COMPUTER-BASED REMOTE CONTROL OF A HIGHWALL MINING SYSTEM

By

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ABSTRACT

The U.S. Department of Interior’s Bureau of Mines, in conjunction with a cooperator in the U.S.A., are developing a new highwall mining system (HMS) for coal extraction in unweaponized and active contour strip mines. This prototype system is comprised of a computer-based remote control (CBRC) system to monitor and remotely control a thin-seam continuous miner (TSCM) and a 76 m long multiple-unit continuous haulage (MUCH) conveying system, plus other manually-operated support equipment located on the highwall bench.

The TSCM and MUCH coal haulage system are both controlled remotely by a single operator in a protective enclosure at an ergonomically-designed workstation located on the highwall bench. Two other personnel work on the bench to operate other support equipment. Full-scale mock-up fabrications were employed in the design of the unique remote control operator workstation.

The HMS should allow the safe and economical exploitation of increased coal reserves where they outcrop in hilly regions of the United States. It should also be competitive with conventional auger mining and other coal extraction techniques, with a productivity goal at a highwall site of 20 tonne/man/h. Extensive simulated surface tests of the miner and haulage system should be completed in early 1988 at Bureau test facilities at Pittsburgh, Pennsylvania. These will be followed by actual coal production trials of the entire system in 1988 at a highwall site in West Virginia/USA.

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INTRODUCTION

In the United States, large quantities of unweaponized coal reserves exist in highwall outcrops adjacent to abandoned or active strip mining sites. It is estimated that 40,000 km of highwall coal remains untouched, with 16,000 km of this in the Appalachian coal fields alone. Very little extraction of these coal reserves occurs as current methodologies are either inefficient, unreliable, uneconomical or lack the specialized qualities required by the unique mining situation.

PRESENT STATE-OF-THE-ART

Presently, the most common method of extracting highwall coal is by auger mining, using single, double or triple head systems. Auger mining allows the extraction of limited quantities of coal that cannot be economically strip-mined and yields very good productivity ratios of up to 6 tonne/man/h. However, these advantages are counterbalanced by disadvantages including that: 1) auger mining usually sterilizes the coal that lies beyond the reach of the augers, preventing extraction when other improved mining technologies become available, 2) it is difficult to precisely control the cutting path of augers, and 3) the depth of penetration is very limited due to losses (caused by friction and transportation of the cut coal along the length of the auger flights) that occur between the highwall bench-based power unit and the cutting face. A typical auger mining system is capable of penetrating only 45 m into a highwall.

Progress has been made in the development of other methods for extracting highwall coal. Examples noted by Kiser, Visorayev and Dusak (1981) include several extended-depth highwall auger mining systems, surface shortwall systems and surface longwall systems. Hybrid systems have also been developed that couple the cutting head from a traditional continuous miner to a subsystem that provides haulage and extension/retraction functions. However, none of these systems has achieved widespread acceptance due to factors such as equipment reliability, high initial capital investment.

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high operating cost, low productivity, personnel safety and environmental concerns.

As early as 1965, attempts were made to mine highwall coal by employing remotely controlled continuous miners coupled to haulage systems. An example is the "Carbide Miner," developed by the Carbide and Carbon Chemicals Company. The design of this system was later licensed by the Joy Manufacturing Company and resulted in the "Pushbutton Miner." These systems were not commercially successful because of cost, reliability, special maintenance requirements and operator control design.

PROPOSED MINING SYSTEM

Since 1981, the U.S. Bureau of Mines has worked to develop a CBRC system to operate TSCM machines from a location out of the line-of-sight to the extraction face. Initial interest in such a system stemmed from the fact that there is insufficient space onboard a TSCM to house an operator in a compartment that provides protection from ground falls. The original remote control system was intended to be used in deep underground mines using a room-and-pillar mining configuration. The system, once appraised by the Bureau's work, proposed a joint venture where the developed remote control system would be adapted to control the operator's proprietary highwall mining system (patent pending). Following discussions and analysis, the Bureau determined that such a mining system held merit and would mutually benefit both parties. The analysis concluded that recent advances in closed-circuit video systems, electronics, sensors and ergonomic design could overcome the problems associated with earlier attempts to mine highwall coal using remotely-controlled, continuous-miner based systems. Therefore, a Memorandum of Agreement was formed between the Bureau and the cooperators. As part of the agreement, the cooperators supplied a new TSCM to be extensively modified by the Bureau for remote control. An additional Memorandum of Agreement was later formalized that allowed the cooperators use of the Bureau-developed MUCH coal conveyance system.

Since 1985, the cooperators and the Bureau have worked together to develop this unique mining system that will allow the safe, economic extraction of untapped highwall coal reserves. A minimum of mining personnel will be required to operate the HMS; because no personnel will be permitted in the mined workings, very safe operation is anticipated.

Fig. 1 is an artist's conceptual drawing of the HMS. It is composed of a Jefflery model 102HP TSCM, the MUCH conveying system, the CBRC system and support equipment based on the highwall bench. A laser, located near the mouth of the active entry (with its beam aligned to a target mounted on the TSCM), provides the capability to maintain parallel or other desired entry orientations.

The HMS is controlled from a protected, human-engineered operator station located on the highwall bench. The CBRC system supervises communications between the operator and the mining equipment. Two microprocessor systems are used—one in the operator station and the other on the TSCM. Operator commands, audio/video signals and sensory data are transmitted between the station and the mining equipment over small cables run alongside the standard power and water lines.

A goal of the HMS mining plan is to minimize the time that the cutting and haulage equipment spend beneath the highwall, by advancing and retracting the equipment as quickly as possible. Thus, the mining plan calls for sustained operation and only rudimentary roof support at the assumed weakest area of the mined entry, near the highwall face. Factors that will influence the ability to achieve the goal include: 1) roof and floor conditions, 2) equipment reliability, and 3) an adequate operator workstation design to allow equipment control over extended time periods (up to ten h of near continuous operation).

Expected benefits

The HMS appears capable of mining certain coal reserves not considered extractable in the U.S. by present systems. Because there are no coal cutting and haulage power losses associated with increased depth of penetration into the highwall, the system is theoretically capable of mining coal over 1000 ft from the highwall face. The HMS employs a unique, ergonomically-designed, operator control station and requires only three workers. This should provide high worker productivity, with a goal of 20 tonnes/man-h. Additionally, the development of the CBRC system is important because the technology employed bridges the gap between current mining methods and future, highly automated mining systems in both surface and deep mines.

DETAILED DESCRIPTION OF THE HIGHWALL MINING SYSTEM

The HMS is composed of an integrated collection of subsystems and components. The unique design and intended application of the mining system required that: 1) proven components be assembled in original configurations, 2) prototype equipment, such as the MUCH haulage system, be employed, and 3) completely new subsystems and components be constructed.
Many of the electronic and mechanical components employed are available "off-the-shelf," with proven track records for high reliability.

**CONTINUOUS MINER**

The system employs a Jeffrey model 102HP TSCM modified for "long distance" remote control. The new machine supplied by the cooperator is shown in Fig. 2. This TSCM was chosen because it offers these advantages over other available machines: 1) more precise control of the extraction process is feasible because the cutting auger is suspended into the face by hydraulic rams, while the main body of the miner remains stationary, 2) the flat upper surface of the machine allows video cameras to be placed in positions with relatively unobstructed fields of view, and 3) more space is available for add-on equipment.

**Modifications to the Continuous Miner**

Although the Jeffrey model 102HP TSCM is advertised as a remotely-controlled machine, what this means is that it can be ordered from the factory equipped with either a radio or tethered control module that allows the operator to be positioned 6 to 15 m from the immediate face area. The TSCM received from the cooperator was equipped with the tethered control module.

Considerable effort was expended to adapt and retrofit the TSCM with the Bureau's CBRC system. This included the addition of two color video systems, explosion-proof housings containing the electronics, and hydraulic, temperature, current, sound, linear displacement, methane and heading sensors.

Modifications to the TSCM to allow operation through the CBRC system included: 1) selecting locations for, mounting and wiring the electronic sensors, explosion-proof electronic enclosures, color camera assemblies and laser alignment target, 2) adding structural members to the rear of the machine to protect the computer system and allow the addition of components for the cooperators' "emergency" retrieval system, 3) extending the width of the cutting auger and the length of the conveyor tail boom, 4) developing and
installing a subsystem to reset the computer and the miner when the breaker is activated. The system is capable of handling a variety of tasks, including:

1. Designing the circuit for the remote operator station.
2. Installing a subsystem for installing a subsystem for treating pressurized air used to clean the camera viewports, and
3. Installing a subsystem designed by the
4. Cooperating for correcting the position of the machine in relation to the roll of the coal

The Jeffrey 102HP TSCM as modified by the Bureau of Mines is capable of operating in seam heights ranging from 899 to 1219 mm. This compares with a standard machine that is capable of operating in seam heights from 813 to 1210 mm.

HAULAGE SYSTEM

Although the design of the IM7S allows for the ease of a variety of continuous haulage systems, this first prototype version employs a modified version of the Bureau’s MUCH system. The MUCH system, as shown in Fig. 3, was

![Fig. 3 - Multiple-unit continuous haulage (MUCH) system.](image)

developed by the Jeffrey Mining Machinery Division of Dresser Industries, Inc. under a former Bureau contract. As described by Evans and Mayercheck (1988), the MUCH system was originally developed to improve productivity and safety in room-and-pillar deep mining by providing a continuous, self-tracking, rubber-tyred, face haulage system to reduce the inefficiencies of conventional shuttle car haulage systems. The MUCH system consists of twelve vehicles, which provide coal haulage over a distance of 76 m and features a unique, patented linkage that allows each vehicle to automatically track and re-track with only two operators. The system is capable of making 90° turns.

Each MUCH vehicle has an integral chain conveyor and features four-wheel steering and two-wheel drive. The vehicles are connected by a unique mechanical self-tracking steering system (U.S. Patent No. 4,382,607), which couples adjacent vehicles into a train with automatic mechanical tracking and re-tracking. The steering system enables all the vehicles to track the path of the preceding vehicle at 24 m/min. Coal is transported along the conveyor/vehicle train at a maximum rate of 12 tonnes/min.

As originally designed for deep mining applications, the train of vehicles was to be steered by an operator in the lead vehicle and an operator at the cutby end. For the IMS, steering of the lead vehicle is being modified by the cooperator to automatically track the path of the TSCM during mining. Limited steering capability was originally provided on the discharge vehicle and will be utilized when the mining system is being retracted from the highwall entry.

The current MUCH system consists of twelve vehicles: one lead vehicle, ten intermediate vehicles and one discharge vehicle with a bridge conveyor. Intermediate vehicles could be added or removed from the train to suit the mining site requirements. The length of the present system to include the bridge conveyor is 76 m. The receiving hopper of the lead vehicle is extended by 2286 mm, compared to an intermediate vehicle, to reduce the frequency at which the train must be "jogged" to follow the TSCM discharge tail-boom during the mining cycle. The bridge conveyor transfers out coal to portable storage facilities located on the highwall bench.

HIGHWALL-BASED SUPPORT EQUIPMENT

Much of the highwall-based support equipment is proprietary property of the cooperator, with U.S. and foreign patents having either been applied for or granted. Thus, specific details of the support equipment will be limited to generalizations on the equipment functions.

Mainframe structure

The cooperator has designed and fabricated a massive mainframe structure that will be situated in front of the highwall entry being developed. The structure will be transported from one active entry to another as mining progresses along the highwall bench. The primary functions of the mainframe structure are to: 1) enclose and protect the remote control operator station, 2) house a cooling system for the electric auger motors on the TSCM, 3) house a system that will allow the
The RMS requires that control signals be transmitted via a network of video and sensory information be sent through the system in the mine. The main objective was to maintain a straight course by using the laser alignment guidance system.  

The operator station to the TSCM and the slave operator stations (SOS) require a high level of reliability and safety. The SOS must be able to respond to any emergency event, such as if a slave occurs, and 4) act as a reference point for the laser alignment/guidance system.

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The CBRC system is built around two computer systems, two closed-circuit video systems, sensors and support electronics added to the TSCM, and a human-engineered workstation that includes video and sensor displays, machine controls and a specialized task chair. The CBRC system was specifically designed as an integrated package to control the HMS.

Communication computers. As described by Schiffer [1986], the core of the CBRC system is two microcomputer systems: one the "HOST," located in the operator station, and the "SLAVE," located on the TSCM. Several advantages are derived from the use of computers including: 1) machine function control and sensory data are converted to a form easily sent over only two twisted-wire pairs, 2) a wide range of sensory information is collected at the face area and displayed to the operator on user-friendly output devices, 3) diagnostic functions are incorporated, simplifying maintenance and repair of the electronic hardware, and 4) operational and hardware changes are easily achieved. Project goals in the development of the CBRC system included reliability, low cost, use of off-the-shelf hardware and operational flexibility.

The TSCM-mounted SLAVE computer system is essentially a computer-controlled input/output port. When a valid command is received from the HOST, the SLAVE outputs an appropriate command sequence that activates relays inside the TSCM. At precise intervals, the SLAVE also samples data on its input ports and analog-to-digital converter channels, encodes the information, and transmits it to the HOST. Because the SLAVE is mounted on the TSCM, the electronic components are packaged to fit within a compact, shock-mounted, custom-fabricated, explosion-proof housing. The primary function of the HOST computer system is to command the SLAVE based on input received from the operator. Validated and encoded data transmitted from the HOST causes the SLAVE to operate the mining machinery and video system functions. The HOST also decodes and checks data packets transmitted by the SLAVE. If sensory data is received, it is processed and displayed to the operator on 16 digital bargraph displays. As shown in Fig. 4, the operator station-based HOST computer system is located in a cabinet that houses the video monitors and several power supplies.

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The HOST and SLAVE computers continuously communicate with each other. The communications link between the two computers is critical; for error-free remote control to be maintained, data must pass intact through two twisted-pair wires contained in the signal cables. The need for error-free transmission of data between the computers, which may be 100 m or more apart, is complicated by any electrical noise at the highwall mine site. This challenge is met by employing short-haul modems, transient suppression devices and special data encoding and decoding software. If faulty data is received by either the HOST or SLAVE, it is discarded and the data is re-transmitted.

As the RNG will be powered by portable electrical power generating units, electrical transients and power fluctuations will surely occur. Because these electrical aberrations cannot be tolerated by computer systems, they are eliminated in the CBMC system by employing un-interruptable power supplies (UPS) to run the computers. As a precautionary step, the UPS inputs are connected to heavy-duty, industrial-grade, power line transient suppression devices.

Machine video system. The operator's primary means of monitoring and controlling the mining system is through a closed-circuit color video system. The video system provides the operator with information on: 1) general or emergency conditions at the working face area, 2) the position of the cutting head relative to the coal/roof interface, 3) flow of cut coal along the conveyors, and 4) the position of the TSCM relative to the laser alignment units.

Two color video camera assemblies are mounted on the TSCM. One assembly, located above and forward of the SLAVE computer enclosure, is fixed and provides an overall view of the area including the alignment laser target. The second camera assembly is located on the right fender of the miner and includes a hydraulically driven pan and tilt mechanism. This camera can be remotely positioned by the operator to an area of interest, such as the haulage system, and serves as a backup for the main face camera in event of failure. Both vision systems consist of a compact solid state color camera coupled to a motorised zoom lens with adjustable iris, focus and zoom. Control of the camera functions is accomplished remotely from the operator control station. Each camera/lens is housed in a custom-designed, explosion-proof enclosure with an anti-reflection coated optical window. In addition, the enclosure was designed to be water and dust proof. Special considerations were given to shock-mounting the camera/lens in the enclosure, and, to also shock and vibration isolate the enclosure from the machine mainframe. Considerations were also given to prevent dust and fine water spray from accumulating on the optical window and deteriorating the resolution of the video system. This was accomplished by passing a curtain of air across and away from the front surface of the window.

Illumination for the video system consists of four compact halogen-type headlamps. Two headlamps are mounted towards the front of the miner and aimed at the face. The other two are each dedicated to the video cameras and mounted adjacent to them on the same base. The lights are aimed parallel to the axis of the cameras; in the case of the movable camera, the light moves with the assembly. Each video system assembly also contains a microphone to provide aural information to the remote operator. The microphones are housed in a specially designed enclosure which environmentally protects the microphones from dust and water while maintaining good frequency response. Care was also taken to shock and vibration isolate the microphones from the machine mainframe.

To prevent damage to the video systems from rock falls, etc., they are protected by robust shrouds. The protective shrouds are not directly mounted to the video system assemblies; instead, they are attached to the machine mainframe. Fig. 5 shows the pan/tilt video system assembly with its protective shroud in the background.

Other sensors. Sensors mounted on the TSCM monitor important events at the working face and selected parameters related to the operation of the mining equipment. This information is transmitted and displayed to the remote operator and augments visual information from the dual, closed-circuit, color video system. Fig. 6 shows the placement of the sensors on the TSCM; Table 1 presents the sensor specifications.
only 16 channels were available on the SLAVE computer to transmit analog data.

**Operator station**

The operator station structure, shown in Fig. 7, was designed and fabricated by the cooper and delivered to the Bureau for installation of the operator workstation. The structure was designed to: 1) provide substantial protection from highwall rock falls that could occur at the mine site, 2) allow the operator to view the highwall-based equipment through two large windows, and 3) provide sufficient space for the operator, controls, displays and additional electrical equipment. The remote control booth was extensively modified by the Bureau to attenuate outside sounds and provide a comfortable work environment.

Fig. 7 - The operator station structure.

Fig. 6 - Placement of the sensors on the TSNH.
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and displays. The success of the mine equipment is highly dependent on the remote operator's proficiency and control over the equipment for extended time periods. An existing deep mining CBEC system was modified from its original design to be specifically for controlling mining equipment. A task analysis of the operator's function concluded that the operator of the equipment could be compared to a "video game" for an extended period of time—the subtasks are repetitive and require intense mental and good manual dexterity. With considerable effort, the major systems of the operator interface were designed to operate in a comfortable and readily available position, with a good degree of freedom for the operator to control the equipment. This includes the operator's ability to change seating positions, while still maintaining all the monitoring functions within easy reach.

A single operator control room, ergonomically-designed control room, and good manual dexterity. With considerable effort, the major systems of the operator interface were designed to operate in a comfortable and readily available position, with a good degree of freedom for the operator to control the equipment. This includes the operator's ability to change seating positions, while still maintaining all the monitoring functions within easy reach.

The major functions of the MEC system, and some functions of the operator interface, were performed by five or more operators usually employed in traditional deep mining systems. The operator is seated in a fully adjustable task chair, with digital displays mounted in an easily accessible position. The sensors mounted on the mining equipment are located in a module situated in front of the operator. This module also contains the bench-top auxiliary equipment. Main operational controls are located in a hand-held module suitable for use by a right- or left-handed operator.

Secondary TSM and other controls are placed in a module located next to the right rear seat of the task chair. Dual 453 mm color video monitors are housed in a computer cabinet at an optimal viewing location from the operator's eye position. The operator is given the option of listening to the face sounds through either a pair of speakers or through headphones.

**HMS EVALUATION**

Before being deployed at a highwall production site, the major subsystems of the HMS will be thoroughly tested, debugged, and refined. This work is ongoing at a site specifically designed for this purpose, the Bureau's Mine Equipment Test Facility (METF) located at Bruceton, Pennsylvania. Factors under investigation during the evaluation include: 1) the ability of the remote operator to adequately control the mining equipment based on the video and sensor input; 2) operator stress and fatigue factors; 3) equipment reliability, and 4) estimates of the HMS production capabilities.

**SURFACE TESTING**

The surface testing of the HMS is being conducted at the METF using a systematic approach involving the incremental testing of components and subsystems. This process assures that equipment functions properly, before being integrated into the overall system. The testing commenced with the installation and calibration of the sensors on the TSM. Next, the controls and displays were installed in temporary fixtures. The HOST and SLAVE computer systems were then directly connected to the controls, displays and TSM. Testing was conducted using this setup to determine if the TSM responded correctly to commands from the controls and if the sensor data was properly processed. This phase of testing revealed some problems with the computer hardware and software, which were corrected.

Testing continued with a series of cutting operations using a block of coal-like material consisting of coal, flyash and cement (cemenrite). Fig. 9 shows the modified TSM at the artificial coal block. The cutting tests are being conducted by several operators using the ergonomically-designed workstation. Much of this testing is taking place in a darkened building, with the simulated face area illuminated only by the four headlamps of the machine video system. During these tests, important information is being obtained on the ability to maneuver and operate the miner, solely from information provided by the video systems and the display console. Critical to the success of the mining technique are such factors as judging when the roof and floor...
interfaces are encountered, maintaining a straight course by referencing to the laser spot, and correcting for errors in machine pitch and roll. Although this phase of surface testing has not been completed, results to-date have been positive, indicating that the CBRC system will provide the operator with adequate control of the mining system.

After tests of the CBRC system with the TScM are completed, units of the MUCH haulage system will be stationed behind the miner for evaluation. Testing/refinement of the cutting/haulage systems will include the capability of the lead MUCH vehicle to automatically track the TScM.

After the surface evaluation and refinement of the major sub-systems are completed, the complete HMS (including all the highwall-based support equipment) will be deployed at a field site. The first site will be a carefully selected highwall bench located in northern West Virginia. It is fully expected that initial production operation of the HMS will uncover some additional problems requiring correction.

**SUMMARY**

The CBRC system presents to the operator pertinent information on the status of the extraction site and mining equipment, and processes the operator's response to the inputs, in the form of commands, back to the equipment. The unique, ergonomic design of the operator workstation allows the operator to efficiently handle these tasks. In a sense, the operator functions as a "biological processor," making all the decisions on the operation of the mining system.

An obvious future improvement to increase the operational efficiency would be to partially or fully automate the mining cycle. This would require the application of additional sensors, especially reliable coal- to-roof and floor interface detectors, and the employment of much more powerful computers. Such computers would be capable of processing the data from large numbers of sensors to implement correct decisions, translated into responses by the mining machinery, at a speed close to real-time. It is very likely that this type of improvement will be achieved in ten to twenty years, based on continued advancements in computer software, particularly "artificial intelligence" and "expert systems," and electronics. However, for the time being, a human being is the best processor of complex information for this system.

**CONCLUSIONS**

The results of the surface testing to-date have been positive, indicating that the remote operator will have adequate control of the HMS when the system is deployed at production sites.

Computer-aided remote control mining systems represent a present day application of advanced electronic technologies to foster increased coal extraction. It is an area that holds great promise for significantly increasing productivity, operator safety, allowing extended flexibility in selecting mining strategies, and expanding the recovery of coal reserves. Moreover, CBRC systems will bridge the gap between current, worker-intensive methods of controlling mining equipment to automated systems likely to be common in the 21st century.

**REFERENCES**

