Report of Investigations 9637

Development of a Mine Hoist and Ore Pass Research Facility

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ILLUSTRATIONS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Metric Units

cm	centimeter		m/min	meter per minute
GHz	gigahertz		ms	millisecond
kg	kilogram		m/s	meter per second
kW	kilowatt		s	second
m	meter		V	volt
mm	millimeter		°C	degree Celsius

U.S. Customary Units

ft	foot		in	inch
ft/min	foot per minute		lb	pound
ft/s	foot per second		°F	degree Fahrenheit
hp	horsepower			

DEVELOPMENT OF A MINE HOIST AND ORE PASS RESEARCH FACILITY

By Michael J. Beus[1] and Todd M. Ruff[2]

ABSTRACT

Research aimed at preventing injuries and fatalities related to vertical movement of personnel and materials in mine shafts and ore passes is being conducted at the Spokane Research Center, a research division of the National Institute for Occupational Safety and Health, in Spokane, WA. The goal of this research is to improve monitoring, inspection, and operating procedures to increase awareness of the proper functioning of mine hoists, ore passes, and chutes; develop means of warning of potentially dangerous situations; and to improve the design of mine shaft and ore pass structures.

Current technology was assessed to determine what conditions and equipment should be monitored and the availability of sensors. Components of various mine hoisting, elevator, and ore pass systems were evaluated, including hoisting machinery and shaft and ore pass infrastructures. Progress to date has resulted in the construction of a state-of-the-art hoisting and ore pass test facility, and the development of new sensors and data acquisition interfaces to monitor hoisting and ore pass operations.

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INTRODUCTION

Some of the deepest mines on the North American continent continue to be important sources of precious and base metals, such as silver, gold, antimony, copper, lead, and zinc. Most important to safety and production is uninterrupted operation of the shaft and ore pass systems. A shaft, as shown in figure 1, provides access to the network of openings used to recover the underground resource, serves as an escapeway in case of emergency, and allows vertical movement of miners and materials. Ore passes provide for movement of ore and waste rock from one level to another. Shaft and ore pass structures must be well designed and maintained for safe and reliable service.

Researchers at the Spokane Research Center (SRC) of the former U.S. Bureau of Mines (USBM) concluded that a research facility and improved technology were required to assess and improve the safety of mine hoisting and ore pass operations. This work is continuing under the administration of the National Institute for Occupational Safety and Health (NIOSH). The present Report of Investigations (RI) describes construction of this facility, retrofitting of the hoist motor with state-of-the-art components, and development of a new device for mine hoist conveyance monitoring. The goal of the research is to improve monitoring, inspection, and control systems to increase awareness of the proper functioning of mine hoists, ore passes, and chutes; to develop means of warning of potentially dangerous situations; and to improve the design of mine shaft and ore pass structures. Monitoring hoist and ore pass operations will allow operators, inspectors, and maintenance personnel to increase their awareness of potentially dangerous situations. Improved ore pass, chute, and gate design will enable ground and muck falls to be controlled in and around ore passes in hard-rock mines
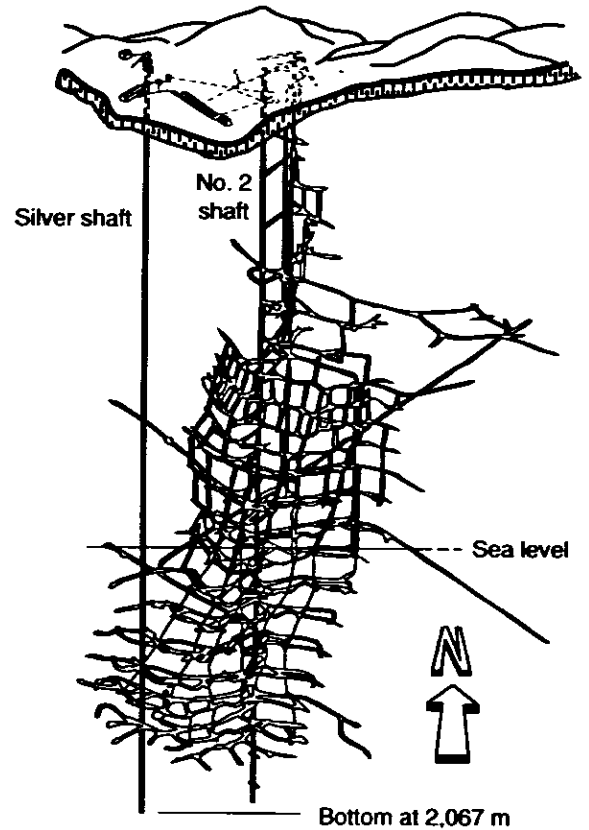

Figure 1.—Typical deep mine shaft system.

and lead to improvements in detection of and remediation measures for ore pass blockages.

STATEMENT OF THE PROBLEM

According to Mine Safety and Health Administration (MSHA) data, many of the shaft- and ore-pass-related accidents in the United States are associated with the hoisting and loading-unloading cycle. Using MSHA accident reports (1989), SRC researchers determined that personnel located in areas related to muck and materials loading and unloading were particularly susceptible to injury or death. For example, a common occurrence is water inundation or muck hang-up in a loading pocket or ore pass. Several fatalities have occurred recently in the United States and Canada because of the sudden inrush of water and muck into these structures. In addition,

recent structural failures of ore passes have underlined the lack of ore pass design capabilities and standards available to both mine engineers and MSHA enforcement staff.

Hoist and elevator machinery must meet the requirements specified in the Code of Federal Regulations (CFR), Parts 57 and 75. MSHA has been reluctant to require new safeguards and accept new design criteria for hoists and ore passes without fully developed technology. Hoist equipment manufacturing companies cannot justify expenditures to develop new technology. The mining industry cannot interrupt production to conduct research in vertical haulageways.

An evaluation of safety features for hoists and ore passes, existing safety standards, and current monitoring and control systems and sensors was conducted (Barkand and Helfrich, 1988; Cseff and others, 1981; Farley and others, 1983; Loynes, 1976). It was concluded that current technology should be assessed, and sensors for determining conveyance loads, slack and tight rope, conveyance position, and ore pass and chute monitoring needed to be developed. For example, existing commercially available systems for slack rope detection range in price from $50,000 to $250,000 and are largely customized to be site specific. Therefore, less expensive systems are needed.

Research tasks now being conducted include—

1. Development of computer models to analyze design and muck flow in ore passes to identify potential safety problems and additional targets for research.
2. Identification of hoisting parameters to be monitored and modification or development of new sensors and data acquisition and transmission capabilities.
3. Development of graphical user interfaces to visualize the hoisting process.
4. Laboratory and field evaluations and transfer of technology to industry and MSHA.

SHAFT AND ORE PASS FACILITY

A computer simulation of the research facility was developed to conceptualize layouts in which all the features of the test facility and preliminary concepts of key sensor technology could be assessed. The computer simulation (figure 2) provided a tool to allow researchers to visualize the hoisting process by animating the hoist components and the sequence of operations.
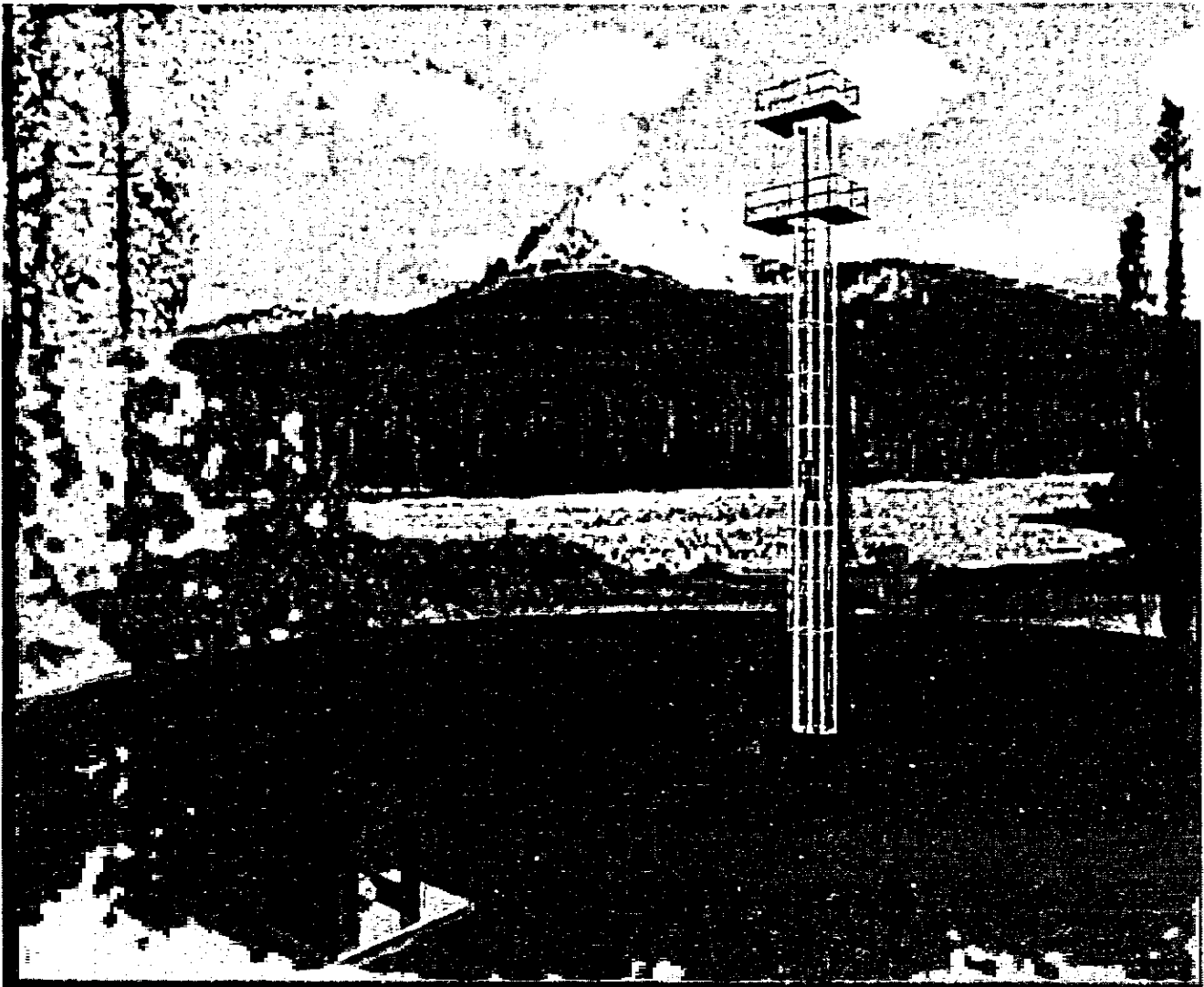

Figure 2.—Computer simulation of testing facility.

This permitted delineation of target areas that might be of special concern and allowed various test scenarios to be considered by altering designs and operating parameters.

Figure 3 shows components of the closed-loop mine shaft and ore pass testing facility. The ore pass is simulated by 30.5-
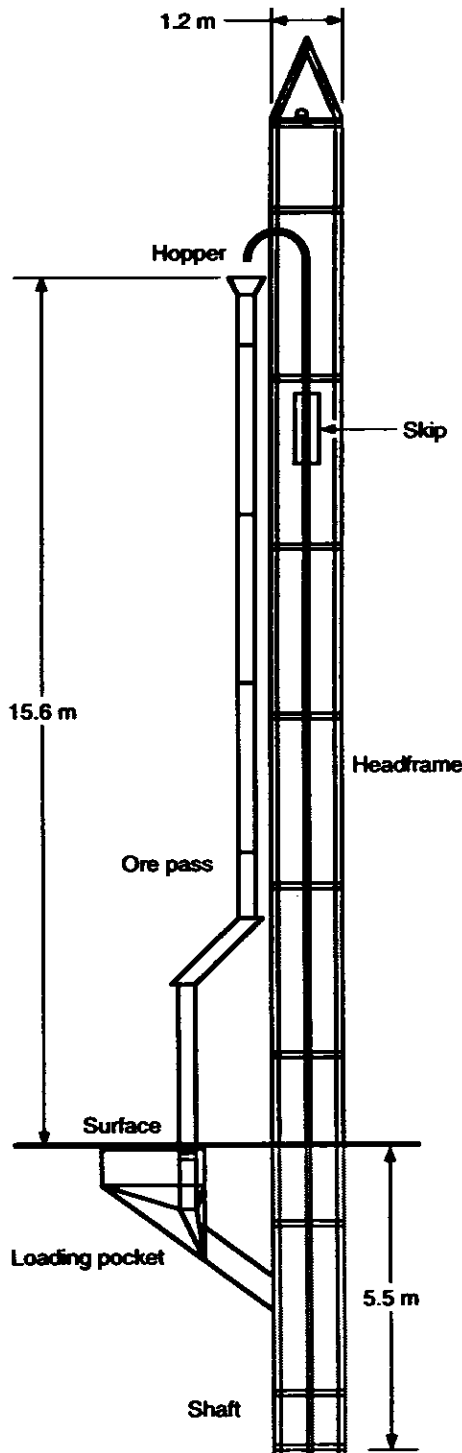
by 30.5-cm by 15.6-m (12- by 12-in by 51.3-ft) long steel sections. It contains two 45° doglegs and is constructed in 3-m (10-ft) long removable sections. The removable sections will allow researchers to change configuration and inclination. A bypass on the lower section allows ore to be cleaned out of the pass and discharged on the ground. Ore is initially loaded through a ground-level grizzly into a gated, below-ground discharge chute and loading cartridge, and then into the skip. The loading cartridge is equipped with balancing load cells to monitor the net weight of material in the cartridge prior to its discharge into the skip. Weight detected by these cells in relation to loading gate position controls skip loading functions. The skip hoists the ore to the top of the headframe, where it is dumped into a hopper connected to the top of the ore pass. The ore is gravity-fed down the ore pass into the below-ground discharge chute, completing the closed loop.

The hoist room components (figure 4) include a winding drum and gearbox, a motor-gearbox interface, a braking system, and a 37-kW (50-hp) dc motor. The electric motor is used to drive the hoist drum. A 6-to-1 gear reduction is achieved with a Rex planet gear speed reducer. An additional speed reduction of 2-to-1 is achieved through a chain drive at the drum. The hoist drum is 76 cm (30 in) in diameter and has a capacity of 152 m (500 ft) of 9.5-mm (3/8-in) diam wire rope. The total system was designed for 227- to 254-kg (500- to 1,000-lb) hoisting capability over 24 m (80 ft). The 18.3-m (60-ft) hoist tower (figure 5) and 20-cm (8-in) diam sheave wheel assembly includes a shaft skip conveyance. The shaft is 5.5 m (18 ft) deep (figure 6) and is lined with concrete sections.
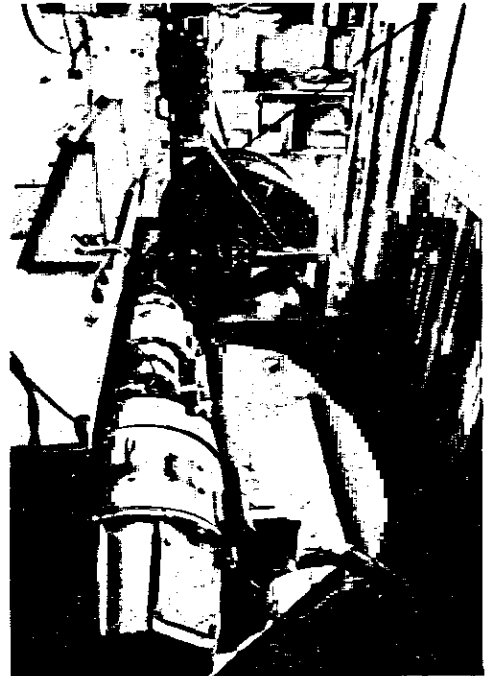

Figure 3.—Closed-loop hoisting system.

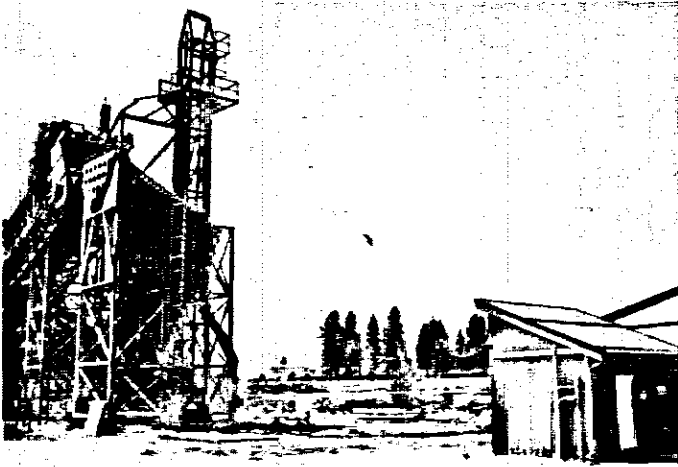Figure 4.—Hoist room components, including dc motor, gearbox, and winding drum.
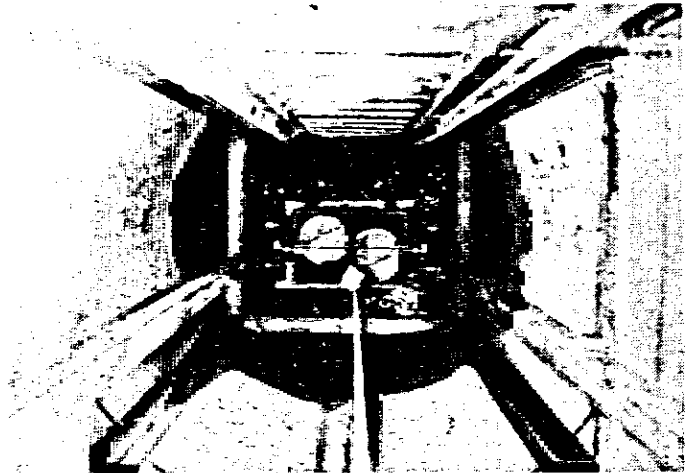
Figure 5.—Hoist tower and headframe.

Figure 6.—Downshaft portion with loading pocket.

HOIST CONTROL

A state-of-the-art, computer-based system controls the hoisting motor, ore chute gates, and related hoisting functions. Hoisting and loading operations can either be controlled manually or the system can be allowed to cycle automatically through the loading, hoisting, and dumping process. Motor control is achieved with a Saftronics DCM-series motor controller (figure 7). The control functions are performed by a

Figure 7.—Motor controller.

16-bit microprocessor. Control parameters are entered on a keypad and stored in electrically erasable, programmable, read-only memory (EEPROM). An RS485 serial interface is also available for inputing control parameters and monitoring outputs with a personal computer (PC). An automatic tuning procedure is run with no load during setup and provides feedback parameters for precise motor control.

Control functions possible with the motor controller include run, stop, motor direction, and motor speed. The run and stop controls are defined by adjustable velocity profiles, as shown in figure 8. Two separate maximum motor speeds are used, depending on the skip's position in the shaft. Figure 8 shows the first velocity profile with the maximum motor speed of 400 rpm. This speed is used while the skip is traveling between stations. As the skip approaches the loading or dumping station, a second maximum speed reference, or creep speed, is used. A maximum motor speed of 50 rpm is used in these areas to position the skip at the station. Two limit switches are mounted near the top of the shaft and two near the bottom. The limit switches are momentarily closed as the skip passes, which activates the appropriate maximum motor speed (400 or 50 rpm) or stops the skip at the station.
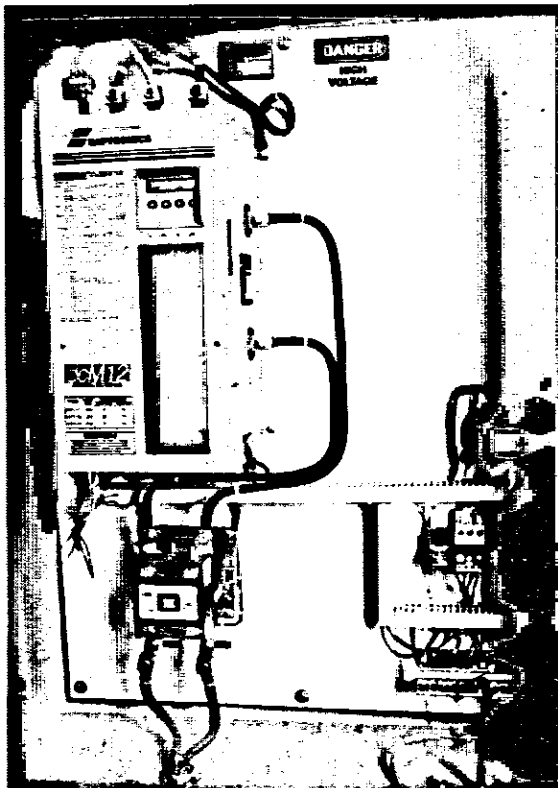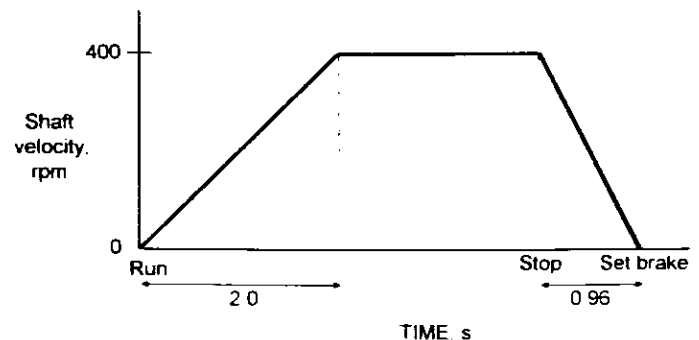

Figure 8.—Speed curve for winder motor.

An electric brake system manufactured by Warner Electric was installed on the motor shaft. While the regenerative capabilities of the dc motor are sufficient to stop the full skip, the brake system provides a positive and safer method of stopping. Brake control is achieved through a Warner Electric torque-adjustable brake controller. The brake provides a maximum static torque at a input voltage of 90 V dc, which is provided by the controller. When the stop button is activated, the motor begins ramping down; however, the braking action is delayed for the duration of the ramp-down before the brake is set.

Motor speed feedback is achieved with a Rotopulser encoder and a Dynapar frequency-to-voltage converter. These units function as a tachometer at a greatly reduced cost when compared to purchasing a conventional tachometer generator. The encoder consists of induction proximity sensors that sense the teeth of a shaft-mounted gear. The resulting output signal is a square wave with variable frequency. This signal is converted to analog voltage by the frequency-to-voltage converter, which provides +10 to -10 V proportional to motor shaft speed and direction. This signal can then be used by the motor controller for speed feedback control.

Further automation concepts are being studied using Windows-based human-machine interface (HMI) software and programmable controller technology. This expands the amount of automatic control functions possible for the hoist. A GE Fanuc series 90-30 programmable logic controller (PLC) runs the logic for both manual and automatic operation. Wonderware's Intouch HMI software is used to provide the operator interface. This software runs under Windows 3.11 on
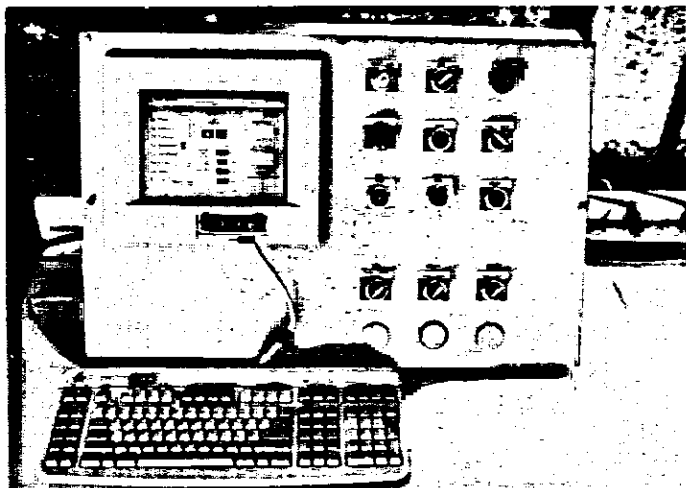
an industrial 486 DX touch-screen computer (figure 9). A control panel is currently set up to provide the operator interface for operating the hoist manually. The panel consists of speed-control potentiometers, hoist motor controls, valve controls for the loading gates, and a flat-panel, touch-screen computer to run the HMI software.

Figure 10 shows the main control screen for the hoisting system. All sensor inputs and PLC outputs can be monitored from this screen. Hoist operation can also be controlled from the screen; however, the hardwired buttons on the control panel override any command given from the touch-screen computer. Real-time graphs are used to monitor and record values such as rope load and skip position, as shown in the upper right of the screen in figure 10. These graphs are easily set up and are especially useful for evaluating the most effective sensor types and configurations. For example, optical encoders are mounted on the hoisting drum and on the skip to determine the position of the skip in the shaft. These sensor values are recorded to aid in determining the effects of rope stretch and other errors that may occur in sensing the skip's position.

Detailed views of the hoisting and ore-loading process can be accessed from the main control screen. For example, pressing "Show Ore Pocket" brings up the ore pocket screen, as shown in figure 11. Operation of the loading chutes and gates, ore levels and loads in the bin, and conveyance net weight loads can all be viewed from this screen.

Automatic operation of the hoisting, dumping, and loading processes is controlled by a ladder-logic program in the PLC. In automatic mode, the status of the process can be viewed on the left side of the main control screen. Automatic operation allows the system to cycle through the loading, hoisting, and dumping processes without manual intervention. In the future, this research will focus on a safety assessment of the sensor systems and control system design.

A back-up Lilly controller is also installed on the hoist system (figure 12). Lilly controllers have been the standard mechanical control devices for mine hoist installations since the early 1900's. They operate as skip position indicators and stop the winding drums and apply brakes in the event of overspeed and overtravel. A centrifugal governor is driven in synchronization with the hoist drum to track the speed of the skip. A pair of cams moves in proportion to skip position and trips a limit switch to turn the motor off automatically and set the brake if an overtravel condition is reached. The Simplex model Lilly control system was installed at the facility to study possible interaction and retrofitting of automated electronic controls on systems typically seen at mining operations.
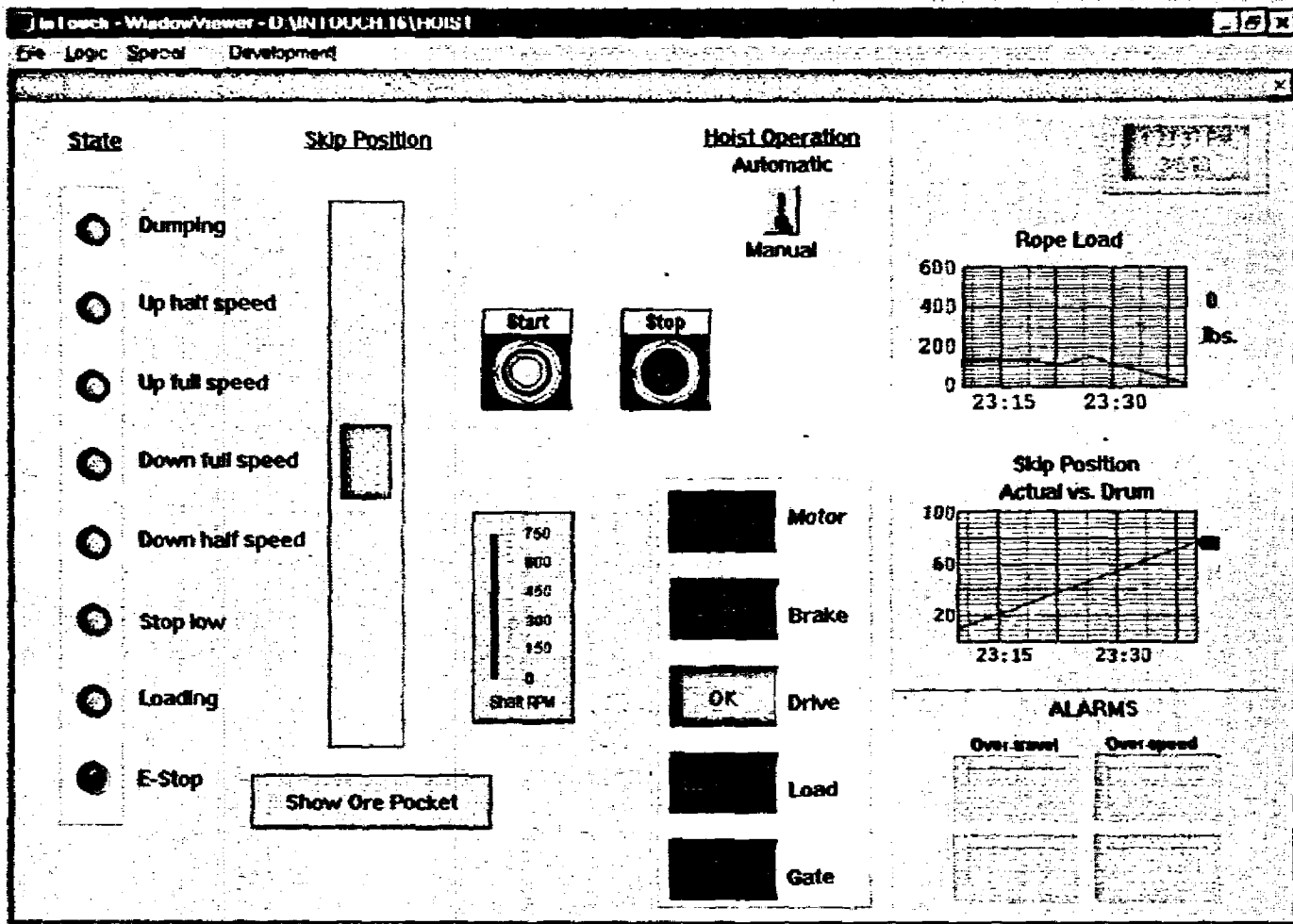

Figure 9.—Control panel.

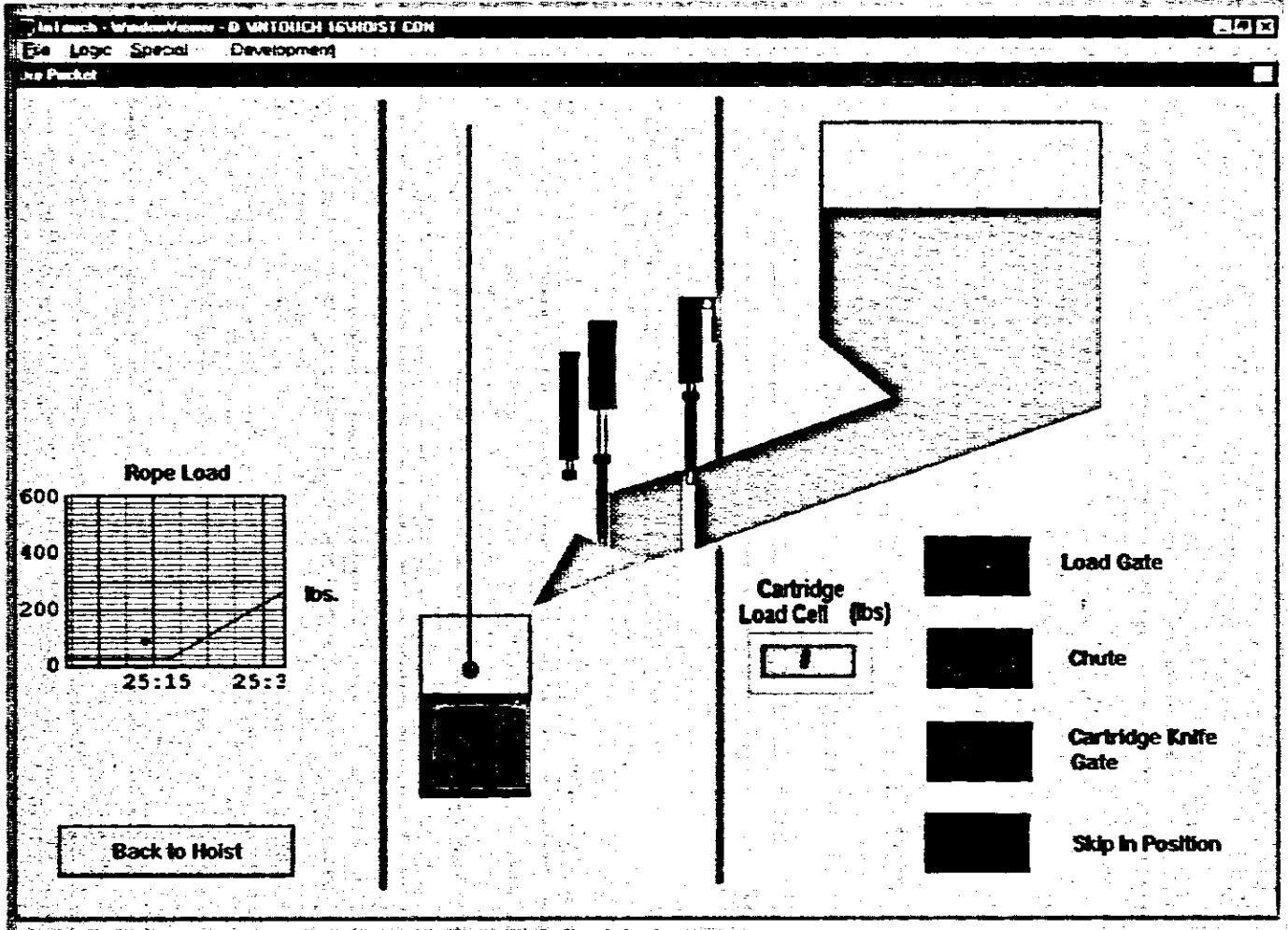Figure 10.—Main hoist control screen.

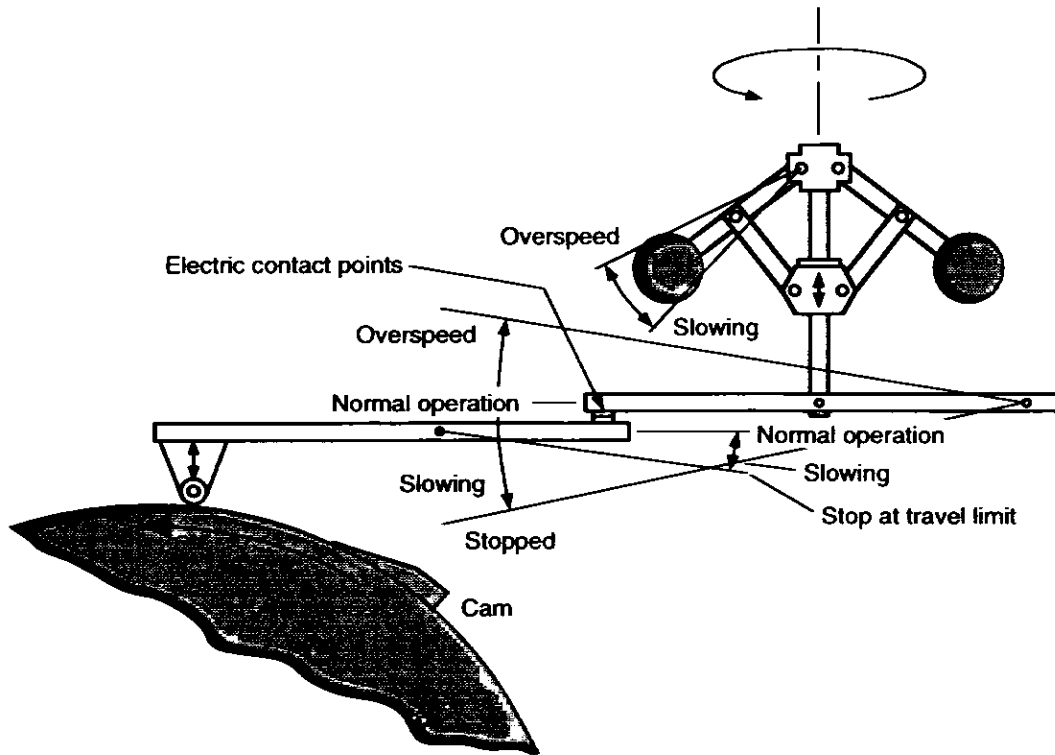Figure 11.—Ore pocket monitoring screen.

Figure 12.—Lilly controller.

CONVEYANCE MONITORING

The development of improved shaft conveyance monitoring systems has focused on the determination of conveyance position, velocity, acceleration, load, wire rope tension, and guide displacement. A position sensor on the conveyance eliminates the need to correct the position of the conveyance because of rope stretch. Conveyance load monitoring protects against slack and tight rope conditions. Measurement of guide displacement can warn of possible slack and tight rope conditions.

Various sensors for monitoring skip or cage position and hoist velocity and acceleration have been tested. For example, on-board ultrasonic and radar-based speed and distance detectors developed for the agricultural industry have been evaluated for determining the position of a skip in a shaft. However, preliminary results indicate that these devices are not sensitive enough to allow accurate positioning, and their response time is insufficient to allow proper control.

An innovative concept called a hoist and shaft conveyance monitoring system (HASCOMS) was developed. This system detects wire rope tension, slack and tight rope, conveyance load, hoist and elevator position, and hoistway guide rail mis-alignment. It consists of two components: the sensor package and the data acquisition and transmission package. The sensor package includes an optical encoder, a rotary potentiometer, thermistor temperature detectors, and a conveyance load sensor.

The key component is the newly developed conveyance load sensor, termed a "flex-cable"[3] load cell (figure 13). A unique design feature allows conveyance weight to be determined independently of the wire rope load path by measuring beam-bending strains resulting from the normal load component of hoist cable tension. The flex-cable load cell is designed to develop a slight curvature in the wire rope at a null load. As the wire rope is tensioned, normal force components develop, resulting in corresponding bending strains at the midpoint of the cell body. The curvature at either end is realigned with the initial unflexed alignment of the wire rope to eliminate wire rope stress concentrations that may develop at entry and exit points. The design principle is based on the theory of elasticity for a distributed line load across and normal to the transverse center of a beam supported at each end. Crosby clips, which are commonly used for wire rope terminations, clamp the load cell to the wire rope at one end, provide the required offset at midpoint, and allow slip at the other end. The design minimizes flexural strain in the wire rope during loading and unloading cycles so as not to compromise its ultimate strength and working life, and yet generates enough flex to provide the required output. Figure 14 illustrates the operating principles.

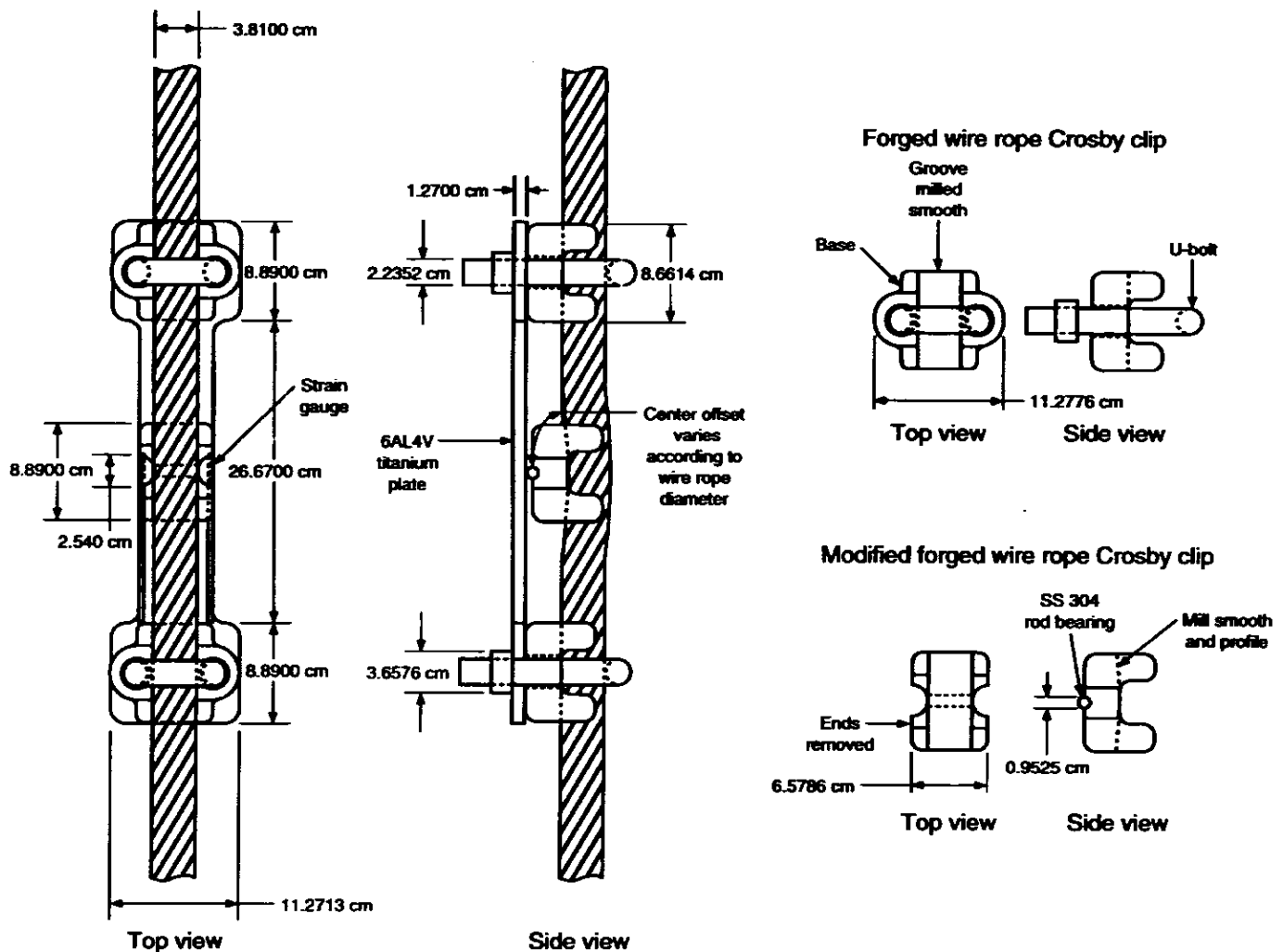[3]Patent applied for as "Cable Load-Sensing Device," MIN/PGH-9603.

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Figure 13.—Design of flex-cable load sensor for 3.8-cm (1-1/2-in) diam wire rope.

The flex-cable load cell is packaged to withstand the rigors of long-term, unattended underground operation and to survive the unusually hazardous conditions of underground hoisting operations. Such conditions include limited access and cramped space; hot, humid, and corrosive atmospheres; water and falling rock and debris; and shock loads from blasting. It is immune to electromagnetic interference and repeated hoisting cycle temperature extremes that may range between -47°C (-50 °F) and +53 °C (+120 °F). It is simple and fast to install and relatively maintenance free. Encapsulation provides electrical insulation, high impact and mechanical shock resistance, and minimal sensitivity to thermal extremes.

A custom-designed data acquisition and transmission package (figure 15) used in conjunction with the HASCOMS includes a battery-operated, microcomputer-controlled signal processing board (SPB), a 2.4-GHz, spread-spectrum radio modem, and a 12-V battery. The SPB was custom designed to meet the requirements of this specific application. The package

dynamically monitors and processes data from six analog channels and one digital channel and provides optically isolated serial data output. The SPB is linked to the 2,400-baud radio modem for data telemetry from the moving conveyance to the hoist machinery room. The data transmission rate is 100 m/s or 10 scans per second. For a conveyance traveling at 183 m/min or 2.05 m/s (600 ft/min or 10 ft/s), this sampling rate provides load and position data for every 300 cm (1 ft) of conveyance travel.

A secondary RS232 serial port on the SPB transfers data to a portable computer or terminal on the conveyance itself (figure 16). The 12-bit analog sensor input transmits information as unsigned, four-character hexadecimal values ranging from 0000H to 1FFEH (0000 to 8190 decimal). An 8-bit analog channel transmits information from the potentiometer, encoder, and thermistors as unsigned, two-character hexadecimal values over a range of 00H to FFH (000 to 512 decimal). The encoder data represent the number of rotations of the encoder wheel
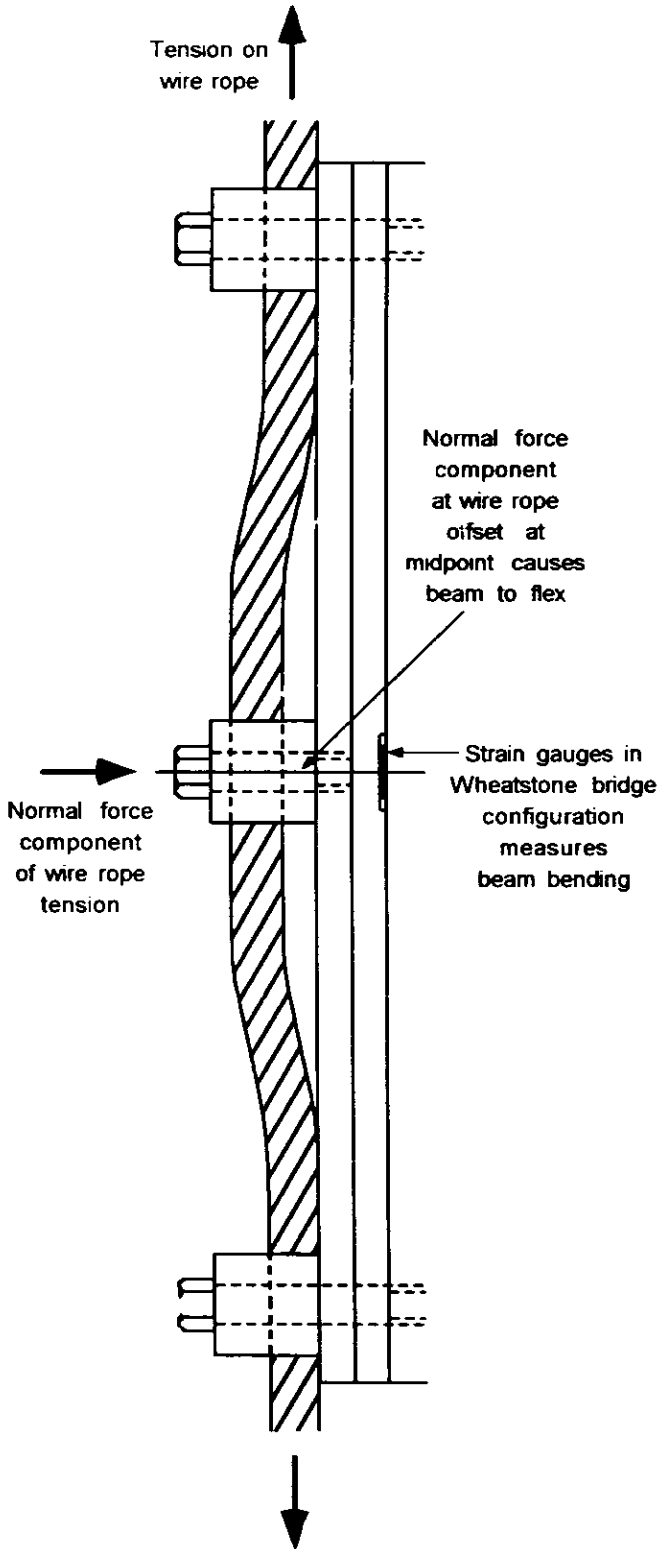
since transmission of the last encoder count. The SPB, the flex-cable load cell, and the remaining sensors on the hoist cable and the hoist conveyance or elevator car are designed for ease of installation and maintenance and minimal interference with hoisting functions. Also being tested is a new concept to charge batteries with an on-board wind-charging system driven from the mine ventilation air stream.
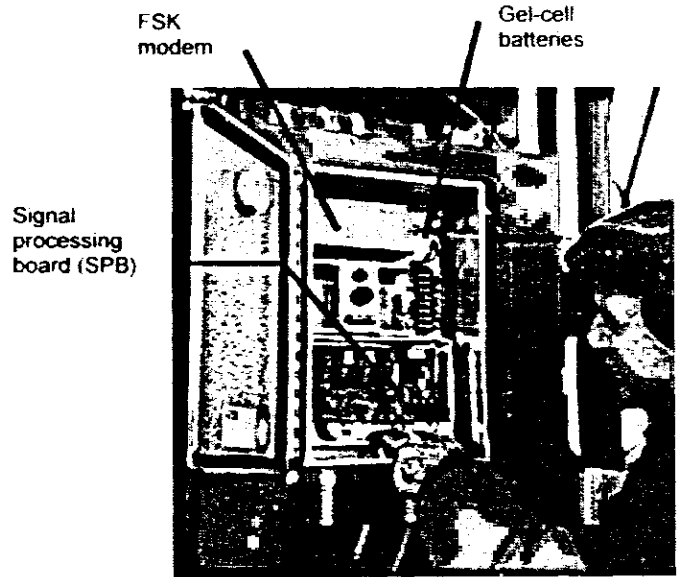

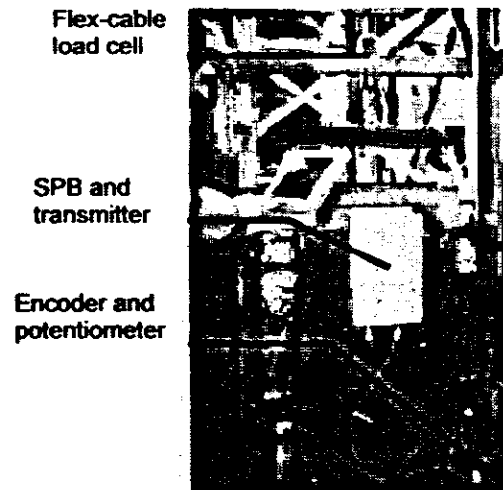Figure 15.—Signal processing board, battery pack, and radio modem.

Figure 16.—HASCOMS showing use of laptop computer for direct data acquisition from conveyance system.

Figure 14.—Operating principles for flex-cable load cell.

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SUMMARY

Hoist and elevator systems for underground metal/nonmetal mines and coal mines must meet the requirements specified in the Code of Federal Regulations. Nonetheless, MSHA inspections and accident reports show that many mine hoist and ore pass accidents have occurred because of electrical, mechanical, and structural failures, despite the requirement for periodic testing of the equipment.

Current technology to enhance safety and control features for mine hoists was assessed and new approaches for ore pass design are being developed. Various components of mine hoisting and elevator systems were evaluated, including hoisting machinery (hoise room controls, motors and gearboxes, and winders) and shaft infrastructrue (support frameworks, guides, wire ropes, and skips and cages). Progress to date has resulted in completion of a state-of-the-art hoisting and ore pass research facility. Sensors and real-time data acquisition interfaces to monitor hoisting operations have been developed. The hoisting test facility and the monitoring system allow personnel to assess critical hoist operating parameters such as conveyance position, conveyance speed and acceleration, load, rope tension, and shaft guide misalignment. In addition, efforts are focused on investigating the causes of ore pass blockages and ensuring safer operations by detecting the locations of blockages and improving hang-up removal methods.

The major benefit arising from this research will be the prevention of numerous injuries and fatalities related to hoisting and ore pass operations. With improved monitoring and control technology and the integration of this function into a broader framework of hoisting and ore pass process control, research will enable miners to be removed from hazardous locations within the hoisting and ore pass infrastructure and improve the safety of the workplace.

ACKNOWLEDGMENTS

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