Mobile Roof Support Load Rate Monitoring System

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Abstract—**Mobile roof support (MRS) machines are used as roof support during pillar recovery in retreat operations in lieu of wooden posts, cribs, or hydraulic props. A Mine Safety and Health Administration-permissible load rate monitoring system was developed for the MRS by researchers at the Spokane Research Laboratory of the National Institute for Occupational Safety and Health. The system uses a dedicated embedded processor to monitor changes in pressure inside the hydraulic cylinders of the MRS through multiplexed data acquisition channels and converts these pressure changes to load rates that sequentially activate three load-rate-indicator lights mounted on the machine. Each light represents a different loading rate to alert mine personnel to dangerous conditions during pillar extraction.**

I. Introduction

Mobile roof support (MRS) machines are used during pillar recovery in retreat coal mining operations in lieu of wooden posts, cribs, or hydraulic props (Fig. 1). These machines consist of a roof canopy, four hydraulic cylinders, a caving shield canopy, and associated electromechanical systems mounted on crawler tracks. Because they are very mobile and allow higher rates of resource recovery, they are currently being used in about 36 U.S. coal mines, as well as in a number of Australian mines [1].

One of the drawbacks with the MRS is its lack of a warning system that would alert miners to dangerous ground conditions during pillar removal. In the past, cracking and crying sounds emitted by wooden posts and visual observations of displacement and failure warned miners of dangerous loading conditions. Hydraulic supports such as used in an MRS provide little or no discernible audible or visual indications of impending roof caving. Therefore, miners have come to rely on the hydraulic dial gauges on the MRS, as well as indications of ground movement, to determine when to cease operations and remove themselves and equipment from the active mining face before a dangerous roof fall occurs. These gauges monitor pressure in the hydraulic cylinders of the MRS and often show a rapid increase in pressure when a roof failure is imminent.

However, these gauges are difficult to read and require that miners approach the MRS to see the gauges (Fig. 2), which brings them close to the active mining face. Not only is this area susceptible to roof falls, but mobile equipment poses additional safety risks. For these reasons, and because miners are often busy performing other work, the gauges are only checked periodically.

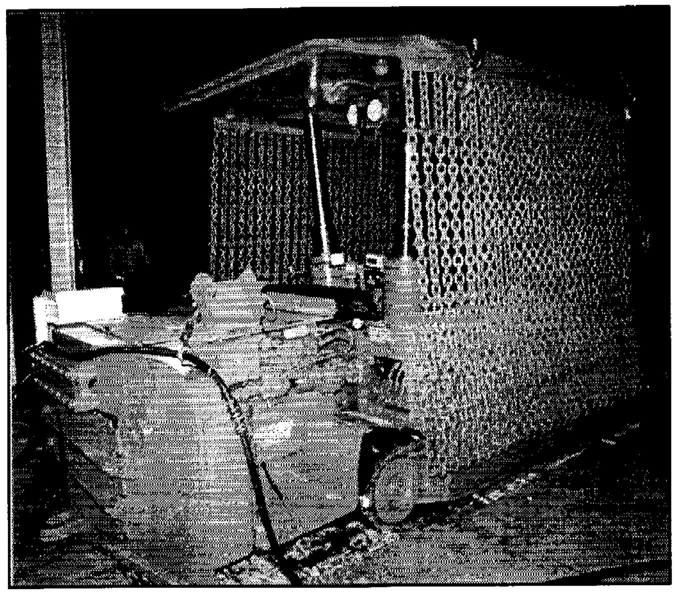

Fig. 1.—Mobile roof support machine

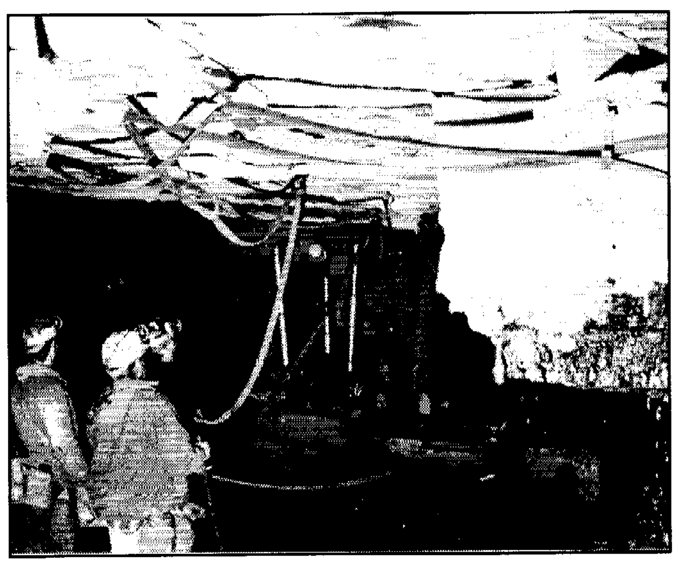

Fig. 2.—Pillar extraction using mobile roof supports

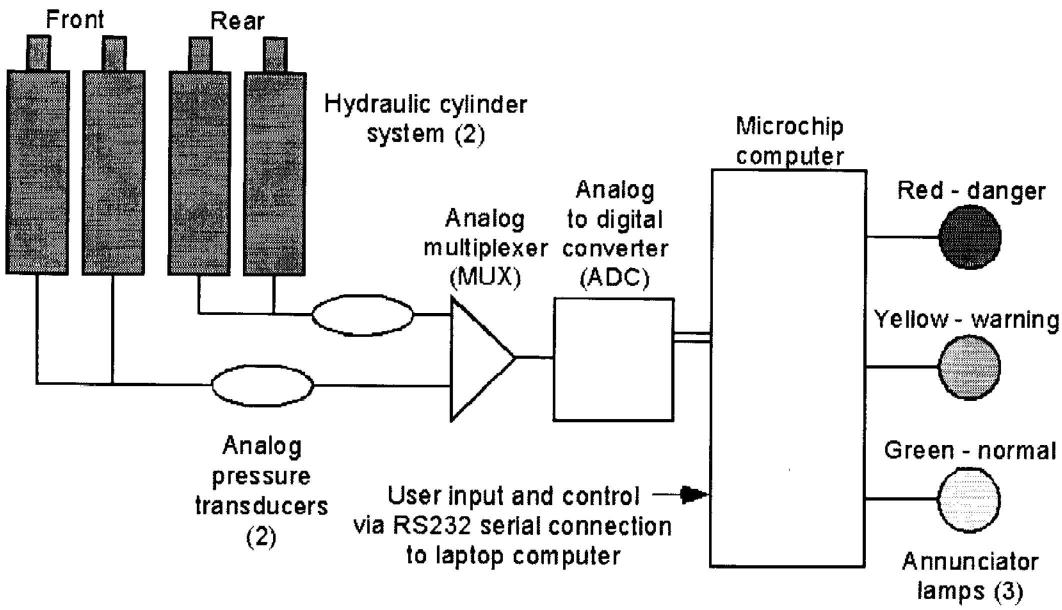

Fig. 3.—Diagram of load rate monitoring system

A load rate monitoring system was developed by personnel of the Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health (NIOSH) to track and display loading rates on an MRS in real time. Such a system installed on an MRS could warn of major events, such as failures of fenders and pillars that generally trigger roof falls. The system was designed to be seen easily by all miners in the vicinity of an MRS.

II. Load Rate Monitoring System

Fig. 3 is a block diagram of the load rate monitoring system. The system uses a dedicated embedded Micro-485 programmable controller to monitor pressure inside two hydraulic systems using standard analog pressure transducers (0 to 34.5 MPa). Pressure is translated by the transducer to an analog voltage of 0 to 5 V, transformed by the analog-to-digital converter to a 12-bit (0 to 4096 level) digital value, and sent to the embedded processor via its integral interface for processing. The controller is based on a highly integrated version of the world standard 8051 microcontroller family. It calculates loading rates using Assembly and C languages and controls output signals to the three load-rate indicator lamps. A socketed 80C51FA central processing unit (CPU) is ideally suited to the control and data acquisition requirements of the system. Fig. 4 shows the nonintrinsic components of the system installed in an electrical starter box located at the front of the MRS.

Loading on a hydraulic cylinder is proportional to internal pressure and surface area of the piston head and is determined by the formula

$$F = A \times P, \quad (1)$$

where F = force (N), A = area (m^2), and P = pressure (Pa).

The embedded processor reads changes in cylinder pressure through two multiplexed data acquisition channels of the controller and converts these pressure changes to load rates. Green, yellow, and red lights globe lights are activated as the load rate increases. Green indicates that there is minimal change in load rate on the MRS. Yellow indicates that the load rate is increasing and that additional caution is recommended. Red indicates a rapid load rate increase and that a roof fall may occur soon. A continuously flashing red light indicates that the hydraulic cylinder load is approaching the yield of the MRS and the unit may soon collapse. As shown in Fig. 5, these lights can be installed on the MRS canopy near the hydraulic pressure gauges. These lights can easily be seen at all viewing angles at a safe distance from the active mining area.

Other devices could be used to meet specific warning requirements for a mine operator or MRS manufacturer, including multicolor probes, LED's, or audible alarms. The system will operate as an integral part of an MRS. Operating parameters can be set prior to or during installation of the system or periodically as mine conditions change, but need not be done by operating personnel at the mine. Operating parameters are set by connecting the system to a laptop computer via an RS-232 null modem cable with the communication terminal emulator acting as the laptop client program. This allows a trained user to change parameters easily to trigger the various load rate indicator devices to suit geotechnical conditions at a mine.

At the request of a MRS manufacturer and mines using MRS's, a static load indicator feature was added to the main load rate monitoring system. The system is transformed into a static hydraulic pressure monitoring system by simply flipping a toggle switch to activate the static load program on the embedded processor. When the machine is operating in the static load mode, each light indicates a range of pressure set by

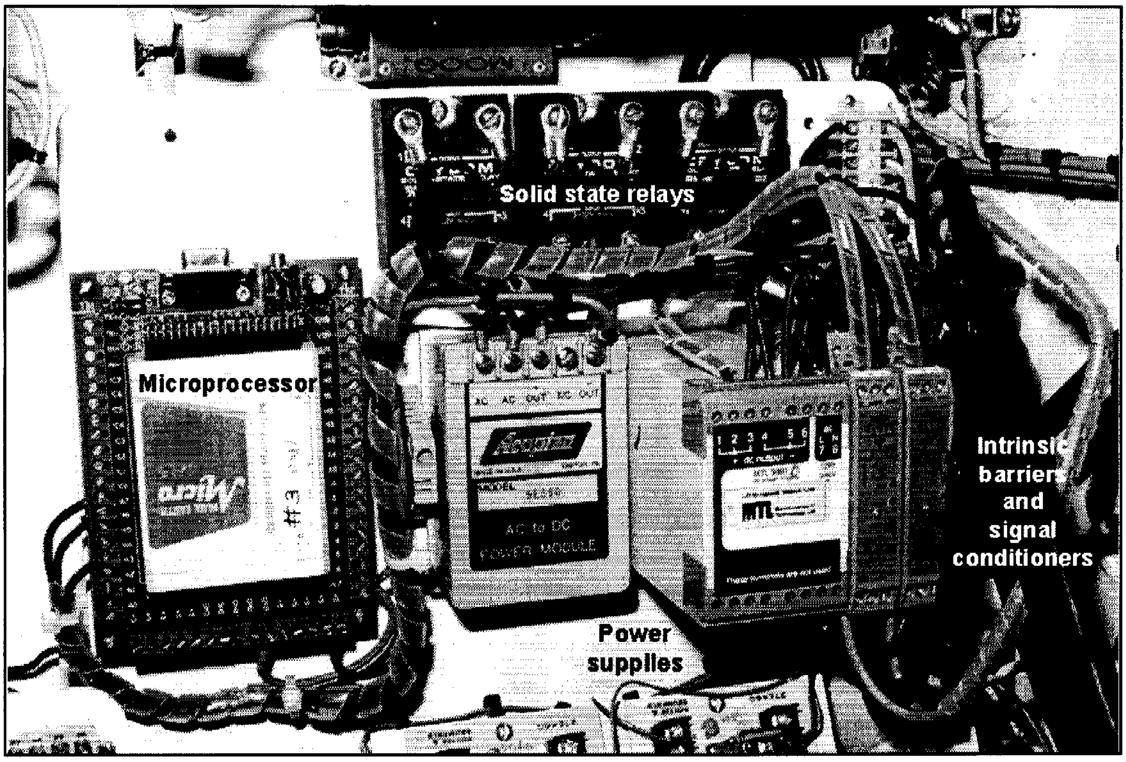

Fig. 4.—Components of load rate monitoring device installed in electrical box on mobile roof support

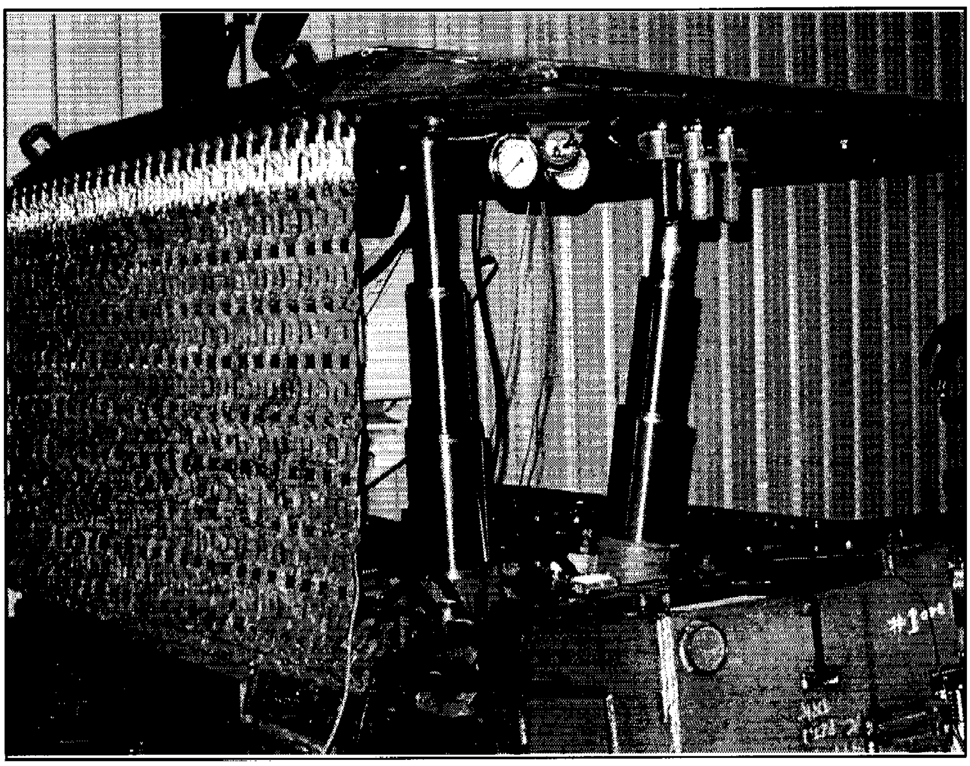

Fig. 5.—Load rate indicators installed on mobile roof support

the user. The green light, for example, could easily be programmed to indicate hydraulic pressures between 0 and 13.8 MPa, the yellow light indicates pressures between 13.8 and 20.7 MPa, and the red light indicates pressures over 20.7 MPa. The red light is programmed to flash continuously when the hydraulic cylinder is within 5% of yield pressure.

A. Load Rate Program

The code was developed in Assembly and C. A compiler package from Franklin Software was used. The program was compiled using a small memory library. It has a custom startup code that must be linked. In addition, special linking options are used to ensure that the code does not interfere with resident on-board programs (the BASIC Interpreter and Monitor-51).

As shown in the software flow diagram (Fig. 6), the software operates in several modes. On power-up, the system executes the program stored in battery-protected random access memory (RAM). This program cannot be changed by a user. The parameter storage area is also in battery-protected RAM, but it can be modified by the user. As the program starts, it accesses the parameter storage area to determine triggering values on the lights as set by the user. These triggering values are stored as conjugates, one positive value and an equivalent negative value. If any error or improper user input has corrupted these values, the program will use default values stored with the program and not accessible by the user. Validation is important even though parameter corruption is virtually impossible as long as the backup battery is functioning. Next the program initializes the data acquisition system. The multiplexer (MUX) is set for the first reading and the analogue-to-digital converter (ADC) is reset. In this way, the transform parameters are set. The system is immediately set in its normal (safe) condition with the green load-rate lamp lit.

The program now waits for user input via the optional RS232 link from the laptop computer. If no inputs are present, the foreground operation begins. If any user input is detected, foreground operation is disabled while the user sets operating parameters from a laptop computer. Background processing occurs in response to detected user inputs. If the optional RS-232 serial cable is not connected, these operations are not performed, and the system operates solely in the foreground mode. If the user is changing parameters via the RS-232 cable from a laptop, all foreground operations are disabled until restarted by user command.

Once the user input has been processed, the foreground program is enabled. A "Start Pad" is set to inhibit warnings or alerts until the program has collected enough data to make valid decisions. In other words, changing the lamp status is inhibited until enough time has passed to establish a baseline. Once in the foreground processing mode, as in most real-time operating systems, both foreground and background tasks are supported. While performing the foreground task, the system monitors for background commands. The foreground task operates the system in real time, monitors pressures, calculates load rates, and sets the annunciator lamps.

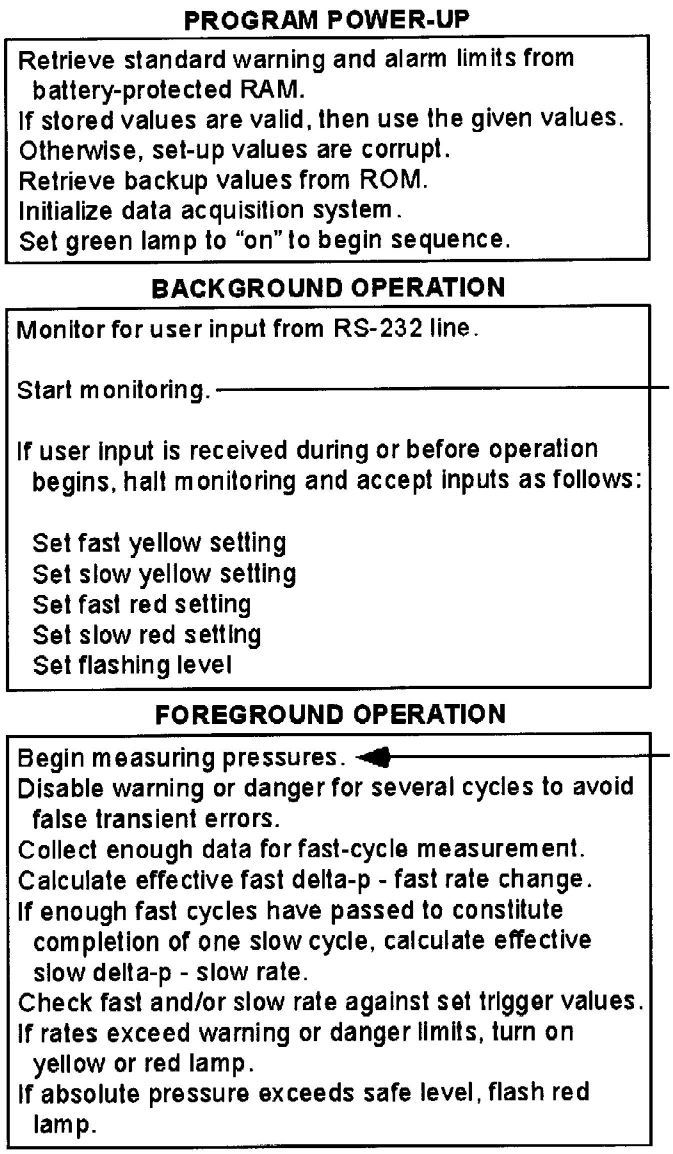

Fig. 6.—Flow diagram of load rate program

Basically, the program takes a series of measurements that constitute a fast cycle of pressure measurements. At the end of this fast cycle, it calculates the rate of change over the cycle. After accumulating the specified number of the fast cycle rates, it computes a slow-cycle rate. The slow- cycle rate is calculated from the load change over a specified number of fast cycles. The intent is that the user can specify two-rate trigger levels. Generally the user will choose to make the slow-cycle triggering rate smaller than the fast-cycle triggering rate. This process allows for warnings to be generated over a large range of both rapid changes and long-term rate changes. No matter what the current load rate range is, when the absolute pressure level of the monitored system approaches that of the pre-set level of automatic system overload (yield) protection, the program will set the red lamp to flashing repeatedly to warn an operator. If loading were to continue, the equipment would be protected through automatic mechanical hydraulic pressure reliefs.

The slow and fast cycle times are 2 and 8 sec, respectively, and can be easily changed by the user if desired. To set the trigger values for the red and yellow lamps, one must convert loading rates in kilopascals per second to bits per cycle. Table 1 presents an example of input values for lamp triggers.

In the example, the red lamp is lit when the loading rate equals or exceeds 168 kPa/sec for the fast cycle and 84 kPa/sec for slow cycle. The yellow lamp is lit when the loading rate equals or exceeds 84 kPa/sec for the fast cycle and 42 kPa/sec for the slow cycle. At startup and low loading rates, the green lamp indicates that the device is functioning properly.

B. Static Load Program

As previously mentioned, the load rate monitoring system was modified to add a static load monitoring option. The coding for both the static load and load rate programs are very similar. Only one hardware change was required, that is, the addition of a toggle switch to provide the operator with a means for selecting the load rate or static load program. The original load rate program was modified to monitor the position of the switch to determine which operating program to use. It then loads the light trigger values appropriate for that program. The program's toggle switch would be set in an area away from the active mining face. The MRS will have to be shut down and de-energized whenever the switch position or operating parameters (light trigger values) of the programs are changed. This safety requirement must be met before removing the access panel to gain access to the program selector switch or to the embedded processor.

III. Conclusions and Future Work

The load rate monitoring system is designed to be MSHA permissible. With the cooperation of a major MRS manufacturer, an experimental permit was obtained from MSHA to allow testing of the MRS load rate monitoring system in underground mining operations. The system was first tested on an MRS in the manufacturer's shop facility. These and other studies identified inaccuracies in hydraulic cylinder pressure measurements of support loading when the bottom stage of a multistage cylinder was fully extended [2]. Load changes would not occur until the roof load acting on the hydraulic cylinder exceeded the force applied to the mechanical stop of the bottom stage.

To maximize the performance of the load rate monitoring system, the MRS should be set against the mine roof with the bottom stage partially extended. Upcoming field studies will focus on evaluating the performance of the load rate system, developing a protocol on how to use the system as a tool for alerting miners to dangerous ground conditions during pillar extraction, and determining critical load rate settings for the system under different geological conditions. An integrated ground monitoring system will be tested in which the simplicity of roof-floor convergence measurements are combined with load rate monitoring on MRS leg cylinders. Measurements from four mines with various geological and support conditions have shown that monitoring roof-floor convergence rates enables miners to detect unstable roof conditions within the whole area of interest at the mining face [3]. Monitoring MRS loading rates will provide warnings about conditions that could result in premature roof caving. It is anticipated that adding this type of device to MRS's will significantly improve the safety of room-and-pillar retreat operations utilizing these machines.

Acknowledgments

The support of J.H. Fletcher & Co. is gratefully acknowledged. Installation and testing of the load rate monitoring system could not have been accomplished without its assistance. Fletcher not only provided MRS's and multistage hydraulic cylinders for testing the load rate monitoring system, but assisted in installing the system and locating mine sites for the upcoming field tests. The company's diligent work was invaluable in obtaining an experimental permit from MSHA to test the system on MRS's in active retreat mining sections.

References

[1] J. Shepherd and T. Lewandowski, "Modified Wongawilli extraction with mobile breaker line supports: preliminary geomechanics," *Australian Coal Journal*, no. 38, pp. 41-47, 1997.

TABLE 1

EXAMPLE OF LOAD RATE PROGRAMMING

Lamp	Fast cycle			Slow cycle		
	Load rate, kPa/sec	2-sec cycle, bits	Load rate, bits/sec	Load rate, kPa/sec	8-sec cycle, bits	Load rate, bits/sec
Yellow	84	20	10	42	40	5
Red	168	40	20	84	80	10

NOTE: 1 bit = 8.4 kPa

[2] T. Barczak and D. Gearhart, "Performance and safety considerations of hydraulic systems," in *Proceedings, 17th International Conference on Ground Control in Mining*, S. S. Peng, ed. Morgantown, WV: Dept. of Mining Engineering, WV Univ., pp. 176-186, 1998.

[3] H. Malcki, "Detecting stability problems by monitoring rate of roof movement." *Coal*, vol. 25, no.12, pp. 34-38, 1988.