Chapter 28

A CONTROL SYSTEM FOR ROOF DRILLING

by

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ABSTRACT

The U.S. Bureau of Mines is conducting research with the goal of automating underground coal mine roof bolters for greater mine safety. In the project described here, the Bureau has focused on automating the drilling portion of the drilling and bolting cycle. A drill monitoring system designed and developed by Parvus Corp. of Salt Lake City, UT, was placed on a Bureau model roof-bolting drill. The drilling parameters of torque, thrust, rotation rate, penetration rate, and position are monitored through sensors connected to an asynchronous, control-oriented local area network (LAN) that communicates with data-accumulating and data-processing nodes. By placing microprocessors at the two data nodes and at the valve control nodes, and combining these nodes with a personal computer (PC), the monitoring and control system can achieve parallel processing capabilities. Such capabilities are referred to as locally intelligent distributed processing. Only data that have changed significantly are reported through the LAN to a supervisory control and data acquisition (SCADA) system mounted on an IBM-compatible 80286 PC. The SCADA system displays the values of the drilling parameters and calculates the specific energy of drilling, which is then used as an indicator of the type of rock being drilled. Besides monitoring the drilling process, an operator at the computer can control the rotation and thrust of the drill from a remote location through the SCADA program and can set drilling parameters on the basis of observed values of the specific energy of drilling.

INTRODUCTION

Roof bolts are placed in underground coal mine roofs to prevent layers within the rock from separating and falling. The process of bolting involves drilling holes into the roof strata and inserting mechanical or resin-grouted bolts.

The U.S. Bureau of Mines is conducting research to develop an underground roof bolter that can be controlled from a remote location. A necessary part of this effort is to establish automatic control of the drilling operation, which will improve drill penetration rate, increase bit life, and allow real-time decisions to be made concerning the best hole depth for good anchorage.

To determine the best hole depth, the roof rock strata and any anomalous conditions in the rock must be identified. An experienced roof bolter operator can often tell by the feel of the drill and by observing the rock response to drilling whether layers, fractures, and voids are present, as well as the hardness and type of material being drilled. By using instruments mounted on the roof-bolting machine, this sense of feel can be expanded to obtain more precise information about conditions in the immediate roof strata. Specifically, the drilling parameters of torque, thrust, rotation rate, penetration rate, and drill bit position in the hole are monitored, and from this information, the specific energy of drilling can be calculated. This information can then be analyzed with a computer to predict rock type and potential hazards.

MODEL DRILL

Bureau researchers have been using a manually controlled model roof drill to drill concrete blocks and test roof bolt anchors. This drill, shown in Figure 1, consists of a standard-sized roof bolter mounted on a mast. The drill is powered by a portable hydraulic power pack. A hydraulic cylinder applies thrust to the drill head. Direction and flow control valves can be used for manual control, or the drill can be controlled from a personal computer (PC). The system is provided with emergency shutdown and manual override capabilities and handles for manual control of rotation and thrust.

The automatic hydraulic system for the model drill (Figure 2) was designed by Rory McLaren and Assoc., built by Fluidics, and instrumented by Parvus Corp.,* all located in Salt Lake City, UT.

*References to specific products or companies does not imply endorsement by the U.S. Bureau of Mines.

For data acquisition, an external bus system was chosen that can communicate with almost any computer via a RS-232 port. An external system was chosen rather than an internal PC board for several reasons. Virtually any size of system can be configured; the data acquisition and control system can be placed in a location some distance from the host computer, which means that it can be close to the field signals; it is possible to off-load some of the data collection tasks from the host computer; and the data acquisition system can be interfaced to virtually any type of computer. The data acquisition and control hardware consists of an assortment of modules ranging from nodes, communication devices, direct I/O devices, and test devices. These modules are grouped together into strings.

Network Protocol

The parvNET network, made by Parvus Corp., was selected as the heart of the communications system among data accumulating nodes, data processing nodes, and the PC. This system is a serial, asynchronous, token-passing, control-oriented, local area network (LAN) and can communicate with the PC over a standard RS-232 port.** ParvNET consists of fairly simple hardware with complex, yet robust, software. Because the hardware design is simple and relies on software to handle application complexity, the physical size of the hardware is much smaller (a module is 2-1/2 in wide by 3-1/2 in long by 1-1/2 in tall) than conventional systems; it does not require special or costly interface components, and it can fit in a small package

**ParvNET uses a standard UART-based NRZ serial stream with start bits, data bits, and stop bits. ParvNET is serial-medium-independent. It can run on fiber-optic, RS-232, RE-422, RS-485, FM, alternating current carrier, and infrared media. The network has a capacity of 1,000 packet stack size; 16-byte data portion packet length; up to 38,400 serial baud rate; serial driver interface; three to five character delays per node; 1 ms clock resolution; and exception, timed, and polled packet transmission.

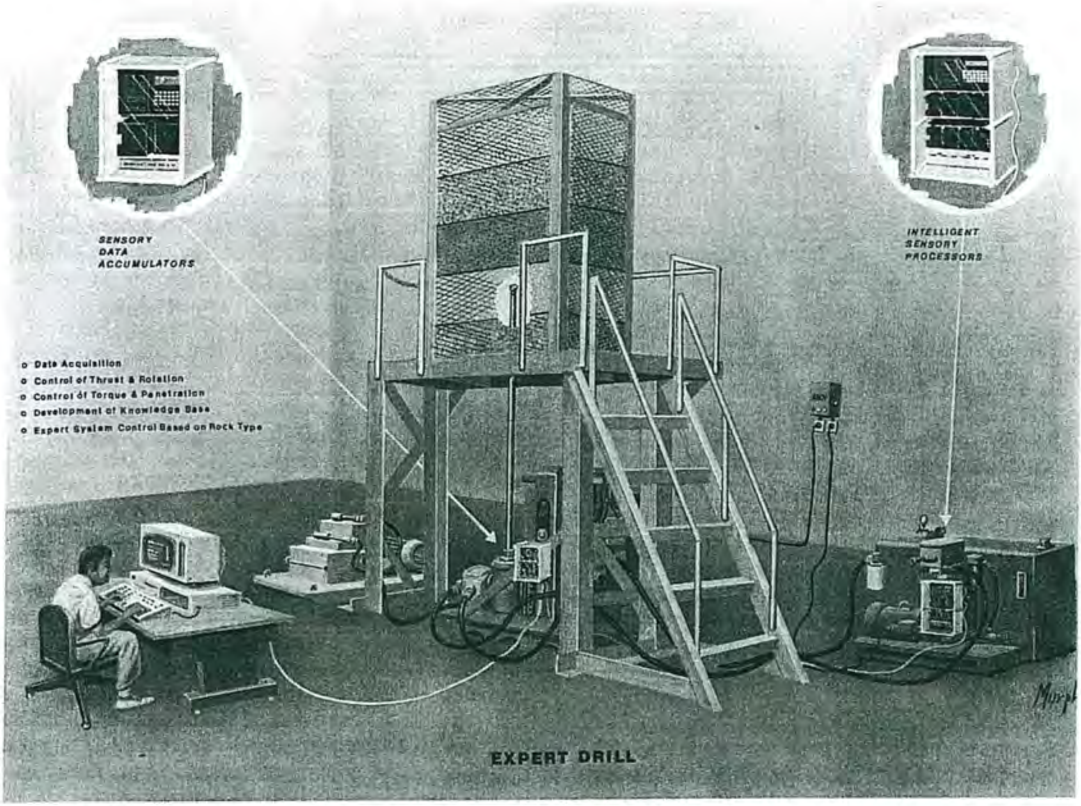

Figure 1. Artist's sketch of the expert drill.

on the model roof drill. This system reduces the complexity and overall cost of the installation while increasing functionality, throughput, and reliability. ParvNET is a processor-independent network protocol, and it has been ported to all major central processing units.

The parvNET network uses a technique called I/O decoupling, which can be best defined as background, interrupt-driven, re-entrant data processing that receives information and stores it in predefined locations in memory. ParvNET itself resides in what is called the background because it is not continuously running. It waits for an interrupt or exception transmission from the application program to begin. The application program is executed in the foreground. Because parvNET is self contained, it can be re-entrant, meaning it can re-enter itself at any time and keep track of where it is through the use of an internal monitor.

ParvNET is written in Assembly language in a modular, table-driven fashion, which refers to how the parvNET memory map is used for immediate data storage and recall within the parvNET application. The memory map is set up in a grid or matrix with the memory address divided into columns and rows. The corresponding location in the table of a particular address holds the actual value of that location in memory. All parvNET values are confined by the table itself.

A token frame is a left and right bracket, '[]'. The one shown would be referred to as an empty token frame. A

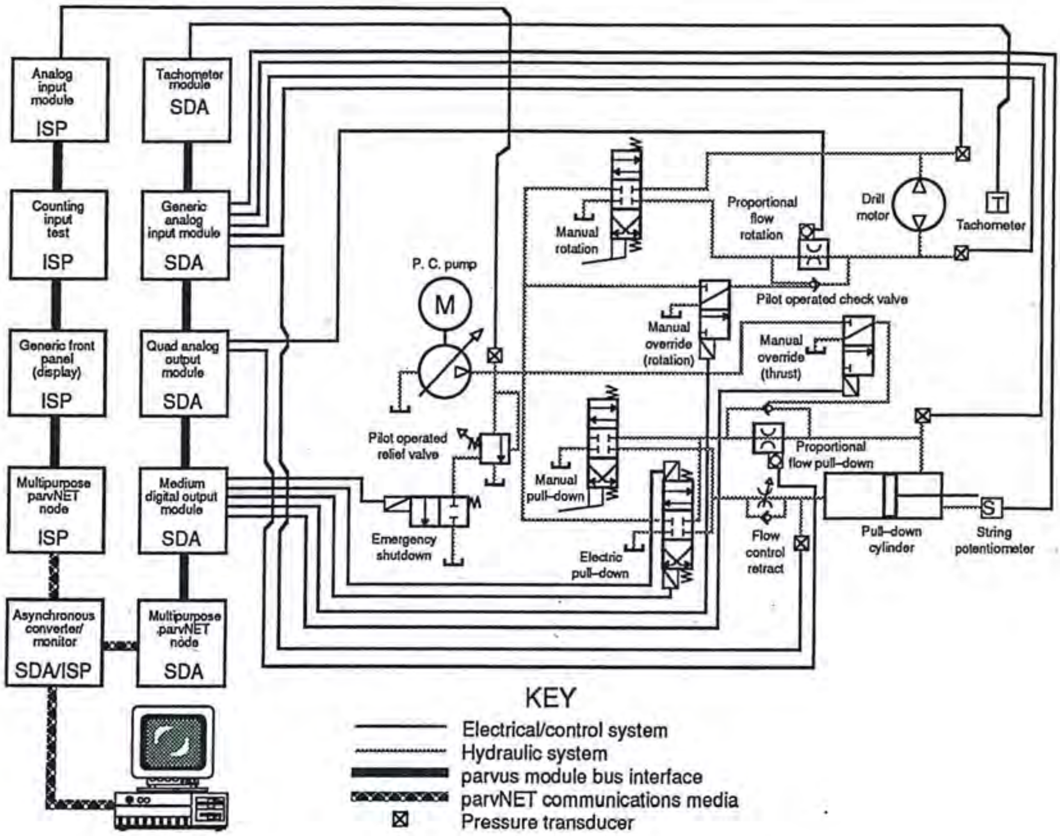

Figure 2. Electrical and hydraulic schematic of expert drill.

packet exists when the token frame carries information; an example is [:000089C008000]. The information within the packet can be represented in ASCII hex or binary format. A packet contains the source address, destination address, packet type, packet data, packet flag, register address, packet length, and data byte count. Token frames are used for data flow control, and start and end tokens are used to frame valid packet transmissions. All transmissions that occur outside of a token frame are discarded. Packets from the token string are presented in serial fashion to all valid network devices. The network's control communications protocol permits peer-to-peer, network-to-host, and host-to-network communication through standard serial ports.

A PC drives network protocol by acting as a master node. A dedicated PC can be directly connected to the network loop to provide immediate access to control and monitoring data. No hardware protocol conversion is necessary because available PC-based software drivers are used.

By including source information, a system hierarchy can be established that gives the nodes interrupt power and includes system level assignments. Such assignments would allow processors to respond only to certain source codes, regardless of the information. The destination information in a packet allows the receiver to not only respond to the packet, but also to consume the packet, which cuts down network traffic. The network also can be used to diagnose whether a receiver node has obtained data because a packet sent to a specific receiver would return it to the sender if no processor with the assigned destination were present. A packet that makes it all the way around the network would be consumed by the originator so as to remove instructions from the network for nodes that are not present. By operating on a closed-loop, token-ring network, all processors can add or remove packets from the network, and any incorrect packet will be consumed by the first processor encountered, which also decreases network traffic. Including the length of the packet with each transmission ensures that all instructions are received and carried out. The check sum ensures that the data are intact and correct.

With these network protocols and communications now set up, node modules, analog and digital input monitoring modules, and various other monitoring and control modules can be connected. Modules will be linked in a daisy-chained structure using a module bus. With this architecture, it is much easier to attach sensors to the monitoring modules, which will allow communication to the control modules.

NETWORK NODES

By placing processors at data nodes and at the valve control nodes in combination with the PC's processor, the monitoring and control systems have a parallel processing capability referred to as "locally intelligent distributed processing." Reliable local intelligence is the key to effective, distributed, node-based processing in industrial or other harsh environments. Each node on the Bureau's model drill has a processor, the Motorola MC68HC11, as well as a module bus interface with the capability of addressing up to eight I/O intelligent modules (with processors) or nonintelligent modules (without processors). This makes a total of nine processors per node that could be available for local intelligent distributed processing at the drill.

This distributed processing capability makes the system respond more quickly while lowering the communication bandwidth and PC speed required. Consequently, there are fewer processes going on at the main processor at the PC, allowing the PC more error-detection capabilities. These nodes are the intelligent link between the system host (PC) and a variety of analog and digital I/O modules via the module bus. The nodes containing processors will perform the initial sensory analysis and pass on data when changes occur through the token-passing network to the PC, which is running a supervisory control and data acquisition (SCADA) program. This sequence will reduce the processing burden on the PC. After receiving instructions from the PC, each node will run independently of the main processor at the PC and other nodes, while transferring any needed data back to the computer.

SENSORY DATA ACCUMULATOR STRING

The model roof bolter has four data accumulators attached to it that measure revolutions per minute (rpm) of the drill head, height of the drill head, and the hydraulic pressures used to rotate and raise the drill head. These four parameters are all that are needed to control rpm, thrust, and rate of penetration independently, and allow applied torque to be calculated. The physical location of the sensory data accumulators is shown in Figure 1. By doing a global timed command, all of the sensors on the drill can receive data at the same time. It takes a few seconds to transmit the data, but all data have a corresponding time tag associated with them.

The network for the model drill is divided into two strings of modules: sensory data accumulators and intelligent sensory processors. The sensory data accumulator string (Figure 2) contains the tachometer module, the generic analog input module, the valve driver module, the medium digital output modules, a multipurpose parvNET node, and the asynchronous converter/monitor node.

The signal from the rotating drill steel is detected and then amplified and converted to rpm by the tachometer module. The rpm sensing is done with a magnetically coupled field sensor that can detect the presence or absence of metal. This sensor is manufactured by Prestolite and uses 12-V dc power. A permanent magnet built into the sensor provides a magnetic field at the base of the sensor. As each hole of the rotating sensor disc passes through the magnetic field, a signal (voltage spike) is produced. The drill head was modified for this sensor by drilling eight holes on the rotating portion with 45° spacings.

The generic analog input module reads the in-port and out-port fluid pressures for the hydraulic motor used to rotate the drill steel, as well as the in-port and out-port pressures of the hydraulic cylinder used to raise and lower the drill head. The position of the drill head is read from the string potentiometer and is sent to the analog input module. By attaching one end to the base of the bolter and the other end to the drill head, the height of the head can be determined. This is a linear potentiometer, so direct processing of the output can be scaled to a height of feet or meters. Penetration rate is then calculated by the multipurpose node as a function of the change of position over time.

The hydraulic pressure differential across the motor is used to calculate drill torque. The torque applied to the drill head is calculated differentially across the input and output of the hydraulic spin unit using model EA PSIG pressure transducers manufactured by Data Instruments, Inc. Using ground and +12-V dc for input, the transducer produces a proportional output voltage scaled to a psig reading. By subtracting the output from the input pressure and multiplying by the flow rate, the mechanical power is obtained. Flow rate is derived from the pressure differentials and known constants using the formula

$$T = \text{power} * 30/(\text{rpm} * \pi) \qquad (1)$$

where T = torque applied to drill head and power = mechanical power.

Calculation of torque is performed in the SCADA software described later.

The hydraulic pressure differential across the cylinder is used to calculate the drill thrust. The thrust of the drill head is measured using the same type of pressure transducers used to measure torque. By subtracting the output from the input, the upward thrust of the drill head can be determined.

Two valve driver modules (custom quad analog voltage output modules) control rotation rate and thrust on the drill head. Currently, commands from the PC operator can hold these parameters constant. For example, the proportional flow control valves can be controlled using feedback from an rpm sensor that maintains constant rpm or from a thrust sensor that maintains constant thrust. The valve driver modules are used to modulate the hydraulic motor and cylinder pressures through the use of proportional-flow control valves. Each control node contains a watchdog timer that will automatically shut down the system if communications to the node are broken. This is accomplished by sending out a clock pulse every 500 msec to the node. If this pulse is no longer present, the node will quickly shut down the valve. The amount of time required to release the hydraulic pressure after shutdown will depend on the current operating pressures, but the times will be on the order of seconds. All network information, including the watchdog timer information, is sent via packet format. The watchdog function exists at node, network, and application levels. Watchdog information is generated both by the network and internally.

The two proportional control valves on the drill system are manufactured by Continental Hydraulics. System flow enters the inlet port and is directed to the main spool and the pilot stage. The pilot stage consists of a pressure-compensating spool, a fixed pilot-flow-control orifice, and a variable pilot-pressure-control orifice. The pilot-pressure-control orifice is controlled by a variable dc signal applied to the axial force motor and results in a variable control pressure that acts on one end of the main spool. A counterforce is applied to the other end of the spool by the counterbalance spring.

A change in the dc signal changes the size of the pilot-pressure-control orifice. As the orifice size decreases or increases, the pilot pressure increases or decreases and unbalances the spool. The spool will shift until a new balance is established, resulting in a new preset flow rate.

These valves are intrinsically safe because loss of power to the valve will cause the fluid output to be shut off. With only three moving parts, these valves have a high level of tolerance to contamination, which is good for working in harsh environments such as where drilling operations take place. The proportional-control valves are attached to a module bus interface via the valve driver module linked to the PC. Communications are sent to the valve nodes in control packets.

The medium digital output module is used to send five system commands: emergency shutdown, manual override for rotation, manual override for thrust, and cylinder up/down signals. A Continental electrically controlled directional valve allows computer-controlled raising and lowering of the drill head on the mast.

The multipurpose node on the sensory data accumulator string can accept and retransmit the parvNET protocol. The node contains a Motorola MC68HC11 processor, operates at 8 MHz, and contains RAM for data memory, EEPROM for permanent memory, EPROM for program memory, 1 serial port, 32 digital I/O lines, and 8 analog channels. A parvNET shell is provided for communication and application-specific register management. The module bus interface has the capacity of a 1 kHz scanning rate, up to 64 I/O points, and an 8-bit analog resolution on the node.

INTELLIGENT SENSORY PROCESSOR STRING

The intelligent sensory processors (ISP) are contained in a second string of four modules within the network (Figure 2). That string contains the ISP multipurpose parvNET module, a generic front panel, counting input test, and an analog input module connected on a module bus. A multipurpose node performs functions similar to those performed by the sensory data accumulator multipurpose node described above. The pressure can be displayed (along with any other network parameter) on the generic front panel. Pressure readings are routed to the PC for monitoring. The counting input test module allows testing before, during, and after installation of the logic of all input modules that use 16-bit values. The ISP analog input module is used to monitor hydraulic system pressures.

The asynchronous converter/monitor node (Figure 2) provides signal conversion between the RS-232 format, which is used in PC serial ports, and the RS-422 format, which is used in the multipurpose parvNET nodes. The RS-422 signals are carried on twisted-pair cables similar to telephone cords. From the asynchronous converter/monitor node, information is routed to the multipurpose nodes and the sensing and control modules used in the network. The modules communicate with each other and with the multipurpose nodes through a proprietary module bus.

Module Programming

The parvNET module programmer is DOS based and is used to program each module on the two parvNET strings: the sensory data accumulator string and the intelligent sensory processor string. By allowing these strings to talk to each other, the system becomes fully automated and ready for monitored operation. In addition to programming, the module programmer can monitor and display packets circulating on the network.

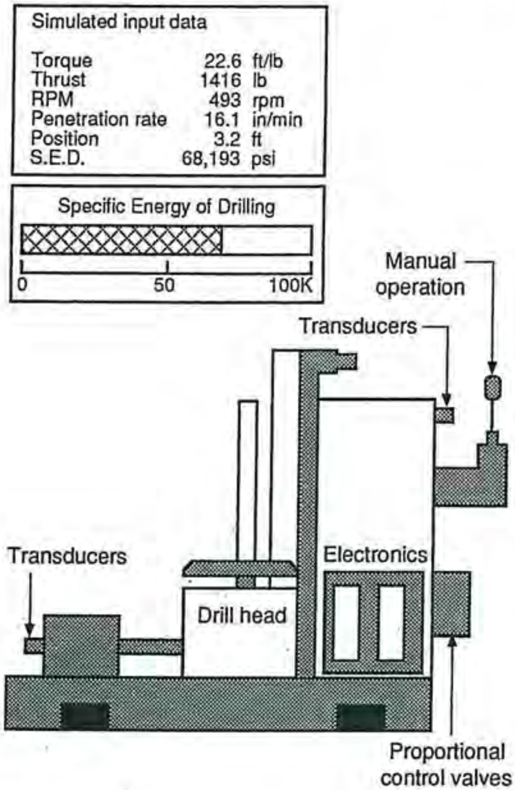

Figure 3. PC display of SCADA monitoring and control system.

SUPERVISORY CONTROL

Rotation rate and thrust are controlled on the PC acting as the master node. The user interacts with the parvNET system through a graphically oriented SCADA program that runs in the foreground with the parvNET terminate-and-stay-resident (TSR) network controller in the background. The SCADA program called Advantage was developed by the T.S.R. Corp. in Salt Lake City. A typical monitoring and control screen may include a block diagram of the system being monitored and controlled. Numbers, bar graphs, and trend plots provide a natural systems interaction environment (Figure 3). Information is transmitted to the network through the asynchronous converter/monitor node.

The SCADA software is a menu-driven program that allows users to write their own applications software. This program is written in FORTH, which is also suitable for data acquisition and analysis. Programming in this language matches that of the future RAM-resident expert shell, thus allowing compatibility and concurrent operation. The SCADA programming environment allows the user to create custom software that is fast, application specific, and yet adaptable to new uses. The SCADA program chosen includes the drivers necessary to provide the interface to the selected I/O hardware.

Because there are less than 64 monitored and controlled points on the model drill and because system-wide response times are in the range of hundreds of milliseconds, a less expensive SCADA program could be used. Reporting by exception, time-tagging to the millisecond, icon-based graphics, communications monitoring, alarm logging, database-controlled operations, historical information, and direct control are available. The SCADA program uses MS-DOS 3.x, a mouse, EGA graphics, and a multiuser, multitasking PolyFORTH-based kernel.

ROOF ROCK IDENTIFICATION

The Bureau is currently investigating four methods of identifying the type of material being drilled: specific energy of drilling, neural networks, fuzzy logic, and drill vibrations. As a first step, the Bureau plans on using specific energy to identify the type of rock in which a roof bolter is drilling (Howie and Frizzell, 1989). The formula for specific energy was developed by Teale (1965) and contains a thrust component and a rotation component as obtained from a rotary drill.

Specific energy of drilling = $(F/A) + (2*\pi*N*T)/A*u$ (2)

where F = thrust,
A = area of hole,
N = rotation rate,
T = torque,
and u = penetration rate.

SCADA contains the ability to perform calculations in real time using equations such as this. Specific energy output is presented as a bar chart. In future research, an expert system will use this information to optimize drilling parameters for the particular type of rock being drilled.

FUTURE CAPABILITIES

To achieve the objective of mechanized, intelligent, remote roof drilling, it will be necessary to control torque and penetration rate of the Bureau's model drill, build a knowledge base, implement an expert system program, and develop a corrective control scheme. Thus, using technology developed by Parvus Corp., a roof bolthole can be drilled automatically without an operator being present. Parvus is now conducting research on controlling torque and penetration rate on the model roof drill. Once this is accomplished, an expert system can be used to optimize drilling automatically in different types of rock without an operator being present.

One way to maximize drilling efficiency is to use an expert system that can optimize not only drilling to achieve maximum penetration rate, but can also extend drill bit life. By monitoring torque and penetration rate of the drill, the expert-system-controlled drill can automatically make adjustments to rotation rate and thrust based on preset rules of optimum combinations of torque, thrust, rotation rate, and penetration rate. These preset rules will be developed through experiments and taught to the expert system. The use of an expert system rather than an algorithm will give researchers the option of applying a fuzzy logic controller to the drill.

In addition to controlling drilling, once the rock type is known, the mine roof could be mapped and hazardous trends identified. Decisions could be made to increase bolt length or change bolt spacing, suggest that the operator take down bad roof, or recommend setting of timber supports. An expert system could command the system to drill roof boltholes to safe anchorage depths and spacings without an operator being present.

CONCLUSIONS

In the future, operator-assisted remote control will allow a roof drill to be operated remotely in hazardous, changing ground conditions. Besides removing the operator from roof-fall hazards during drilling, the drill's intelligent controller can improve bit penetration rate and bit life. A monitoring and control system for a model roof bolter drill has been developed. Torque, thrust, rotation rate, penetration rate, and position of the drill, and specific energy of drilling are sensed and/or calculated. A PC operator can control the rotation rate and thrust of the drill. Future applications of remote-control technology to roof drilling will reduce the number of roof-fall and industrial accidents in underground coal mines by removing an operator from hazardous areas.

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