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Monitoring and Process Simulation of Shaft Construction and Operation

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ABSTRACT

A data acquisition and monitoring system developed, packaged, and field tested by the U.S. Bureau of Mines for a deep mine shaft is described. This system provides process information to mine supervisors and shaft operators. An in-mine sensor package monitors the rock mass and support in deep mine hoisting operations. The sensors are based on linear and rotary potentiometers, platinum resistance temperature detectors (PRT), strain gauge load cells, and quarter-bridge strain circuitry. Data are acquired through a distributed network of intelligent measurement pods (IMPS) connected to an interface card and a personal computer (PC). The system scans the sensors at a predetermined rate (up to 600 scans per second) and provides real-time trend plots, process graphics, and a spreadsheet of the current data set. Data are transmitted via short- and long-haul modems to PC's for detailed analysis and plotting. The system is low cost, efficient, and reliable, and it is currently being integrated with shaft ore handling and hoisting process sensing, supervision, and control.

INTRODUCTION

A recent survey of the Canadian mining industry (Pathak and Udd, 1990) listed ground control and ground conditioning equipment as the No. 1 candidates for mine automation. Automating ground conditioning equipment for functions such as scaling, bolting, grouting, and shotcreting is well underway. However, sensing and processing rock mass and support data, which are prerequisites to controlling these operations, are poorly developed. The objective of the present research is to monitor and assess the condition of the rock mass and the supports around critical mine accessways. A secondary objective is to simulate the hoisting process for real-time operator interface and control. By integrating this latter function into a broader framework of shaft process control and overall mine automation, research may lead to increased production and productivity, lower costs, and improvements in health and safety.

Certain mine openings are more crucial to the operation of a mine than others. One such structure is the mine shaft, which is used for access to an ore body when preparing for recovery of a resource and for production hoisting once the shaft is in service (Figure 1). Since the shaft is literally the lifeline of a mine, it must be particularly well designed and provide for a long service life. In addition, shaft construction and maintenance functions are among the most hazardous and costly in all of mining.

Efficient ore hoisting is a key to maintaining or increasing production. Integrated centralized monitoring and control of the total hoisting function is the ultimate goal. However, ground control and a "shaft condition" system that monitors the state of a shaft are prerequisites. Both construction activities and in-service operations need to be closely monitored. Real-time visualization of this entire process could provide an operator with a desktop tool for control of construction and hoisting operations.

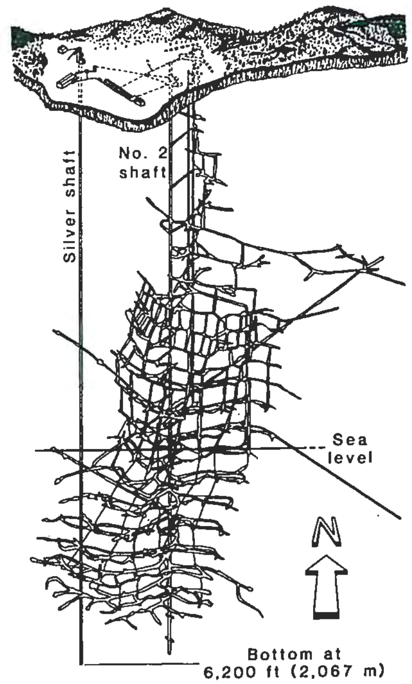

Figure 1. Deep mine shafts access the ore body and provide production hoisting in service.

SYSTEM DESCRIPTION

Personal Computer/Data Acquisition System

The major component of a mine monitoring system is obviously the processor/ data acquisition system. There is considerable research effort, both within the Bureau and by industry, directed toward automating mine monitoring and process control. However, previous developments in mine monitoring systems have often not met the requirements of cost effectiveness, sensor diversity, or simplicity and ruggedness for withstanding the rigors of underground, long-term, unattended operation.

The Bureau has done extensive work in developing and testing environment-proof, cost-effective sensors and computerized data systems for use in deep hard rock mines (Whyatt and Hardin, 1986). The basic components of one such system are shown in Figure 2. The system is centered around a DOS-based PC housed in a protective enclosure interfaced to IMPS, which can provide I/O, signal conditioning and A/D conversion for up to 20 channels. The IMPS are inherently protected from the environment and require no further packaging. The network can extend up to 1 km from the PC. Communication is via short haul and high-speed (9600 baud) modems to remote terminals. Figure 3 shows the overall layout for a typical shaft monitoring system with both surface-collared and internal shafts.

An off-the-shelf motherboard-type PC is used if factory conditions can be maintained. A passive backplane computer housed in a air-to-air heat exchanger NEMA IV box is used in highly corrosive sulfide mines. The passive backplane allows fast, easy replacement of the board-level computer as well as enhances environmental protection. A self-contained mine-proof DOS-based PC, modified and configured as a mine data acquisition system (DAS) for humid, very hot or very cold mine environments has evolved. Currently being investigated for cost-effectiveness and reliability is a 80386 PC minitower nested in a stainless steel housing.

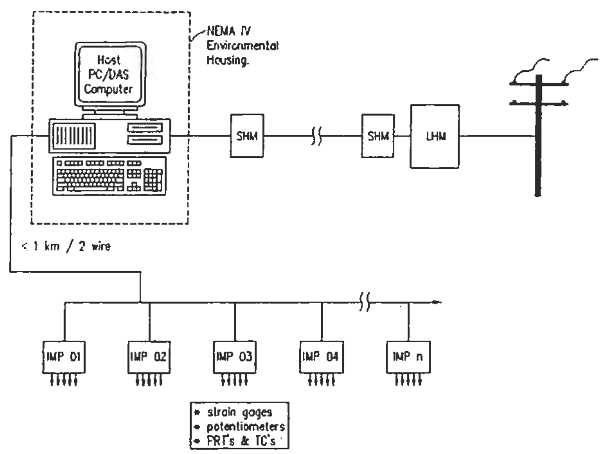

Figure 2. Schematic layout of a PC/DAS interfaced to in-mine sensors and modem access.

Sensors

The second major component of monitoring and control systems is in-mine sensors. Sensors must be designed for the unusually hazardous conditions of underground operations, including installation in hot, humid, and corrosive atmospheres, water, falling rock and debris, and shock loads from blasting. Most importantly is that the system must be cheap, simple and fast to install, and durable over long periods of time.

Monitoring rock movement is the most important aspect of sensing. The preferred design for sensing rock movement uses linear potentiometers linked to four to eight individually anchored sensing locations down the length of a borehole 3.5 cm (1-3/8 in) in diameter. The mounting head provides for in-hole adjustments to accommodate an infinite range of rock movement. In addition, the device is recoverable upon completion of work or abandonment of the site. The location, orientation, and depth and size of installation holes are impor-

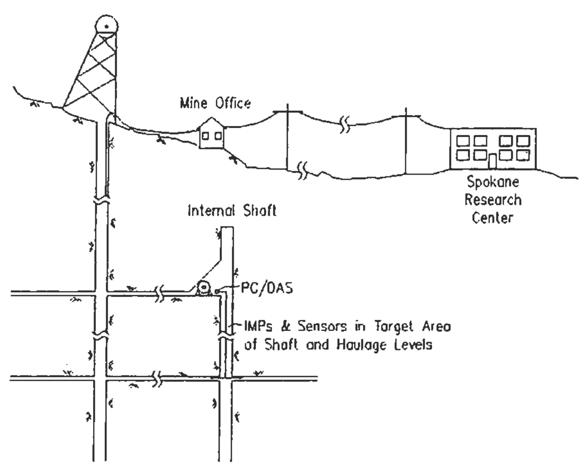

Figure 3. Overall layout for a typical shaft monitoring system.

tant, although economics often dictates how many holes can be drilled. Other basic types of ground condition sensors include timber and bolt load cells, rotary potentiometers for structural deformation measurements on shaft sets, and blast and temperature detectors. These will be discussed in more detail in the case studies.

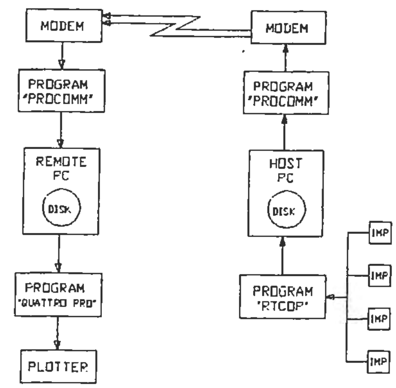

Figure 4. A flowsheet of major hardware and software components.

Software

The Bureau has done extensive work in developing and testing procedures for processing and visualizing output from ground-condition sensors. For the results to be useful, the data must be available in real time. Real time has been defined in a broad sense as "the amount of time sufficient to make decisions." For example, by monitoring ground movement and liner loads during shaft sinking, design decisions are made daily by construction supervisors. Therefore, data must be available within minutes or hours of the activity. Real-time monitoring of ground response to actual mining and natural forces such as high stress can vary from seconds to days or even years. In the case of rock bursting, instantaneous results are required. In deep mines experiencing heavy ground and rock creep, data must be accumulated and assessed over periods of months or years in order to arrive at design decisions or activate ground control measures. In any case, decision-making obviously depends on the scope of the process being controlled and can vary from a few milliseconds to days or weeks.

The key to real-time operations with operator interface and programmable logic controllers (PLC) is the processing and communication software. PC-based DOS software has been used exclusively because of its availability and because there is a large base of experienced users. The applications run in both the background and foreground and as subroutines to general purpose communication and spreadsheet programs. The core of the software is RTM[1] (Micro Specialties Systems, 1987), a real-time data acquisition extension to DOS.

The data can be displayed in a variety of formats, including a row by column spreadsheet, bar graphs, trend graphs, and alarm summaries. The coprocessor can be left operating in the background, which permits other programs, such as a communications package, to be operated in the foreground. This program is left in host mode waiting for an incoming call from a remote computer to download data files. Figure 4 shows the major hardware and software components of the system.

[1]Reference to specific equipment or trade names does not imply endorsement by the Bureau of Mines.

CASE STUDIES

Lucky Friday Mine and Caladay Mine

Deep shafts at these two mines in northern Idaho were monitored to provide construction data during sinking (Beus and Board, 1984). The data provided shaft sinking personnel with warnings of impending hazardous conditions and guidelines for sinking and shaft support. Based on a real-time assessment of the data, adjustments could be made in excavation rate, drilling patterns to control overbreak and concrete thickness, opening shape, sequencing of liner and bolt installation, and cycle adjustments. With these data, liner safety factors and thicknesses could be controlled over selected segments of the shaft. When coupled with a structural analysis, the data also served as a tool for validating automated design procedures.

Homestake Mine and Sunshine Mine

Deep shafts in service are subject to long-term effects from rock mass creep and block falls from nearby mining. Monitoring instruments in the Homestake Mine in South Dakota and the Sunshine Mine in northern Idaho provide warnings of potential instabilities from nearby shaft pillar recovery operations and indicate shaft maintenance requirements. At stake is the recovery of significant resources of gold, silver, copper, and antimony. Automated monitoring is required because a large number of sensors must be installed, the time needed to evaluate the data completely and alter the mining process is lengthy, and obtaining adequate data in the shaft environment is difficult. For example, over 100 sensors (79 linear displacement transducers, six temperature detectors, one humidity detector, six flat compression load cells, six rock bolt load cells, and weldable strain gauges on steel set members) have been installed at the Homestake Mine. Control sensors were also installed to verify the reliability of the overall system. Trends show the effects of shaft pillar removal over a 3-year period, illustrating the importance of long-term reliability.

The field test at the Sunshine Mine determined if shaft repair measures to correct damage from nearby mining was adequate. It was envisioned that advance warnings of potential hazardous conditions could result in more timely maintenance scheduling and ultimately control over hoisting speeds. Figure 5 shows shaft distortion from rotary string potentiometers measuring diagonal distortion in the timber shaft set.

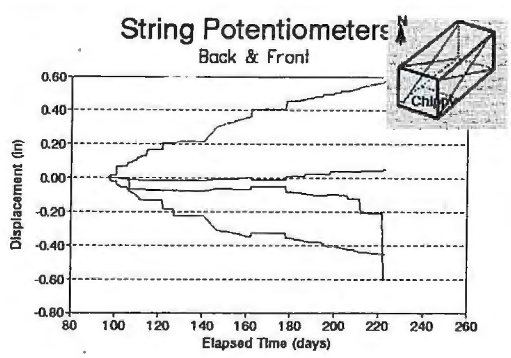

Figure 5. String potentiometers measure the diagonal distortion in a timber shaft set.

To investigate the potential for integrated graphic simulation and process control with rock condition sensing, the complete shaft hoisting and material handling process must be fully understood. The hoist is basically a conveyance consisting of a skip or cage traveling between selected loading and unloading stations. Its primary function is to convey miners and materials. Skip and cage operations consist of personnel riding, materials hoisting, long load slinging, and shaft examination. The approach to developing a simulation of these processes is based on the RTM process-graphics package.

Figure 6 shows a general graphics screen of the overall hoist section, including stations and loading pockets. Conveyance position sensors locate the cage or skip in the shaft section. A personnel sensor traffic light lets the hoist operator know if the cage is occupied. Cage position is also indicated by an analog meter similar to the analog indicator in the hoist room. The trend of conveyance speed is given as a graph in feet per minute with alarms for overspeed; rope load is given as a bar graph in percent of allowable maximums.

Selected subprocesses can be enlarged and scrolled onto the screen for more detail. For example, as the skip approaches a loading pocket, an

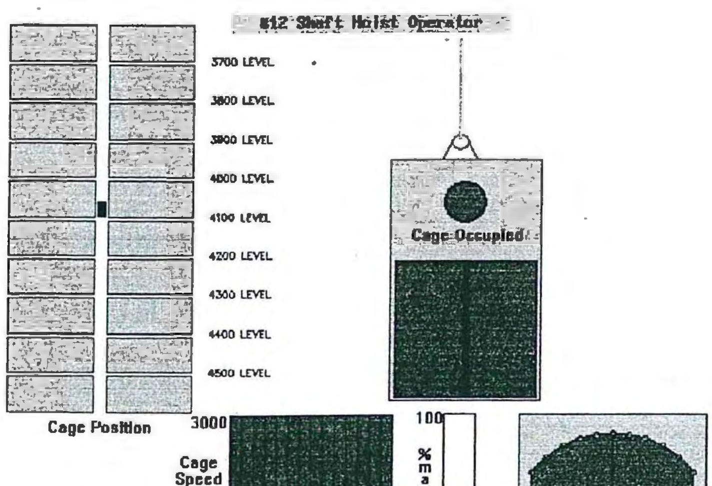

Figure 6. Schematic of a vertical section of the shaft as simulated on a graphics screen.

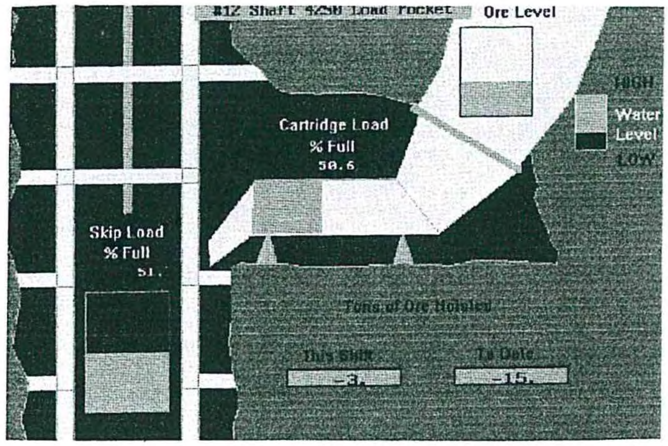

Figure 7. Detailed process graphics of the skip/loading station.

appropriately detailed screen graphic would appear. Figure 7 shows loading pocket components, that is, skip, muck cartridge, storage bin, and muck chute doors, and the fill condition of the various containers. In addition, the graphic could be used as a hoist production indicator. A separate water level indicator with appropriate alarm levels is also shown, since water buildup in the muck chute is a particularly hazardous condition.

The biggest problem in integrating mine production processes and natural environmental processes such as rock movement is the time over which they occur. Natural processes can be either continual or intermittent. They can respond to and affect production processes over very short intervals (rock bursts, rockfalls, subsidence) or long periods (rock creep). In order to display this information as a process graphic, it is necessary to be able to gather and process large amounts of data at different rates and present the information in a format suitable for operator action or automated process control.

In the case of shaft ground condition sensing, it is obviously desirable to simulate operator interface at the same time normal hoisting functions are being controlled automatically. Figure 8 shows a screen graphic of set loads in a squeezing area of the shaft, where long-term load data are combined with load trends over 15-s intervals and updated on 1-s intervals. In conjunction with this screen, time trends of rope load and conveyance speed are also shown to indicate the effects of ground squeezing on a tight compartment. Other options include set distortion and ground deformation.

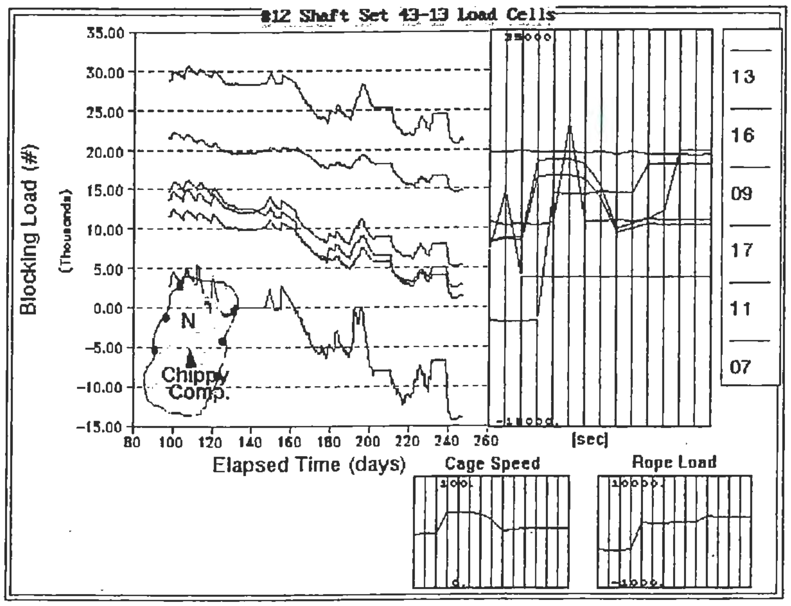

Figure 8. Process simulation of timber set long- and short-term load trends.

CONCLUSIONS

Process monitoring provides supervisors and operators with remote monitoring capabilities, potentially eliminating several of the most hazardous duties in deep mine hoisting. The automation of many of these processes is fairly straightforward; in fact, many shafts have already instituted various levels of sensing and automation. However, shaft ground conditions often have a direct influence on hoisting or mining processes. By combining short- and long-term ground-condition sensing into an overall shaft automation scheme, significant benefits could be realized.

Both short- and long-term trends are readily apparent in the field studies at the Lucky Friday and Caladay Mines. These results verify the capability of gathering and processing a lot of data from comprehensive mine field tests on both a real-time and a long-term basis. By monitoring ground movement during shaft sinking, adjustments can be made in excavation rate, drilling patterns, design factors, shape, sequencing of liner and bolt installation, and cycles.

At the Homestake and Sunshine mines, sensors showed long-term effects, particularly creep, from nearby mining and shaft pillar removal. Continual maintenance, especially where faults or vein structures cross, is required.

The hoisting process can be optimized with real-time information about rock mass deformation, and set loads and distortion information can be integrated with conveyance operating parameters.

Other effects that should be investigated in the future are:

1. Shaft conveyance speed control based on long- and short-term rock mass deformation and support loads.

2. Maintenance scheduling based on coupled rock mass and set distortion data.

3. Evaluation of hoisting and production efficiency based on net skip loads in conjunction with information about slack or tight ropes and set deformation conditions.

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