became obvious that mounting it would pose many problems. It is for this reason that NASA, FMA, and Adjunct Systems decided to terminate this portion of the field test effort.

The methane sensor data logger testing was performed at the No. 3 mine site and since there were virtually no constraints for mounting this equipment, a test area was readily available. Since the system was designed to measure the methane concentration of the air within the mine, yet the D/P-methane sensor configuration had not been mine-approved, a suitable compromise was reached. One of the exhaust fans at the mine site was chosen for testing. Although this gave us the average amount of methane for the whole mine, and would not enable us to detect fast level changes, it did supply reliable data for testing.

7.5.2 Hardware Description

The system used had three major components: the Adjunct D/P, the methane sensor unit supplied by MSHA, and the power supply. A power supply was needed here to eliminate the need for regular charging of the batteries, allowing the system to run as long as ac power was not interrupted. The methane level signal output was not readily available on the sensor unit and had to be tapped off the circuitry inside the detector housing. This signal was scaled up to usable levels for the D/P by a simple amplifier circuit needing only a single OP-AMP chip. This was the only modification needed to interface the two units.

7.5.3 System Software

All the software needed to run the system was stored in the calculator's nonvolatile memory, hence avoiding the need to reload the program after powering down. The software, while seemingly simple, was extremely powerful, and had to perform many tasks at once. A description of the softwares task follows.

Every 10 sec, the D/P must read the methane level voltage from the sensor. The calculator then performs a mean and standard deviation on this data, updating these values continuously. The value of the highest reading is also saved every 10 sec. Every hour, the mean, standard deviation, and highest reading are stored in data registers for later use. A trend analysis is now performed on all means for the past hours (this calculation starts only after the fifth hour of the 24-hr reading period). At the end of 24 hr, all the hourly data is stored onto the digital tape recorder.

Within the 10-sec loop there was also data displayed on the LCD display of the calculator. The present value of percent methane was displayed for approximately 1 sec. The trend value, up, down, or no trend, was also displayed. The third and final display within the 10-sec loop was the most powerful. This display contained the hour and fraction of an hour, the mean for that hour, and the highest reading for that hour. Every 10 sec, the data set displayed in this frame would commutate from the present hour down to the first hour. This data would be rotated once each 10 sec so that first the present data would be displayed, after 10 sec the past hour's data would be displayed, and so on. Set up in this manner, it would take a person 3 min to view 24 hr worth of data.

Although the data acquisition program did do a partial analysis on the data, there is usually a need to analyze the data more thoroughly. For this reason, a program was developed to analyze and plot the data after it has been saved on the tape. Two examples are shown in Figures 81 and 82. With this routine, it is possible to print out the mean or peak for the 24 hr of any specified day. It is also possible to plot this same data to get a more understandable display.

7.5.4 Results of Methane Monitor - D/P Testing

Before testing at the mine site had begun, we found it necessary to change a major parameter of the program for the D/P; the program loop execution time. It was found that the worst case execution time for the trend analysis was approximately 25 sec for the case of 24 hr worth of data. To avoid backlogging, and eventually losing data due to buffer overflow, the execution time

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DAY1.

MODE	MEAN
R24=	0.50124
R25=	0.50159
R26=	0.54834
R27=	0.52134
R28=	0.50159
R29=	0.48025
R30=	0.47392
R31=	0.48287
R32=	0.48683
R33=	0.49477
R34=	0.49663
R35=	0.45623
R36=	0.41279
R37=	0.41947
R38=	0.43214
R39=	0.44611
R40=	0.42684
R41=	0.43406
R42=	0.44067
R43=	0.44446
R44=	0.41555
R45=	0.42837
R46=	0.45643
R47=	0.48245

DAY2.

MODE	MEAN
R48=	0.55326
R49=	0.57552
R50=	0.65887
R51=	0.72798
R52=	0.75304
R53=	0.72585
R54=	0.74973
R55=	0.74278
R56=	0.75656
R57=	0.73562
R58=	0.77754
R59=	0.78532
R60=	0.75441
R61=	0.75006
R62=	0.74670
R63=	0.80742
R64=	0.78766
R65=	0.79764
R66=	0.80253
R67=	0.79385
R68=	0.72963
R69=	0.75042
R70=	0.75985
R71=	0.76281

DAY3.

MODE	MEAN
R72=	0.77479
R73=	0.76095
R74=	0.74966
R75=	0.71683
R76=	0.68647
R77=	0.70382
R78=	0.75530
R79=	0.75400
R80=	0.72904
R81=	0.73672
R82=	0.72674
R83=	0.66961
R84=	0.54723
R85=	0.55817
R86=	0.59272
R87=	0.58605
R88=	0.60443
R89=	0.59706
R90=	0.57634
R91=	0.56065
R92=	0.53091
R93=	0.52176
R94=	0.53174
R95=	0.57345

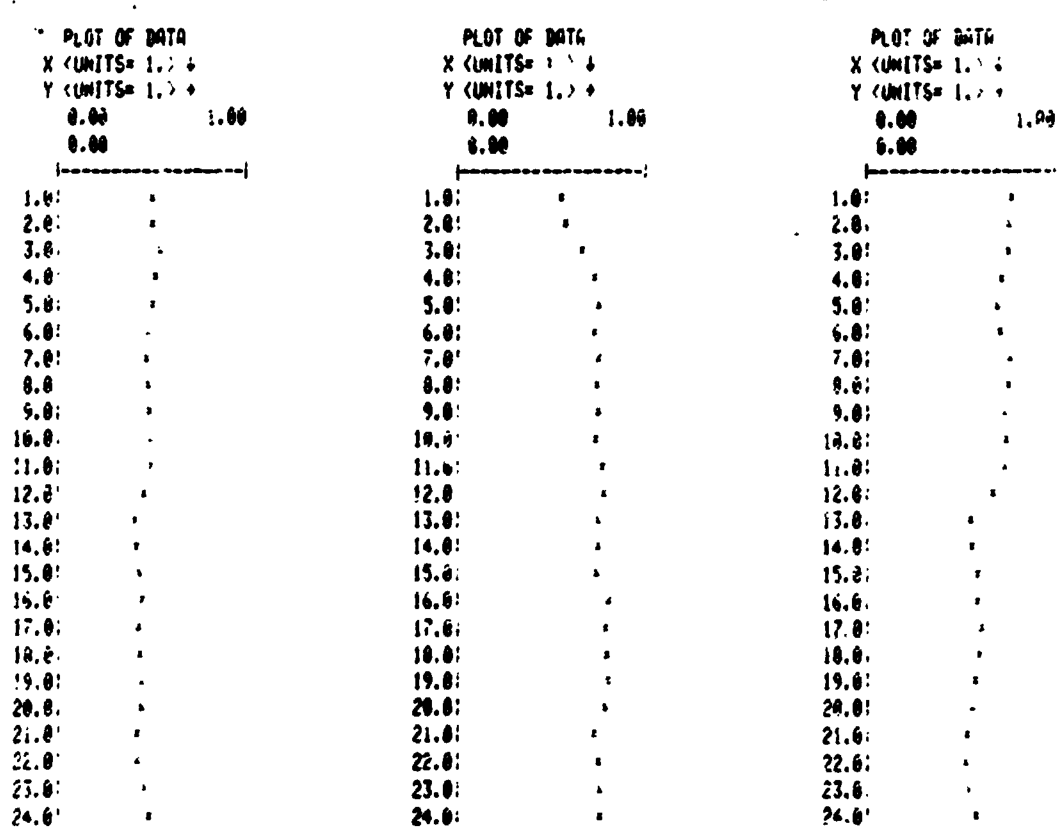

Figure 81. - Hourly means and daily plots of mean.

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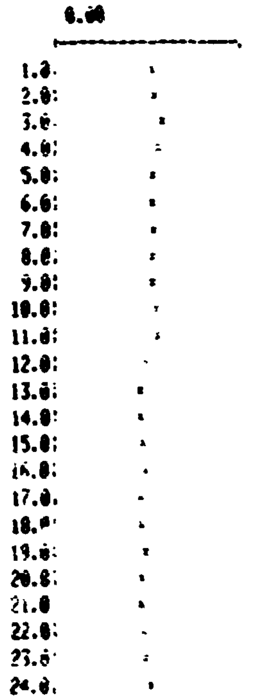
DAY1.
HOUR PEAK

R24= 0.52064
R25= 0.53696
R26= 0.57024
R27= 0.56166
R28= 0.52064
R29= 0.52064
R30= 0.53690
R31= 0.52064
R32= 0.52064
R33= 0.55342
R34= 0.56166
R35= 0.49566
R36= 0.46256
R37= 0.46256
R38= 0.47908
R39= 0.49560
R40= 0.46256
R41= 0.47082
R42= 0. [illegible]566
R43= 0.47082
R44= 0.47082
R45= 0.47908
R46= 0.49566
R47= 0.52064

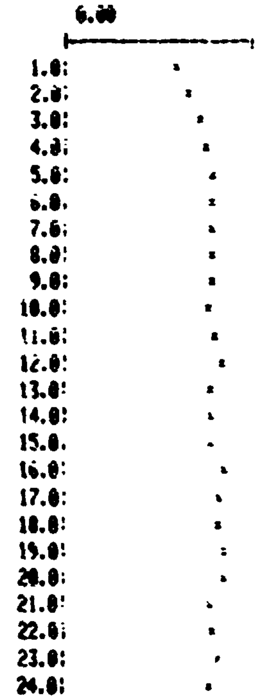
PLOT OF DATA
X (UNITS= 1.) +
Y (UNITS= 1.) +
0.00 1.00
0.00



DAY2.
HOUR PEAK

R48= 0.59472
R49= 0.66000
R50= 0.72680
R51= 0.75992
R52= 0.79296
R53= 0.79296
R54= 0.79296
R55= 0.79296
R56= 0.79296
R57= 0.77644
R58= 0.80948
R59= 0.84252
R60= 0.79296
R61= 0.79296
R62= 0.79296
R63= 0.85904
R64= 0.82600
R65= 0.82600
R66= 0.85904
R67= 0.85904
R68= 0.79296
R69= 0.80122
R70= 0.82600
R71= 0.79296

PLOT OF DATA
X (UNITS= 1.) +
Y (UNITS= 1.) +
0.00 1.00
0.00



DAY3.
HOUR PEAK

R72= 0.80946
R73= 0.70476
R74= 0.79296
R75= 0.74340
R76= 0.72680
R77= 0.80122
R78= 0.80948
R79= 0.80302
R80= 0.79296
R81= 0.79296
R82= 0.80122
R83= 0.74340
R84= 0.62776
R85= 0.59472
R86= 0.66000
R87= 0.62776
R88= 0.64428
R89= 0.62776
R90= 0.66290
R91= 0.59472
R92= 0.56168
R93= 0.56168
R94= 0.65254
R95= 0.66000
PLOT? R/S

PLOT OF DATA
X (UNITS= 1.) +
Y (UNITS= 1.) +
0.00 1.00
0.00

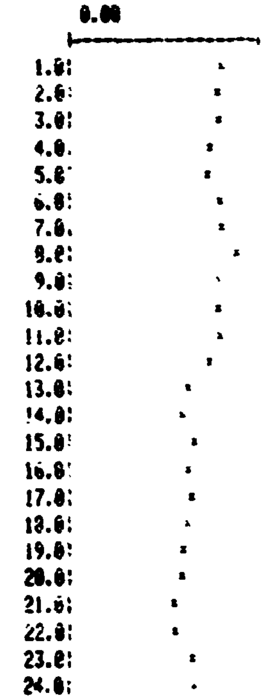


Figure 82. - Hourly peaks and daily plots of peak.

was increased from 10 sec to 30 sec. If only the present methane level was displayed, or if the trend analysis was deleted, the methane level could be recorded every 10 sec or less.

As mentioned before, the data is stored on the tape every 24 hr. The file is actually a copy of 147 registers of the HP memory. Each register has a permanently designated function. Figure 83 illustrates the contents of the file for data accumulated during day one which started at 10:45 a.m. on December, 1981.

The prefix "R" stands for the register that the various data are stored in. R19 and R20 store the message relating to the trend; in this case they contain the message that for day one the trend is down. The trend is based on the 24 hourly means which are stored in registers R24 through R47, R24 being the mean of the first hour (10:45 a.m. to 11:45 a.m.) etc. Registers R48 through R71 contain the standard deviations about the means for each hour. To show an example, the mean for the first hour was 0.501 percent and the standard deviation was 0.014, the mean for the second hour was 0.502 percent and the standard deviation was 0.016.

Registers R72 through R95 contain the peak for each hour, for example, the highest value of methane recorded in the first hour of day one was 0.529 percent, the highest in the second hour was 0.537 percent and so on. Registers R96 through R119 contain for each hour the number of readings which were greater than 0.4 percent and less than 0.5. Again, referring to the data for day one, R96 shows that there were 51 readings between the two limits during the first hour, R97 shows 56 for the second hour, etc. The registers R120 through R143 represent the number of readings for each hour that lie between 0.5 and 0.6, and registers R144 through R167, the number that lies between 0.6 and 0.7.

For some applications, a numerical listing of the data may be sufficient but a graphic display of data can convey much more information at a single glance. Figure 81 and 82 demonstrate this. From the plots of means it is easy to see the trend of the data. For the three days of data acquired at Jim Walter Resources we found that the trend for day one was down, day two was up and day three was down.

The data stored on tape can be analyzed in a number of different ways. The analysis done on the data here was minimal and represents only a small part of what the calculator is capable of. If it was ever found necessary, it would be possible to download the accumulated data into a larger computer system for more complex analysis.

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DAY1.
MODE DAY

R20= [illegible]
R21= 0.00033
R22= 24.00000
R23= [illegible]
R24= 0.50124
R25= 0.50159
R26= 0.54034
R27= 0.52134
R28= 0.50159
R29= 0.40025
R30= 0.47392
R31= 0.48267
R32= 0.40603
R33= 0.49477
R34= 0.49663
R35= 0.45623
R36= 0.41279
R37= 0.41947
R38= 0.43214
R39= 0.44611
R40= 0.42684
R41= 0.43406
R42= 0.44067
R43= 0.44446
R44= 0.41555
R45= 0.42037
R46= 0.45043
R47= 0.48245
R48= 0.01425
R49= 0.01627
R50= 0.01661
R51= 0.01196
R52= 0.01183
R53= 0.02616
R54= 0.02147
R55= 0.02048
R56= 0.02218
R57= 0.02489
R58= 0.02483
R59= 0.01424
R60= 0.01394
R61= 0.00977
R62= 0.01969
R63= 0.01809
R64= 0.01308
R65= 0.01536
R66= 0.01936
R67= 0.01326
R68= 0.02715
R69= 0.02306
R70= 0.01326
R71= 0.01151
R72= 0.52064
R73= 0.53690
R74= 0.57020
R75= 0.56166
R76= 0.52064
R77= 0.52064
R78= 0.53690
R79= 0.52064
R80= 0.52064
R81= 0.55342
R82= 0.56168
R83= 0.49560
R84= 0.46256
R85= 0.46256
R86= 0.47900
R87= 0.49560
R88= 0.46256
R89= 0.47002
R90= 0.49560
R91= 0.47002
R92= 0.47002
R93= 0.47900
R94= 0.49560
R95= 0.52064
R96= 51.00000
R97= 56.00000
R98= 1.00000
R99= 4.00000
R100= 49.00000
R101= 90.00000
R102= 101.00000
R103= 92.00000
R104= 88.00000
R105= 75.00000
R106= 60.00000
R107= 119.00000
R108= 101.00000
R109= 119.00000
R110= 118.00000
R111= 119.00000
R112= 116.00000
R113= 118.00000
R114= 118.00000
R115= 118.00000
R116= 72.00000
R117= 89.00000
R118= 119.00000
R119= 117.00000
R120= 69.00000
R121= 64.00000
R122= 119.00000
R123= 116.00000
R124= 71.00000
R125= 22.00000
R126= 19.00000
R127= 27.00000
R128= 30.00000
R129= 45.00000
R130= 52.00000
R131= 0.00000
R132= 0.00000
R133= 0.00000
R134= 0.00000
R135= 0.00000
R136= 0.00000
R137= 0.00000
R138= 0.00000
R139= 0.00000
R140= 0.00000
R141= 0.00000
R142= 0.00000
R143= 3.00000
R144= 0.00000
R145= 0.00000
R146= 0.00000
R147= 0.00000
R148= 0.00000
R149= 0.00000
R150= 0.00000
R151= 0.00000
R152= 0.00000
R153= 0.00000
R154= 0.00000
R155= 0.00000
R156= 0.00000
R157= 0.00000
R158= 0.00000
R159= 0.00000
R160= 0.00000
R161= 0.00000
R162= 0.00000
R163= 0.00000
R164= 0.00000
R165= 0.00000
R166= 0.00000
R167= 0.00000
PLOT? R/S

Figure 83. - Day 1 data.

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8. TESTING AT CARBON COUNTY COAL CO.

8.1 BACKGROUND

During the months of November and December, 1981, the NASA-developed NBS system was installed, calibrated, and tested on an operating longwall at Carbon County Coal Co.'s (CCCC's) mine in Hanna, WY. The system operated quite well for several weeks while it was in operation, and was routinely used by one of the longwall crews to supplement roof-coal thickness data obtained by drilling.

The purpose of the testing at CCCC was to test the NBS as a coal thickness sensor in an operational mining environment. The equipment to be tested included the following:

1. *Sensor module* - Includes 4 × 4 × 8 in. NaI (Tl) crystal (for detecting gamma radiation from the roof rock), photomultiplier tube, power supply and pulse amplifier.

2. *Electronics module* - Containing signal processing and display drive electronics.

3. *Display module* - Containing LCD meter for displaying coal thickness in inches, and LEDs for indicating to raise or lower the ranging arm.

4. *Battery module* - Providing power to the system for one shift (8 hr).

5. *Interconnecting cables* - The equipment was designed to be mineworthy for the duration of the test phase, but was not intended to be a commercial design. To achieve portability and to avoid the problems associated with interfacing with mine power during the test phase, the system was designed to be battery-powered.

The following subsections will discuss some of the previous work conducted by NASA-MSFC at CCCC. In addition, sample data results for the FMA activity will be presented.

8.2 CCCC FACE DESCRIPTION

The test mine for the NBS field trials was CCCC's Mine No. 1 in Hanna, WY. This mine has a 16-ft thick seam of sub-bituminous (11,000 Btu) coal, pitching down at 6 deg in a northwesterly direction. The overlying rock is black shale. Due to incompetence of the shale CCCC leaves 2 to 3 ft of roof coal for roof control.

There is one longwall in operation at CCCC No. 1. An Eickhoff 300L shearer is used. A 10- to 11-ft cut is taken, leaving at least 2 ft of floor coal as well. Floor coal is necessary for proper advancement of the roof supports.

8.3 PREVIOUS TESTING

Initial contacts with CCCC were made by NASA-MSFC. FMA's initial involvement was in field support of data gathering. Data was necessary to determine the basic level of gamma activity at CCCC. The sensor is a 4 × 4 × 8 in. crystal. Without shielding to make it directive, it will detect gamma radiation from all angles. Lead shielding is employed on the sides and bottom of the crystal to limit the view angle. A simple diagram of the angles through which radiation enters the crystal is given in Figure 84. In order to reduce the view angle, a collimator was fabricated from 1/4-in. steel plate. The effect on the view angle is illustrated in Figure 85.

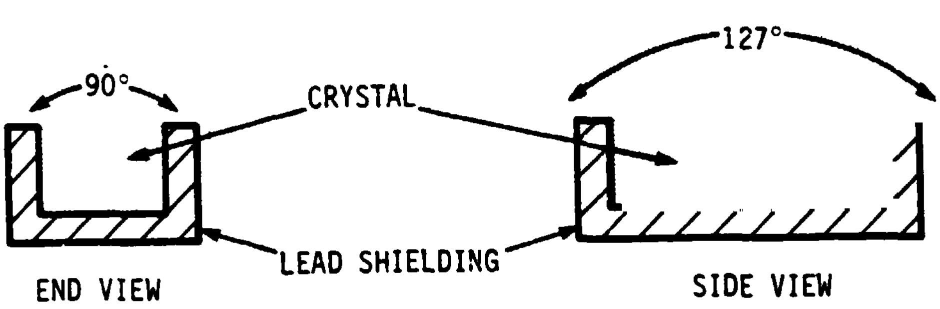

Figure 84. - View angles of NBS sensor.

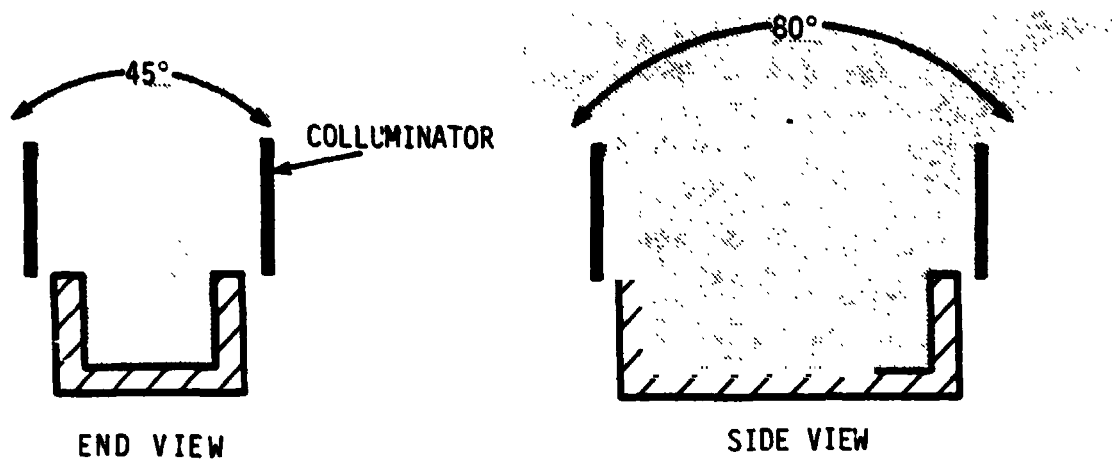

Figure 85. - View angles of NBS sensor with collimator.

Some testing of the NBS on a continuous miner took place, but a number of problems occurred simultaneously. The continuous miner got stuck in deep mud and then the NBS failed due to moisture intrusion.

A major roof fall and subsequent problems caused a 4-week shutdown of the mine.

8.4 NBS TEST RESULTS ON THE LONGWALL

The NBS field test effort resumed in November. FMA was responsible for the installation on the shearer, calibration, data taking, maintenance of equipment and test evaluation based on test results. The NBS was to be mounted on the Eickhoff 300L shearer to give indications of roof coal remaining. Ideally, the NBS would be located near the roof and immediately behind the lead drum. This is not possible, however, for several reasons:

1. CCCC does not want any equipment near the roof where it would interfere with roof supports.

2. A mounting location near the drum (within 4 ft) would put the sensor in the path of coal as it is deflected over the cowl.

The mounting location chosen for the tests at CCCC was at mid-body of the shearer. The sensor mounting bracket was mounted on the top surface of the shearer body. The sensor mounting is shown in Figures 86 and 87. As can be seen in the front view, the sensor was tilted into the face at 20 deg. The sensor bracket as fabricated positioned the sensor at 25 deg but this was excessive. Wooden shims were used to set the sensor angle at 20 deg.

During the first week of data taking after installation on the longwall, very little meaningful data was obtained. This was due to the fact that CCCC was leaving between 3 and 4 ft of roof coal at the time and the NBS was essentially reading background radiation. The measurement of roof coal thickness is made during the first pass on each shift. While the shearer is at the headgate, shields 30 to 80 are sumped in. When the shearer gets to shield 30, the shearer is stopped and the shield tips are extended on either side of the point to be drilled to protect the miners. Three miners stand on the body of the

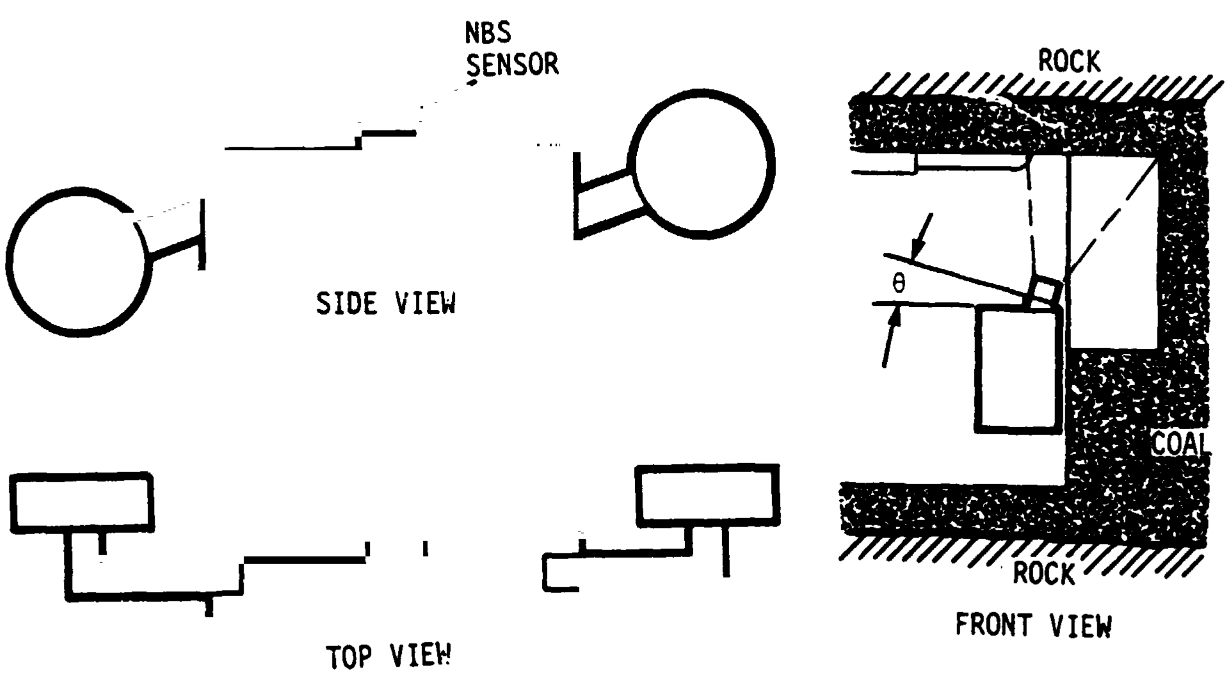

Figure 86. - NBS mounting.

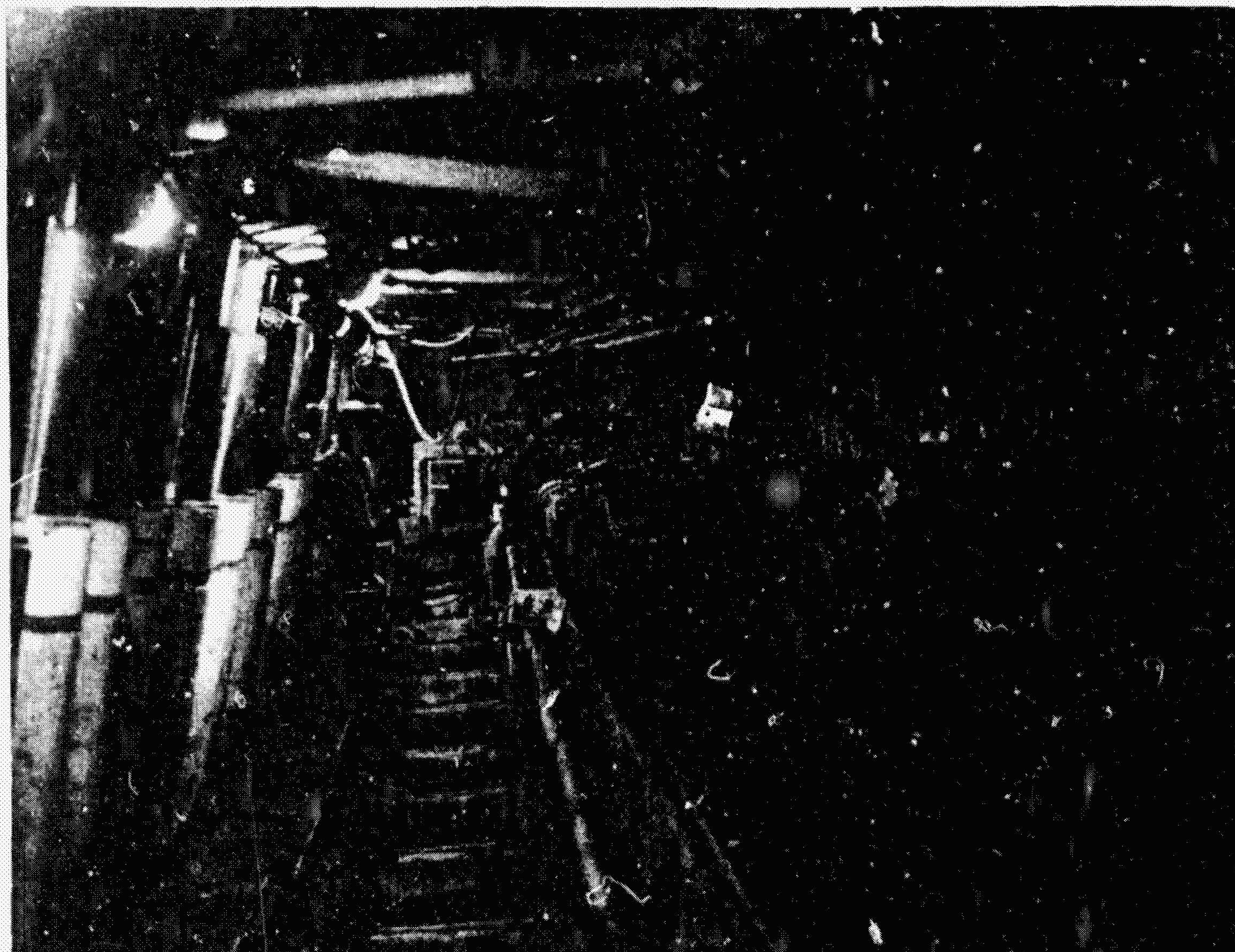

Figure 87. - Photo of NBS installation at CCCC No. 1.

shearer and the shelf of coal left by the lead drum. A drill powered hydraulically from the shearer is used by two of the miners to drill a hole into the roof coal. The third miner observes the tailings as they fall into his (or her) hand. Drilling is stopped when the tailings indicate shale. A tape measure is used to check the depth of the hole. The process is repeated at shields 40, 50, 60, and 70. On the cleanup pass, holes at shields 20 and 10 are drilled. Additional drilling during a shift is on an "as-needed" basis.

Whenever the shearer was stopped for a hole to be drilled, the actual NBS counts and/or the NBS coal thickness was recorded. Whenever possible, 10 readings were taken at each drilling location; usually, there was only time to get 5 readings before the shield tips were moved forward. Table 5 shows the data obtained.

During the second week (9 to 13 November), additional data was taken (Table 6). There were a number of readings taken during the week that allowed a curve of counts versus inches-of-coal to begin to take shape. The number of counts per 8 sec was considerably lower than the data taken by NASA earlier in the year.

TABLE 5. - NBS DATA TAKEN ON 2 NOVEMBER 1981

Shield No.	Coal thickness		Coal thickenssing next pass	
	Measured (by drilling)	NBS meter	Measured (by drilling)	NBS meter
10	45	36.4 36.8	No drilling	36.1
20	43	36.7 37.8	No drilling	34.5
30	42	35.3 36.3	42 in.	37.7 37.9
40	48	33.2 32.6	No drilling	34.0
50	48+	34.0	No drilling	35.3
60	40	36.7 37.7	35	36.6 35.7
70	48+	36.2 37.3	-	-

TABLE 6. - NBS DATA TAKEN 9 TO 13 NOVEMBER 1981

Shield no.	Measured	NBS meter	Counts
10	43	-	118.8
20	42	-	126.0
30	31	-	143.6
40	36	-	128.3
50	19	-	182.2
60	27	-	174.3
30	28	-	137.0
50	26	-	143.0
57	21	-	159.5
70	36	-	128.8
Data taken by CCCC			
	14	-	227.5
	30	-	129.7
	30	-	142.2

At the beginning of the third week of activity (15 to 20 November), the angle of the sensor was reduced from 25 deg off vertical to 20 deg off vertical. No significant difference in counts versus coal thickness was noticed. This data (see Table 7) is plotted in Figure 88 and shows a definite reduction in sensitivity relative to the mine survey data taken by NASA for low sensitivity shale.

There are several factors which probably caused the decrease in sensitivity. These are:

1. The NBS is mounted at an angle in order to look at the present cut.

2. NASA's data was taken with the NBS mounted on a jeep in the middle of entries, whereas when mounted on the shearer the view angle of the sensor may include some of the face.

3. The shale layer may be thinner than before or may be of lower activity.

TABLE 7. - NBS DATA DURING 16 TO 20 NOVEMBER 1981 (REPOSITIONED NBS TO POINT ONLY 20 deg INTO THE FACE)

Shield no.	Coal thickness		Counts/8 sec
	Measured	NBS meter	
November 17			
41	41	36.1	
50	29	35.5	
60	32	34.5	
70	41	36.8	
November 19 - swing shift			
30	36	39.8	131.0
40	18	34.2	174.0
50	30	40.2	133.4
40	11	21.6	282.0
60	30	37.7	148.2
November 19 - day shift			
40	34	40.9	139.7
50	>38	38.8	122.0
60	27	39.8	139.3
70	>42	42.2	100.8
Readjusted arrows to 20 in. $\downarrow$, 31 in. $\uparrow$. Recalibrated integration time = 14 sec.			
November 20 - day shift			
	31	31.5	128.0
	25	28.9	144.0

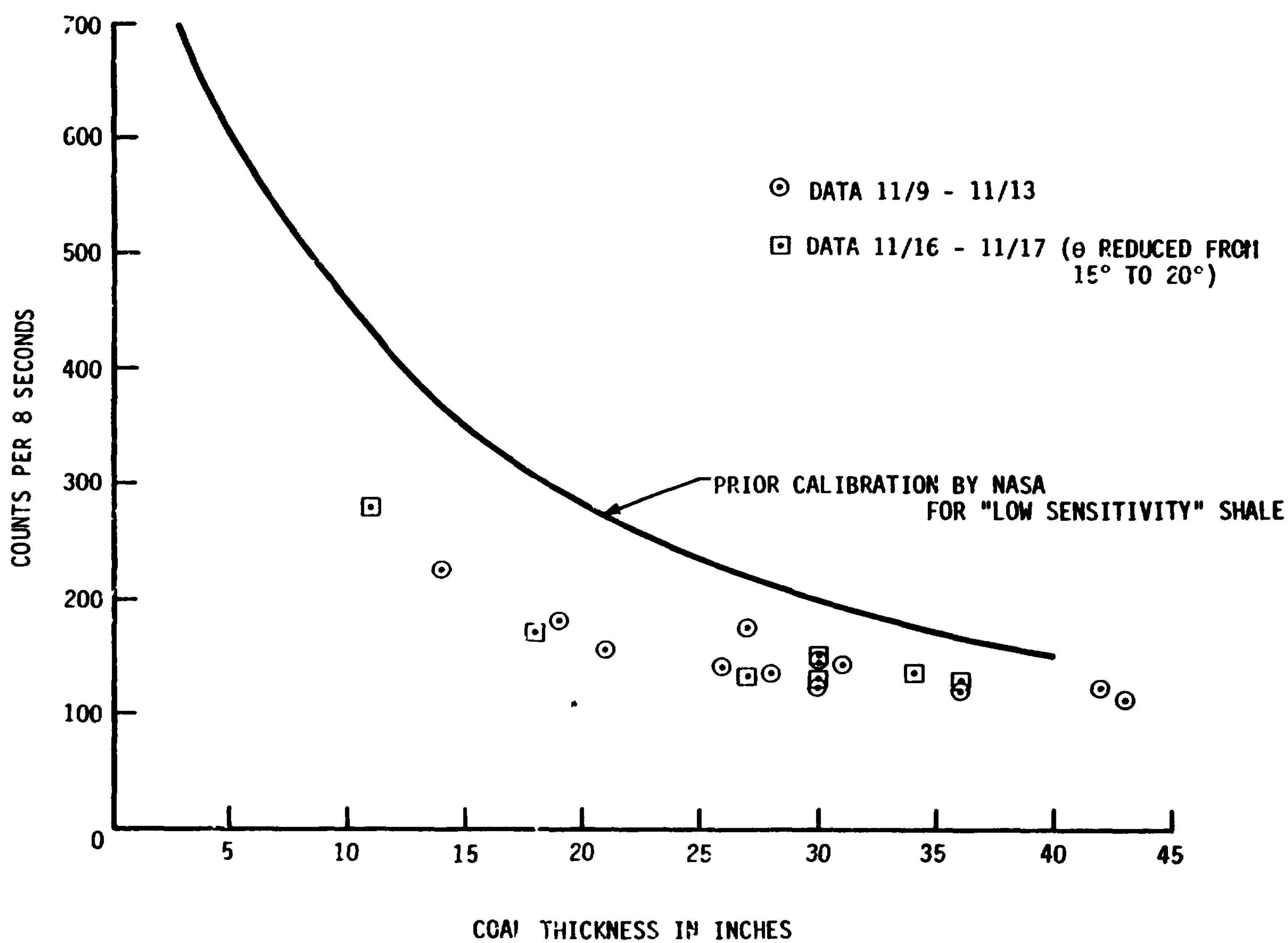

Figure 88. - Coun per 8 sec as a function of coal thickness.

In order to get agreement between the set of data taken on the longwall and the calibration curve existing in the signal processor, the integration time for counts was increased from 8 to 14 sec. The *up* arrow on the display was adjusted to illuminate if coal thickness exceeds 31 in. The *down* arrow was adjusted to illuminate if coal thickness is less than 20 in. If coal thickness is between 8 and 31 in., a green "bar" was displayed.

Data taken on 20 November after the circuit was adjusted showed good agreement between measured (drilled) coal thickness and readings from the NBS. An actual coal thickness (verified by drilling) of 31 in. was displayed by the NBS as 31.5 in. A later set of measurements further down the face yielded 25 in. (actual) versus 28.9 in. (NBS).

The following week (30 November to 1 December), the electronics box was severely damaged by a roof support. The roof support was low and the electronics box (sitting on top of the shearer) hit the support as the shearer trammed down the face. The circuit boards were undamaged and were transferred to a spare electronics box enclosure. By continuing to use the same electronics boards, the calibration was unchanged.

The system was reinstalled on the shearer at the beginning of day shift on 3 December.

Three holes were drilled on the first run and the results were as shown in Table 8. On the following shift additional data was taken, shown in Table 9. There was a significant difference between data from the two shifts. Either the two crews drilled differently or the shearer had entered a region of more active shale.

Data taken during the last week at CCCC (7 to 11 December) again showed good agreement between the NBS and actual coal thickness, as shown in Table 10. Unfortunately, there were no measurements taken during the last week that were made for coal thickness less than 24 in.

TABLE 8. - COMPARISON DATA, FIRST RUN

Shield no.	Coal thickness in inches		Comments
	Display	Drilled	
26	32.9	40	Out of range
39	27.7	24	+3.7 in. error
55	13.9	12	+1.9 in. error

TABLE 9. - COMPARISON DATA, FOLLOWING SHIFT

Shield no.	Coal thickness in inches		Comments
	Display	Drilled	
30	31.0	41	-10.0 in.
40	26.8	33	-6.2 in.
57	15.3	24	-8.7 in.
70	27.4	44	Out of range

TABLE 10. - COMPARISON DATA, 8 DECEMBER 1981

Shield no.	Coal thickness in inches		Comments
	Display	Drilled	
40	25.90	28	-2.1 in. error
50	24.30	24	+0.3 in. error
60	32.90	>48	Out of range
70	27.80	46	Out of range
9 December 1981			
30	28.70	32	Out of range
40	31.50	24	+7.5 in. error
50	27.60	31	-3.6 in. error
60	34.15	41	Out of range

8.5 SUMMARY

There were no failures of any of the electronics during the month-and-a-half underground. The only replacements of parts were due to physical damage. The sensor itself was in a relatively safe position on the shearer body and did not get hit by any large pieces of rock or coal. The electronics box, however, was damaged twice and in the future should be relocated to the gob side of the shearer or protected by a cover. The problem with a protective cover is that the cover itself would be even more likely to be hit by a roof shield.

9. CONCLUSIONS AND RECOMMENDATIONS

Since this work covers a number of developments and test results, this section has been limited to those areas showing the most promise for further work or implementation by industry. Specifically, the following paragraphs will be limited to a discussion of the VCS as a system, man-in-the-loop, and pertinent individual sensors.

9.1 VERTICAL CONTROL SUBSYSTEM

Certainly the work at the surface test facility has proven the basic feasibility of operating the front and rear drums of a longwall shearer under closed-loop control. In addition, with the exception of the LCF, the work at Old Ben has demonstrated that a successful survivable system retrofit of an operational shearer is possible.

Beyond this, extensive underground demonstrations of the VCS are required to define the ultimate performance and hence value to the operations.

9.2 MAN-IN-THE-LOOP

The work at the surface test facility has once again proven the basic feasibility of this operational technique. The sensors required as well as their location reflect the work of the VCS. Therefore, it can be said that, with the exception of the processor display hardware, basic survivability is possible. However, we would also have to recommend, in this case, that extensive underground trials be undertaken to define the actual performance and value to industry.

9.3 SENSORS

The NBS is undoubtedly one of the more promising sensors to emerge from this work. The underground test performed under this contract, as well as those performed elsewhere by MSFC and the work abroad, have clearly indicated that the technical feasibility and the practical application of this device has been proven.

Additional work with the unit in a variety of United States shales would more clearly define the material applicability. In addition, a redesign of the hardware into a more useable sensor is in order.

The acoustic cut follower was also demonstrated to be a most useful and reliable sensor. The need to measure distance in a non-contact manner in the hostile underground environment will be extensive as more automation is introduced. Similarly, this approach would benefit from extensive underground testing.