RI 9623

REPORT OF INVESTIGATIONS/1996

Design and Demonstration of a Continuous Dust Control Parameter Monitoring System

By Ellsworth R. Spencer, Paul D. Kovscek, and Kenneth G. Fields

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This work was performed by the U.S. Bureau of Mines prior to transferring to the Department of Energy on April 4, 1996

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International Standard Serial Number
ISSN 1066-5552

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	L/s	liter per second
cm	centimeter	m	meter
cm/s	centimeter per second	mA	milliampere
cfm	cubic foot per minute	mg/m^3	milligram per cubic meter
ft	foot	m/s	meter per second
fpm	foot per minute	MPa	megapascal
gpm	gallon per minute	mm	millimeter
Hz	hertz	mV	millivolt
in	inch	psi	pound (force) per square inch
ips	inch per second	rpm	revolution per minute
kHz	kilohertz	V dc	voltage direct current
kPa	kilopascal		

DESIGN AND DEMONSTRATION OF A CONTINUOUS DUST CONTROL PARAMETER MONITORING SYSTEM

By Ellsworth R. Spencer,[1] Paul D. Kovscek,[2] and Kenneth G. Fields[3]

ABSTRACT

The purpose of this joint U.S. Bureau of Mines-Mine Safety and Health Administration study was to assemble an intrinsically safe, continuous dust control parameter monitoring system and demonstrate the capabilities of the system to augment a coal mine's dust control plan. Monitoring of the dust control parameters will assist the mine operator in restricting respirable dust levels in underground coal mining by keeping all dust control systems operating in concert and at optimum levels. Extensive laboratory tests were completed to determine appropriate sampling stations for the continuous monitor sensors to ensure accurate measurement and analysis of operating parameters. Field testing was done in an active longwall coal mining section to test the monitor's durability and assess the reliability of the sensors and data acquisition system. It was demonstrated in this study that intrinsically safe instruments are available to be assembled into a continuous dust control parameter monitoring system. Therefore, with cooperation and support from the mining community, monitoring systems can be engineered into coal mining machines to assist in controlling respirable dust.

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INTRODUCTION

The Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) limits the respirable dust exposure of mine workers to an average of 2.0 mg/m^3 over an 8-hour shift *(1)*.[4] Compliance with the dust standard is designed to minimize the risk of mine workers contracting coal workers' pneumoconiosis, commonly referred to as black lung disease. As part of the exposure monitoring, coal mine operators are required to conduct bimonthly dust sampling in their mines and submit these samples to the Mine Safety and Health Administration (MSHA). MSHA determines the average dust concentration of these samples and has the enforcement power to levy fines, request changes to dust controls, and ultimately force closure of the mine if the dust samples are out of compliance. Worker exposure and the related threat of black lung disease remains a problem, particularly in light of ever increasing production levels.

MSHA REQUEST FOR STUDY

In response to the Secretary of Labor directive, MSHA established the Coal Mine Respirable Dust Task Group on Dust Control Plan Criteria and Improved Methodology. Formally convened in 1992, the Task Group reviewed previous MSHA dust control procedures and methods, to ensure that the respirable coal mine dust control program reflects the current state of technology and provides the greatest possible protection of the work force. The Task Group studied the current program and recommended the development of new or improved dust control technology, with emphasis on dust control methods for high-production longwall mining units. The Task Group concluded that until a newly conceived continuous dust monitor is developed for underground use (4 to 5 years hence), other methods must be employed to immediately control and reduce dust levels in coal mines *(2)*. The Task Group also requested that the U.S. Bureau of Mines (USBM) Pittsburgh Research Center investigate and develop a comprehensive list of currently available instruments, equipment, and procedures for MSHA inspectors or mine operators to monitor underground dust and ventilation parameters. The initial USBM report listed portable, handheld systems that met these criteria and recommended monitoring strategies. This report was followed by a second internal report, that listed continuous monitoring and recording systems for dust control parameters. After acceptance and review of these reports MSHA concluded that "a monitor for dust control parameters would provide valuable information to the mining industry."

MSHA-USBM JOINT VENTURE

Subsequent to the Task Group Report, MSHA and USBM drafted a Joint Venture Proposal for the evaluation of an intrinsically safe continuous monitoring system for dust control parameters. This document defined the monitoring system, the objectives of the research, and joined MSHA and USBM personnel for this research effort. USBM acquired the datalogger system, sensors and other appropriate items, then assembled and laboratory tested the monitoring system. MSHA was responsible for locating a coal mine and for establishing this research at the mine site. MSHA and USBM personnel installed the monitoring system in the mine and returned to the mine weekly for battery replacement, manual readings on the systems being monitored, and data recovery. Together, MSHA and USBM personnel analyzed, during and after the field test, the monitoring system's physical and electrical integrity, data reliability, and data acquisition capabilities.

RESEARCH OBJECTIVES

Research objectives were to—

1. Develop and analyze strategies to continuously monitor operating parameters in underground coal mining.
2. Define criteria for continuous monitors that can operate successfully in the hostile environment found in underground coal mining. Monitors will be developed using current technology.
3. Acquire instruments and sensors, build prototype and perform laboratory tests.
4. Obtain MSHA Approval and Certification Center experimental approval for testing the continuous monitor in the coal mining environment.
5. Perform underground tests and evaluate the integrity of the overall system.

MONITORING DUST CONTROL PARAMETERS

The selection process examined a restricted field of MSHA intrinsically safe certified dataloggers, sensors, and transducers. Other dataloggers and sensors that were certified by other approval centers were also considered, but they also had to pass MSHA certification. This selection of equipment does not reflect endorsement by the USBM or MSHA.

The continuous dust control parameter monitoring system consists of an MSHA-approved, intrinsically safe, data

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[4] Italic numbers in parentheses refer to items in the list of references preceding the appendix.

acquisition system, data storage modules, sensors, solid-state relays, intrinsic safety barriers, and battery power supplies (figure 1). The monitoring system was designed so that it could be adapted to either a continuous miner or longwall shearer with minimum modifications of the existing machine and preclude the need for connections and modifications of existing machine electrical power circuits and enclosures. Several intrinsically safe system components were available and could be combined into a monitoring system. The total intrinsically safe monitoring system by design is smaller and lighter in size and weight than a system that utilizes explosion-proof enclosures.

A low-energy-consuming, battery-powered system was essential to enable long-term (28 working shifts) monitoring and recording. The sensors were chosen on power consumption, ruggedness, intrinsic safety, and efficiency. Compact and lightweight sensors were preferred. The parameters to be monitored were selected to generate a database for both immediate and long-term use by face personnel, mine operators, or MSHA. This database could be used as an engineering tool to define dust control parameter levels, indicate trends, and illuminate problems with the dust control system.

Air velocity was selected because it is the primary agent for dilution and removal of dust-laden air from the working face *(3)*. Minimum air velocities reaching and sweeping the face are needed to maintain a healthy working environment. Air velocity defines the air volume quantity that affects the dilution and concentration of mine air contaminants. Typically, mine personnel obtain the average air velocity with a vane anemometer and a stop watch. Air flow volume is calculated from the average velocity and the cross-sectional area of the entry. These measurements are made at discrete intervals in compliance with mine operational practices and State and Federal statutory requirements.

Water supply pressures and water flow quantity delivered to the cutting drum and work area directly influence the quantity of coal dust that is released into the air stream. Water sprays

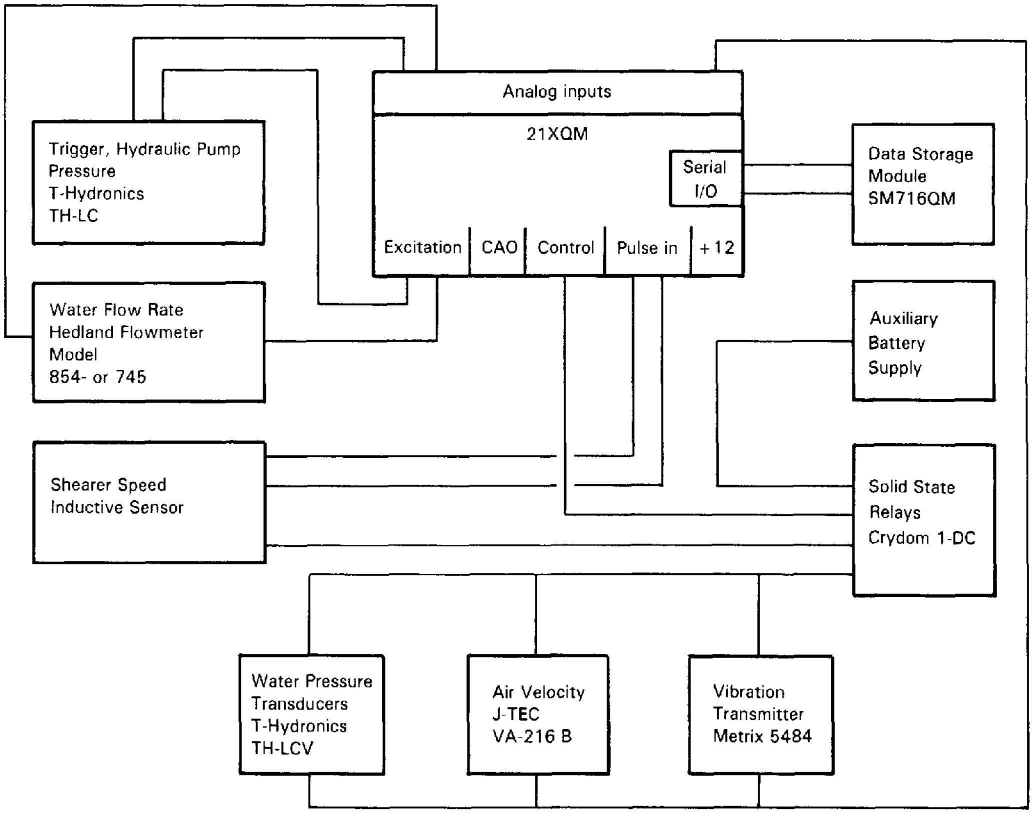

Figure 1.—Diagram of continuous dust control parameter monitoring system.

directed at the dust source capture or entrain the dust contaminants, thereby decreasing the quantity of dust released into the mine air *(4)*. For both the air and water spray systems, it is presumed that pertinent values were established and implemented.

Machine vibration was selected to provide an estimate of the type and kind of activity occurring during the production shift. Vibration intensity is directly related to the machine design, mechanical condition, and transducer mount location. Energy intensity delivered to the coal or rock surface through the cutter bits is reacted by the mining machine structure. A portion of this energy is manifest by vibrational waves. Therefore, monitoring machine vibration should provide data on mining machine activity. Machine vibration could also be used as a trigger by the data acquisition system.

Shearer tram rate was also selected for longwall shearer monitoring to aid in determining the type of mining activity, i.e., cleanup or production pass occurring during a production shift. For the cleanup pass, the shearer moves faster since there is no cutting involved, and the drums only move previously cut coal onto the armored conveyor. Transducers for shearer location, direction and velocity were investigated and could be implemented; however, retrofitting one or more of these transducers to the shearer required more machine modifications than with a noncontact transducer. Shearer tram speed was selected because it could be monitored by a noncontact transducer that could be installed with minimal machine modifications and also provide sufficient data on shearer activities with respect to its influence on dust generation levels.

The mining machine hydraulic supply pressure was selected for the data acquisition system trigger. The trigger enables data acquisition only when the machine is active. This input was essential for long-term monitoring of the equipment. The trigger channel facilitates battery supply conservation and reduces the quantity of trivial data stored in the data storage module.

For the continuous miner, a differential pressure transducer was selected to monitor the pressure drop of the dust scrubber system. A differential pressure transducer was to be installed just upstream of the fan inlet. At this location, any obstructions in the dust scrubber system, inlets, filter or mist eliminator, would alter the fan differential pressure.

CONTINUOUS MONITORING SYSTEM

Numerous data acquisition, signal conditioning, data recording systems, and transducers were reviewed at the initiation of this investigation. Sensor, data acquisition, and recording hardware compatibility for the intended purpose were examined. Intrinsic safety compliance and deficiencies were appraised for each item reviewed. Two currently available MSHA-approved data acquisition and recording systems were located—the 21XQM and CR10XQM,[5] both manufactured by Campbell Scientific, Inc. These units are low-energy-consuming programmable dataloggers with voltage source capabilities, multiple-channel capacity, and programmable analog-to-digital conversion. Additional capabilities include mathematical, statistical and logical functions, digital control ports, and frequency and pulse counters. Both units are similar, and could be used for monitoring dust control parameters; however, the 21XQM was chosen because of greater input channel capacity and full-scale input voltage range.

SYSTEM ENCLOSURE

The dust parameter monitoring system consists of a central datalogger that records and controls logger and sensor activity, a data storage module that stores data over an extended period of time, a relay module that controls sensor power, intrinsic safety barriers, and two battery power supplies. These components are all mounted in a 30.5-cm (12-in) by 35.6-cm (14-in) by 14-cm (5.5-in) fiberglass-reinforced polyester enclosure (figure 2). The enclosure is rated by the National Electrical Manufacturers Association (NEMA) as 4X (provides protection against water, dust, and other environmental pollutants). A weather-tight lead entrance manifold was attached to the lower end of the enclosure. Nine external sensors with hose conduit can be connected through this manifold.

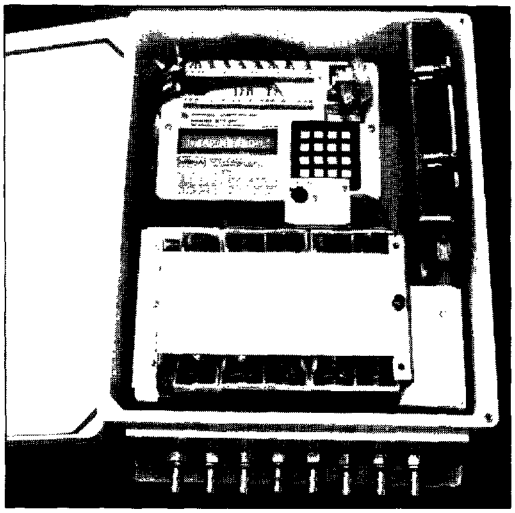

Figure 2.—Continuous dust control parameters monitoring system, mounted in a fiberglass-reinforced enclosure.

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[5] Datalogger Model 21XQM, approval 2G-3731-0. Storage Module Model SM192QM, MSHA approval 2G-3849-0. Power Supply Model 020/ALKQM, MSHA approval 2G-3849-0. Campbell Scientific, Inc., 815 West 1800 North, Logan, UT 84321-1784.

DATALOGGER

The instrumentation package consists of the Campbell Scientific, Inc., model 21XQM permissible datalogger, and data storage peripherals.[5] These instruments are rated intrinsically safe and operate from a nominal 12-V dc battery source. The Campbell Scientific 21XQM is a complete unit with batteries, keyboard and display incorporated into one enclosure. The 21XQM has eight differential analog input channels, four counter or frequency input channels, four switched and programmable excitation channels, six digital output, and three continuous analog output channels. The in-mine monitoring system was designed to use eight of the analog input, one pulse count, four digital output, and three excitation channels. These are air velocity (1), water flow (1), shearer speed (1) (pulse or analog channel), vibration (1), water pressures (3), hydraulic pressure (1). The interconnection between the datalogger and sensors is shown in figure 1. The number of channels is not only limited by the installed channel quantity, but also by the quantity and current limitations of the switched excitation supplies.

Three sensors, air velocity, vibration, and inductive sensor require a nominal 12-V dc power supply. The pressure transducers can be either a full bridge circuit or configured with a low-power amplifier. To extend operational and monitoring time periods, a Campbell Scientific, Inc., model 020/ALKQM permissible power supply[5] was added to power those sensors that require a 12-V dc supply. Four solid-state relays[6] were added to control the power for the air velocity, vibration, inductive and pressure sensors. The 21XQM program will activate these sensors for a predetermined warmup period by actuating the solid-state relays, record data from these sensors and then deactivate them. The program will repeat this cycle according to a predetermined interval.

The shearer tram velocity sensor would be powered continuously whenever the data acquisition system is active to obtain continuous estimates for the average and maximum shearer tram velocity over each interval.

DATA STORAGE CAPABILITIES

The 21XQM has three memory areas. Input and intermediate memory is used to temporarily store and manipulate the incoming data. The final memory, 19,296 data points, stores the data temporarily until transferred to a storage module or computer. This memory is configured so that incoming data replaces the oldest data points in the final storage. For the in-mine test, data were transferred to the data storage module at 1-hour intervals.

The SM716QM data storage module can store 358,256 data points. It has an internal battery-backed RAM memory. Battery life is approximately 5 years under normal (room temperature) conditions. For in-mine service, the battery life expectancy would decrease. This storage module was used to retrieve mine data, and transfer programs to and from the 21XQM. This module can store more than 48 shifts of data at a rate of 15 data points per minute.

SOFTWARE

To augment data collection, an information feedback network and analysis system was developed to handle stored data from the monitoring systems. This system was derived from software provided by the datalogger manufacturer.

This software package contains modules for real-time monitoring, telecommunications, data retrieval, data reduction, and program editing (real-time monitoring of the data acquisition system was only performed during aboveground tests).

A real-time graphics and terminal emulation program enables real-time monitoring and control of the datalogger. Program control flags and output port are controlled from the PC. Datalogger programs and data can be transmitted and received. Data trends and values are identified when graphed to the screen as time line, bar, and data values.

A telecommunication program enables assisted or unassisted data retrieval through a phone modem connection, modem to modem, or direct connection through an optical interface.

A datalogger program editor is used to compose, edit, and document datalogger programs. This program creates both a printout of the program with comments and also generates the datalogger compatible format, which is downloaded to the datalogger or data storage module.

A separate program enables communication between a computer and a data storage module. This program facilitates data retrieval from the storage modules, downloading and retrieval of datalogger programs, configuring internal switch settings and resetting or clearing programs and data.

A data processing program is used to extract and reduce raw data files into smaller more manageable files or to combine separate data files into a single data file. This program is used to perform preliminary data analysis and break the data files into smaller sections that can be either printed or imported into spreadsheet programs. Data processing with math-operators, file reformatting, and limit testing are used to implement data reduction on a PC. A graphics routine is used to plot the data to verify data integrity and identify trends.

AIR VELOCITY SENSOR

The selected air velocity sensor was the J-TEC VA-216B.[7] The air velocity sensor consists of two basic modules, the sensor head and the sensor body. The sensor head is a vortex shedding device that uses an ultrasonic transmitter and receiver mounted

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[6] Solid-State Relay HEXFET P/N D1D07. Bulletin 1-DC, Crydom series 1-DC MOSFET output solid-state relay, Newark Electronics, 1399 South 700 East, Salt Lake City, UT 84105-2148.

[7] Air-Velocity Sensor, classification G. J-TEC Associates, 5255 Rockwell Dr., NE., Cedar Rapids, IA 52402.

behind and perpendicular to a cylindrical strut. As the air stream passes around the strut, vortexes are generated that modulate the ultrasonic carrier. The vortexes shed are proportional to the air speed through the sensor. The associated electronics, in the sensor body, quantifies the vortexes generated by the sensor head, as an analogous voltage proportional to the air velocity. A range of 0.25 m/s (50 fpm) to 5 m/s (1,000 fpm), and signal output of 0 to 5 V dc was used for this study. The power requirements of the air sensor, at this output level, is from 10 to 20 V dc @ 35 mA.

PRESSURE TRANSDUCERS

T-Hydronics, Inc., models TH-LC and TH-LCV pressure transducers[8] were used to monitor the machine hydraulic and dust spray water pressure lines. These devices are bonded strain gauge pressure transducers. The TH-LC is a nonamplified full bridge circuit that was powered by one of the datalogger excitation channels. It was used for the trigger channel of the data acquisition system. Model TH-LCV is an amplified pressure transducer with an internal low-power MSHA class G amplifier. The power requirements of the pressure transducers are from 10 to 35 V dc, with a nominal current rating of 2 mA. These transducers were powered from the auxiliary power supply.

WATER FLOW METER

A Hedland, Inc., model 854-013,[9] a variable area water flow meter, was used to monitor water flow rate. The flow meter uses a sharped edge orifice and spring retained piston within a metering cone. It has a visual flow indicator and linear potentiometer. The flow indicating ring is mechanically coupled to a linear potentiometer that is magnetically coupled to the piston. Flow through the meter moves the piston against the spring and the flow rate is visually indicated on the meter. The position of the linear potentiometer is measured by the datalogger. The piston position and linear potentiometer position is proportional but nonlinear with respect to the flow quantity; however, the position is linear over a subinterval of the flow range and can be approximated within the rated accuracy of the flow meter with a linear function (see appendix).

The linear potentiometer is nonenergy-storing and completely resistive. It was considered to comply with the acquisition system's approval requirements and is approved by MSHA under this experimental permit.

PROXIMITY SENSOR

A shielded inductive sensor[10] was intended for sensing metal gear tooth passing for rotational velocity measurement to provide data for shearer tram speed. The inductive sensor is a two-wire analog output device and is Factory Mutual (FM) approved intrinsically safe. The available nominal sensing range is from 2 mm (0.08 in) to 20 mm (0.8 in), with maximum switching frequencies from 5 kHz to 200 Hz. The inductive sensor used for the belt tail roller monitor had a nominal sensing range of 10 mm (0.4 in) with a switching frequency of 0 to 500 Hz. The surface test sensor had a nominal range of 5 mm (0.2 in) and 1 kHz switching frequency. The inductive sensor was powered from the auxiliary battery supply. A resistor was inserted in series with the transducer to generate the pulses for the pulse count channel of the 21XQM datalogger. The inductive sensor is rated at a nominal 8.2 V dc, with a current change range of greater than 2.2 mA (nonactivated) to less than 1.0 mA (activated).

VIBRATION TRANSDUCER

The vibration transducer[11] used to monitor the stageloader activity level, has a full-scale range of 12.7 cm/s (5 ips) over a frequency range of 6 to 1,500 Hz. Power requirement of this transducer is from 10 to 60 V dc, provided from the auxiliary battery power supply. The all solid-state vibration transducer uses a two-wire 4- to 20-mA current-loop for the power and signal return line.

INTRINSIC SAFETY BARRIERS

Intrinsic safety barriers[12] were installed in all circuits of the 21XQM, i.e., excitation, analog inputs, digital outputs, and counter input. Intrinsic safety barriers were also installed in the auxiliary power supply leads. The intrinsic safety barriers were primarily a safety mechanism to reduce the possibility of methane and/or coal ignitions from any electrical faults that may occur.

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[8] Pressure Transducer Model TH-LC & TH-LCV, sensor classification G. T-Hydronics, 149 Stelzer Ct., SunBury, OH 43074.

[9] Water Flow Sensor With Linear Potentiometer. RAM Flow Sensor 1-1/4" Series, Hedland 845-013, Hedland Div. of Racine Federation, Inc., Racine, WI 53404.

[10] Inductive Sensor NAMUR, analog output, (DIN 19 234). Catalog TPS 101, TURK, Inc., 3000 Campus Dr., Minneapolis, MN 55441.

[11] Vibration Transducer, model 5484. Metrix Instrument Co., 1711 Townhurst Dr., Houston, TX 77043-2899.

[12] Instrinsic Safety Barrier, RST 49 8/93, R. Stahl, Inc., 150 New Boston St., Woburn, MA 01801-6204.

CABLE

Cable lengths, mounting locations, and cable placement on the machine were determined when a mine site and mining machine was selected. For the in-mine test, the longest run from the datalogger was 67 m (220 ft) to the air velocity sensor, at shield number 19. The only other long run was to the proximity sensor, a run of 23 m (75 ft). Standard cable lengths and types as supplied with the transducers are used in conduit in this test; cable lengths are 3 m (10 ft) for the pressure transducers and 3.6 m (12 ft) for the vibration transmitter; the wiring to the water flow meter was preset at 7.6 m (25 ft). When the distance between the datalogger enclosure and transducer exceeded the standard cable lengths (as is the case for the proximity sensor), NEMA 4X junction boxes were installed in-line to complete the connection to the datalogger enclosure.

LABORATORY SHEARER STUDY

The basic components of the system were tested individually and then assembled into the intended in-mine test configuration. The units were checked for minimum warmup time requirements, operating current requirements, stability, and accuracy. Battery life was investigated so that optimum system operation could be obtained and to establish a battery replacement schedule. Data storage module operation was also investigated to establish data storage capacity and replacement schedule. The batteries and data storage modules were to be replaced at equal intervals.

Each unit was tested individually and calibrated. The datalogger was calibrated with a voltage source over each A/D range. The pressure transducers were calibrated with a dead weight tester, and the flow meter was checked with the visual display. During testing, the operation of the pressure transducers were checked with pressure gauges. The flow meter values were compared with the visual indicator. The air flow sensor was checked with a hot wire anemometer. The signal from the inductive sensor, mounted on the ranging arm to sense drum vane passing, was compared to measured drum rotational rate.

To aid in establishing a battery replacement schedule, each component's current requirements were measured. Table 1 shows the current requirements of each transducer.

Table 1.—Power consumption of sensors

Sensor	Current, mA	Rise time, seconds
Air-draft	40.0	4.0
Pressure	5.9	0.02
Inductive sensor	8.0	0.5
Vibration	20.0	3.0
Datalogger:		
Acquiring data	66.5	—
Processing data	25.0	—
Quiescent state	1.0	—
Only sampling trigger	5.0	

The rise times were needed to establish the minimum time needed to wait for the data signals to reach steady-state values. Rise time is defined as the minimum warmup time for the sensor output signal to attain steady-state levels.

Datalogger batteries needed to maintain power to the datalogger for both active and idle periods. It was also necessary to estimate a derating factor for ambient temperature levels of the mine atmosphere, shelf life, and battery manufacturing tolerances. The addition of intrinsic safety barriers to safely isolate the datalogger and sensors, if fault conditions occurred, reduced the voltage level available to the transducers, but did not degrade input signal levels. These barriers effectively reduced the operating range of the transducer battery supply to approximately 50% of the nominal energy capacity.

Two battery power supplies were used to operate the system. Eight D cells in the datalogger powered the datalogger. Ten D cells were used to power the air-draft, pressure, vibration, and inductive sensors. Battery life expectancy for eight alkaline power cells is approximately 7.5 amp-hours. To obtain 28 shifts of data, the average current utilization of the 21XQM and sensors should be no greater than 30 mA. The sample rate was optimized for idle periods at one sample every 5 seconds for the trigger channel. This channel was needed for verification of mining activity and used to only acquire data when the shearer was powered. The vibration transducer aided in determining when the shearer was mining or if no extraction activities were occurring. The vibration transducer would also be used to determine if the machine was mining rock or coal (it was expected that the vibration levels would increase during a hard extraction process).

The laboratory test setup was used to formulate the mine data acquisition program and evaluate sensor operating characteristics. The laboratory longwall face was equipped with a JOY 1LS shearer and ventilation gallery for experimental dust suppression testing. The shearer was held stationary with the lead drum simulating a production pass. The mockup face was ventilated by two auxiliary fans.

The water flow meter and pressure transducer were installed in the water supply line to the shearer. A pressure transducer was installed in the water supply line to the shearer drum, and one branch water circuit to external spray blocks. The trigger pressure transducer was installed in the main water supply line because the shearer hydraulic pump was not working. The tram rate sensor was installed on the cutter drum because the shearer was stationary on the mock-face test configuration.

The datalogger was set to trigger on the supply line water pressure. The drum and branch sprays could be activated separately from the shearer drum sprays. The units were activated at the beginning of each minute interval. The data observed on the datalogger LCD display compared reasonably well with hand or visual readings. The 1-minute data sampling interval was shown to be appropriate for the expected steady-state conditions of monitored parameters.

One disadvantage detected during the surface tests was that the power line fluctuation of the auxiliary battery supply caused false counts to be generated on the inductive sensor channel. This problem was alleviated by powering all of the auxiliary sensors at the same time and ignoring the counts on the pulse channel during the power up interval. Adding intrinsic safety barriers appeared to alleviate this symptom; however, the programming was developed to a point where it was not feasible to significantly alter the acquisition programming for the in-mine tests. All of the auxiliary-powered transducers were activated simultaneously. The inductive transducer was powered to continuously monitor the shearer drum rotational rate.

The continuous parameter monitoring system was operated and data collected over extended time periods. Preliminary data were transferred with software routines and a hardware interface that enables the data to be transferred through the serial port of a PC computer from the datalogger. The data were checked for completeness and accuracy during ten 8-hour dynamic tests and several 36-hour static tests.

UNDERGROUND MINE STUDY

This study investigated the feasibility of using the continuous parameter monitoring system to control dust levels in underground coal mining. This study developed and analyzed strategies to continuously monitor key operating parameters on production or development coal faces. The study defines criteria for future continuous parameter monitors so they can operate successfully in the hostile environment found in underground coal mining.

In September 1994, preliminary continuous parameters monitor installation meetings were held between MSHA, the USBM, and a cooperative coal mine located south of Pittsburgh, PA. The mine utilized a Joy 4LS shearer. It was determined that placement of the continuous parameters monitor onto the longwall shearer was not possible because of space limitations within the shearer. It was therefore decided that the monitor would be mounted on the stageloader. This installation location provided the opportunity to monitor all of the parameters. It also provided the ability to monitor air flow at a fixed site on the face. An underground trip to the headgate area by the research personnel to assess and plan for the installation was conducted. Changes to the numbers and types of sensors, and cables and conduit lengths, were quickly accomplished. After these changes, the new installation plan and proposed study was submitted and accepted by the mine. In late November 1994, the continuous parameters monitor system was installed at the coal mine's longwall headgate, on the stageloader-crusher. Installation was done over a 10-hour maintenance shift while the longwall was still being set up on a new coal face.

The datalogger and its associated electrical barriers, relays, and batteries, are in one fiberglass-reenforced environmental box. This enclosure was magnetically mounted onto the stageloader-crusher. The monitor for water flow and pressure to the longwall shields' canopy spray system was located nearby. These sensors are in a metal crush-resistant enclosure with a plexiglass window for reading the visual water flow indicator, mounted on the water flow meter. Two water pressure sensors were also plumbed into nearby lines, using preinstalled staple lock fittings and T-connectors. All of the sensors' pressure lines were plumbed with T-connectors into quick-connects. The quick-connects are for a pressure gauge attachment and enable the pressure readings to be taken by the research personnel.

The hydraulic pressure sensor was plumbed into a branch line off the main 5.1-cm (2-in) hydraulic line to the shields, again using a T-connection and staple lock fittings. The branch line was connected to an on-off valve on the main line that allowed easy access to the hydraulic pressure without shutting off the hydraulic pumps. This sensor, mounted in a metal crush-resistant enclosure and wired through a conduit to the datalogger, monitored the hydraulic pressure to the shields. This pressure information would be used by the datalogger as a trigger for longwall operation. When the longwall was down for a long period of time, the hydraulic pumps were turned off. The shield legs would lock up under a no-hydraulic-pressure situation, and the normal >27.6 MPa (>4,000 psi) would fall to near zero. The datalogger would not need to be on during this period and would go into a dormant state when the hydraulic pressure fell below 13.8 MPa (2,000 psi). This would conserve the monitor's batteries and the storage module's memory. When the longwall goes back on-line and the hydraulic pumps turn on, the hydraulic pressure builds up over 13.8 MPa (2,000 psi) and the datalogger would activate the needed sensors, take readings, convert the signals from programmed calibrations into engineering units, and store the data.

To measure the main air stream on the longwall face, the air velocity sensor had to be positioned as close to the panline as possible. This area would subject any sizable object to damage from the shearer and interfere with the longwall mining. To protect the air sensor's electronics in the sensor body, the air velocity sensor was divided into two modules. A second sensor head, with a 1.8-m (6-ft) cable extension was purchased so this smaller module could be extended into this area less intrusively. To protect the sensor head, and provide a smooth air flow, the head was mounted in the middle of a 10.2-cm (4-in) diameter by 25.4-cm (10-in) long pipe. This armored sensor head was magnetically mounted to the canopy underside of shield No. 19 over the cable tray. To further protect the sensor body, it was magnetically mounted to the same shield back near the shield's hydraulic legs, behind a florescent light, the light brackets, and water lines. To provide power to the air velocity sensor and return the information signal to the datalogger, 67 m (220 ft) of shielded cables were run through an MSHA-approved rubber conduit line connecting the two instruments. This interconnect wiring was routed along the existing service lines loops, connecting the shields to the stageloader and on to the datalogger enclosure.

A proximity sensor was magnetically mounted near the conveyor belt drum shaft to measure the speed of the conveyor belt. A 23-m (75-ft) conduit run was needed from the datalogger enclosure to the tail piece of the stageloader, where this drum is located. Three metal lugs were already in place on the end of the conveyor drum shaft for the mine's proximity switch. Their sensor would turn off the stageloader if no movement was detected. Our sensor system would count the rotations of these lugs per minute. The datalogger would convert these data into the speed of the conveyor belt and record those numbers.

Soon after the installation, USBM representatives held a meeting for operational approval at the mine with a Pennsylvania Department of Environmental Resources (DER) Deep Mine Safety inspector. The MSHA Experimental Permit[13] had been received before this meeting and a copy was made available, along with the monitor's electrical schematics to the DER inspector. A subsequent underground visit was conducted by the DER inspector and USBM representatives to the longwall headgate monitoring site for intrinsic safety verification. A formal DER Approval Permit[14] was received soon after this underground trip.

The system operated through all of December 1994 with some minor, fixable problems occurring. USBM and MSHA personnel visited the mine eight times during this month to make repairs, replace batteries, change out the data storage module, and take manual readings on the monitored systems for future comparison studies of recorded data.

In January 1995, the mine was visited six times by USBM and MSHA personnel to replace batteries, change out the data storage module, and take manual readings on the longwall parameters. In late February 1995, following four visits for research purposes, the monitoring system and related sensors were recovered. After spending over 3 months underground, the continuous monitor recorded more than 1,080,000 data points.

RESULTS AND ANALYSIS

The dust parameter monitor system operated in-mine for 2,014 hours. These 2,014 hours were acquired between December 1, 1994, through February 23, 1995. In-mine hours are composed of—

	Hours	*%*
Monitored activity	1,878	93.2
Malfunctions	123	6.1
Idle periods, not recorded	10	0.5
Battery-storage module exchange	3	0.2
Total	2,014	—

Thirteen hours are attributed to idle periods, battery replacement, and storage module exchanges. These exchanges occurred when the longwall face was idle due to a load center move, conveyor belt repair, or some other longwall mining cycle delay. The data record would contain the last or first active data value based on when the shield supports were pressurized. Some sensor calibration and evaluation were performed during this time.

Mechanical malfunctions on three separate occasions accounted for 123 hours of lost monitoring time. The first occurrence was due to mine personnel shutting off the shield pressure line to the trigger pressure transducer, which resulted in 36 hours of lost monitoring time.

Two hours were lost apparently because of desiccant packs impacting the datalogger on-off switch, and 85 hours were lost because of an undetermined cause. On both occasions, datalogger power was reset and automatic program download occurred; however, date and time data were lost. Data were recorded during these malfunctions; however, there was no way to determine how much mine operational data were missing.

The datalogger acquired 1,604 hours of data during the 1,878 hours of active monitored time. The active monitored time includes holidays, weekends, and all downtime that occurred during the monitored interval for that specific data storage module. Some nonmining activity was recorded due to the valve problem, where the datalogger was set for continuous recording until arrangements were made to maintain pressure to the shield trigger transducer. Also, the default program, when activated by power interruption, reverts to continuous data sampling. Table 2 shows the test results based on the 1,604 hours of data.

Table 2.—Monitored parameter activity, %

Monitored parameter	Activity/%
Trigger	97.2
Vibration	53.8
Shield spray pressure	53.6
Shield spray flow rate	33.9
Crusher spray pressure	52.5
Stageloader top spray	37.6
Belt activity	33.2
Face air velocity:	
Less than 1 m/s (200 fpm)	19.1
Greater than 5 m/s (1,000 fpm)	11.5
1 (200) < m/s (fpm) < 5 (1,000)	69.4

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[13] Experimental Permit Code No. 609600. Nov. 22, 1994, MSHA Approval and Certification Center, Industrial Park Rd., RR 1, Box 251, Triadelphia, WV 26059.

[14] Approval Number BISC 133-94, Dec. 7, 1994, Commonwealth of Pennsylvania, Department of Environmental Resources, Bureau of Deep Mine Safety, Room 167, Fayette County Haelth Center, 100 New Salem Rd., Uniontown, PA 15401.

The pressure transducers performed adequately for the entire test period. The shield canopy sprays are pressurized when the face is actively mining and is indicated by the equal time percentages of stage loader vibration and shield spray pressure. However, the lower time percentage for flow rate can be attributed to two factors. Although the water line is pressurized, the spray water only flows when a shield or shields are advanced. Because the flow quantity is noncontinuous and the datalogger program was set to sample at 1-minute intervals, there is a notable probability that some flow data or activity may be excluded. Therefore, later in the test period, the water flow sampling interval was changed to 5 seconds, to obtain a more representative estimation of water flow quantity over each minute interval.

The crusher and top spray locations are controlled manually by the stage loader operator. The crusher sprays were activated in close conjunction with stageloader vibration activity; however, the internal top sprays were at times turned off or operated at a much lower setting than the crusher sprays. This operational method was verified during on site visits when fresh batteries and data module were installed.

The magnetic mounts were problematic for the belt, vibration, and air velocity sensor for the entire test period. The inductive sensor for belt rotational velocity was mounted to the belt tail roller frame assembly with a single magnet. The optimum position at the top of the tail roller was already occupied by the belt sequence switch. Therefore, the inductive sensor was mounted on the lower half of the roller at a 45° angle and approximately 135° from the top position. Vibration and normal operation of the belt caused the magnet to move and dislodge from the set position resulting in loss of signal and data. The sensor would be reinstalled during site visits and belt activity monitoring would be resumed. The initial vibration location on the crusher motor produced excellent signal levels for determining when the crusher was operating. However, at this location, particularly when the rib clearance was low, this sensor was knocked off its position by mine personnel. This sensor was relocated to the underside of the top cover, where the signal was lower, but readable. Fortunately, vibration signal levels were sufficient for those occasions where the transducer was dislodged, or when it fell into the mud near the stageloader. Also, the air velocity sensor was occasionally displaced from its set position. A portion of low air velocity values under 1 m/s (200 fpm) were due to this sensor head and air direction misalignment.

A problem that occurred during the early part of in-mine data acquisition was with the air velocity sensor. To measure the main air stream on the longwall face, the sensor head was positioned as close to the panline as possible. The air readings would also fluctuate when the shearer passed this location. After 2 weeks in the mine, the "armored" sensor head's output was full scale under most operating conditions. Manual air readings taken during this period were much lower than the recorded data. After testing the electronics in the sensor body, wiring and grounding between the air sensor head and body, it was decided to replace the armored head with the original head that is mounted to the sensor body. The air velocity sensor was then moved over the walkway. After this change, the air sensor's performance and transmitted data remained constant and consistent with manual readings throughout the rest of the test period. Manual readings taken simultaneously at the air sensor head and over the panline were correlated so recorded readings from the air velocity sensor can be converted directly into face air velocity.

The "armored" sensor head was sent to the manufacturer for evaluation and repair. However, it operated within the manufacturer's specifications and was returned. Additional laboratory tests were performed to determine or duplicate in-mine sensor malfunction condition. The sensor head was immersed in water for several days and then covered with coal dust to duplicate the wet and dirty in-mine conditions. Some random spurious signals were observed, and loss of signal occurred when substantial coal dust quantities covered the sensor. However, the in-mine malfunction was not observed during this laboratory test.

The source cause of the air sensor malfunction was not duplicated or determined, and additional testing was considered outside the scope of the present project. Mine air turbulence, ambient noise levels, sensor protective enclosure geometry and mount location are several factors that may have contributed to the in-mine malfunction.

GRAPHED DATA EXAMPLES

Data recorded by the continuous parameter were resolved over short and long periods of time and correlated with mining activity. This allows the behavior of a dust control parameter to be scrutinized during the mining cycle. An example of this is shown in figure 3, where a drop in air velocity across the fixed-point monitor occurred each time the shearer cuts out at the headgate. Also, when the shearer passes the fixed-point monitor, the air velocity should increase because of the constriction of the air course by the body of the shearer. A decrease in air velocity after the shearer passes occurs because of a wide air course. Shield advancement, upwind and downwind of the fixed-point monitor, interrupts and redirects air movement. Air turbulence is also caused by the shearer water sprays, drum movement and coal transport.

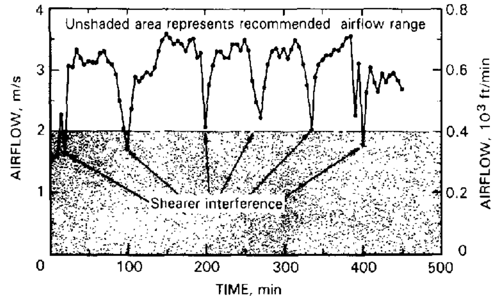

Figure 3.—Air velocity reduction as the shearer cuts out at the headgate.

If the proximity sensor could have been mounted onto the shearer's tram cog-wheel and these data assimilated with the air velocity data, it would give a much clearer picture to when and what is occurring on the face. The data shown in figure 4, from the proximity sensor mounted on the conveyor belt drum, show the movement of the conveyor belt. The stageloader-crusher is linked to the conveyor belt, both mechanically and electrically. When the conveyor belt is stationary the stageloader-crusher will not operate and therefore only under unusual circumstances will the shearer be operated. It was observed that when the conveyor belt was running loaded with coal an average of about 138 rpm is recorded, when unloaded, a speed of 142 rpm occurs and rpm 0 when the belt is off.

As discussed earlier, water sprays are an important dust control parameter. An example of recorded water pressures to the stageloader sprays over one shift is shown in figure 5. When the conveyor belt stops, the stageloader water sprays are normally, manually turned off. As shown in figure 5, the water pressure falls to zero five times after being on for a period of time. It was observed, during several mine visits, that occasionally these water sprays were not immediately turned back on after the conveyor belt and stageloader were restarted, and the shearer resumed cutting coal. Recorded data, not taken during mine visits, showed extended periods of zero water pressure to these sprays. Other sensor data taken at these same periods showed confirmation of mining activity. It is unknown whether or not the stageloader water spray system was being worked on, or inadvertently, the water was not turned back on after a shut down. When water pressure is too high, dust can be produced and moved into the air course. When water pressure is too low or off during an extended period of time, the coal surfaces dehydrate allowing previously captured coal dust to be released into the mining atmosphere.

The data recorded by the continuous parameter monitor, when compared to the longwall mining cycle, and fully analyzed, illustrate air velocities, coal mining production cycles and water usage. This data collection and analysis can enable the mine operators to implement corrections in air flows, water pressures, and other mining parameters, for improved respirable dust control.

Information taken manually during the field test was compared periodically to retrieved recorded data. These comparisons verified that the data recorded by the continuous parameter monitor was the same as the longwall's operating dust controls, i.e. gage water pressures and flow, and vane anemometer readings on the longwall face.

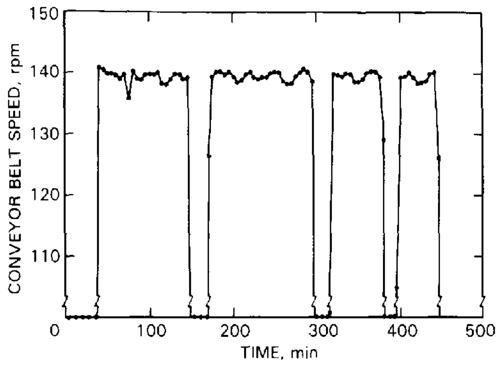

Figure 4.—Conveyor belt speeed.

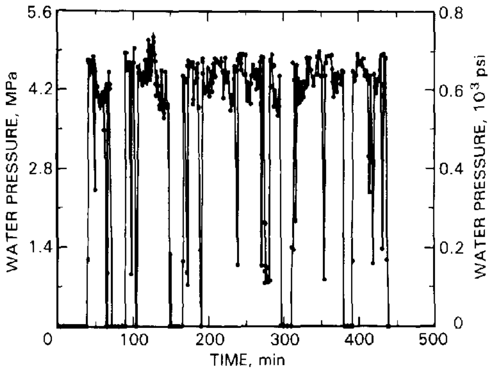

Figure 5.—Water pressure to the stageloader sprays.

SUMMARY AND RECOMMENDATIONS

This study has shown that the monitoring system is a viable instrument to continuously observe and record dust control parameter activity in underground mining and can be used as a tool for keeping respirable dust levels at a minimum. The next step is to implement the continuous parameter monitor into mining machines.

The objective of future work will be to engineer a dust parameter monitoring system into a longwall shearer. The technology is available and with a cooperative effort, the datalogger, data storage module, and associated transducers and sensors can be installed and powered from a longwall shearer. A minimum list of monitored parameters are machine tram rate, vibration, water flow rates and water pressures, to each drum and external dust spray system. However, shearer design and space constraints impedes retrofitting this system onto an existing longwall shearer. This system can be designed and installed into a longwall shearer that is currently being manufactured. Therefore, the recommendation is to actively engage the mining community and shearer manufactures to join with us in this undertaking. Currently, MSHA is attempting to identify a longwall shearer manufacturer to incorporate this monitoring system into the design of a longwall shearer.

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APPENDIX.—TRANSDUCER CALIBRATION

Prior to in-mine installation, all transducers were calibrated. The pressure transducers were calibrated with a dead-weight tester. The water flow meter was calibrated with the visual indicator located on the meter. The air velocity sensor was calibrated with a wind tunnel, and the vibration transmitter was calibrated on a shaker table.

AIR VELOCITY SENSOR

The air velocity was calibrated with the remote sensor head prior to installation in the mine. This remote head was subsequently replace with the original sensor head, and the air velocity sensor was calibrated in-mine with a vane anemometer. The in-mine air velocity measurements were taken just beneath the sensor head and the sensor readout was adjusted to the anemometer measured value. A calibration was performed on the original sensor head when the unit was retrieved from the mine. Figure 6 shows the precalibration, in-mine, and postcalibration values for the air velocity sensor. The in-mine calibration curve is extrapolated from manual vane anemometer measurements. As seen in figure 6, the in-mine setting was much higher than the wind tunnel values. This discrepancy may be due to the location of the sensor head adjacent to the shield canopy, where the air velocity and interference of the nearby structures tended to decrease the magnitude of the air velocity at this near-roof location. The comparison of the pre- and postcalibration values shows that air velocity sensor with either sensor head performed comparably, but does not compare with the in-mine calibrations. Mine air turbulence intensity is one factor that introduces error in the measurement of mine entry air velocity. Teale reported that mine air fluctuations caused vane anemometers to read high *(5)*. An amplitude of fluctuation of 30% corresponds to an overestimate of air velocity by a vane anemometer of 17% *(5)*. Cohen reported that turbulence intensity was shown to have a similar effect on the VA-216B. A turbulence intensity of 20% to 30% resulted in an air velocity overestimate of 30% *(5)*.

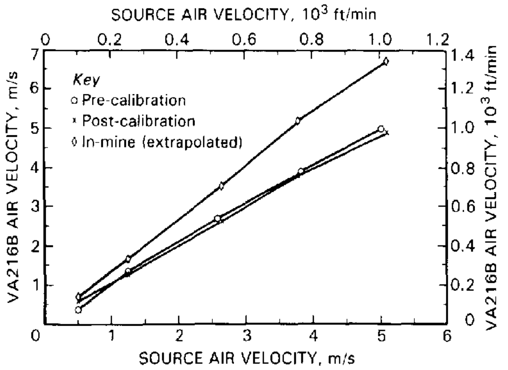

Figure 6.—Air velocity sensor, precalibration, in-mine, and postcalibration values.

Therefore, the mount location of the VA-216B, near the roof where the air velocity decreased, was apparently the dominant factor in the reduced in-mine readings when compared to the vane anemometer.

Turbulence intensity and amplitude fluctuation are both measures of the same phenomena; however, they cannot be readily compared because:

Turbulence intensity is defined as—

$$\frac{\text{RMS average of turbulent component of velocity,}}{\text{Average velocity}}$$

and amplitude of fluctuation is defined as—

$$\frac{\text{Maximum velocity - minimum velocity.}}{\text{Mean velocity}}$$

WATER FLOW METER

The flow meter transducer output is a nonlinear function of the flow rate; however, the flow rate can be approximated by a linear function over a major portion of the sensor range. The flow sensor was calibrated over a range of 1.3 L/s (20 gpm) to 8.5 L/s (130 gpm) with the visual indicator located on the sensor prior to in-mine installation. Figure 7 shows the sensor output voltage for both prior to and after installation. A calibration

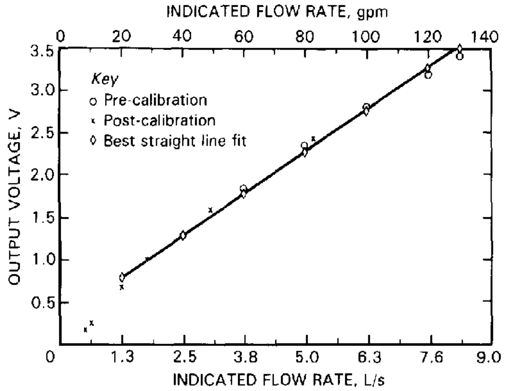

Figure 7.—Water flow meter, pre- and postcalibration.

range 0.5 L/s (8 gpm) to 5 L/s (80 gpm) was used for the postcalibration because the recorded data were within this lower range. The calibration results show that the flow transducer worked suitably during the test period.

PRESSURE TRANSDUCERS

The pressure transducers were calibrated with a dead weight tester prior to installation and again where the transducers were retrieved from the mine. Figure 8 shows the shield canopy spray transducer pre- and postcalibration values as an example for all of the transducers. Calibration results show that the shield canopy spray transducer values changed -6.1 kPa (-0.89 psi) over the 6.9-MPa (1,000-psi) measured range. The crusher throat and stageloader top spray transducers changed 21.4 kPa (3.1 psi) and 16.5 kPa (2.4 psi) over their 6.9 MPa (1,000 psi) measured range.

VIBRATION TRANSDUCER

The vibration transducer was precalibrated with a shaker table over a range of 10 to 1,500 Hz and 0 to 12.7 cm/s (5 ips). The vibration transmitter was not calibrated after removal from the mine. The vibration values for this study were used for relative comparison of operating versus nonoperating conditions.

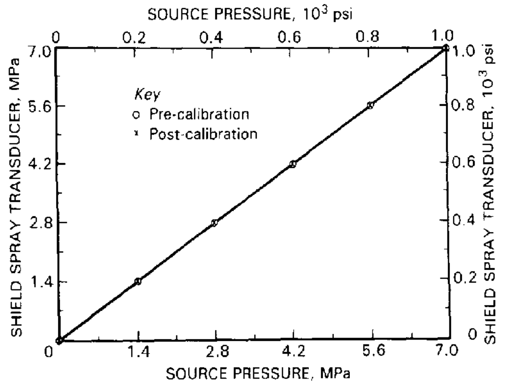

Figure 8.—Shield canopy water spray pressure transducer, pre- and postcalibration.

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