

Information Circular 9244

Longwall Automation: A Ground Control Perspective

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**UNITED STATES DEPARTMENT OF THE INTERIOR
Manuel Lujan, Jr., Secretary**

**BUREAU OF MINES
T S Ary, Director**

Library of Congress Cataloging in Publication Data:

Listak, Jeffrey M.

Longwall automation : a ground control perspective / by Jeffrey M. Listak and Deno M. Pappas.

p. cm. - (Information circular; 9244)

Includes bibliographical references.

Supt. of Docs. no.: I 28.27:9244.

1. Longwall mining--Data processing. 2. Ground control (Mining). I. Pappas, Deno M. II. Title. III. Series: Information circular (United States. Bureau of Mines); 9244.

TN295.U4 [TN275] 622 s--dc20 [622'.334] 89-600351
CIP

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cps	count per second	min	minute
ft	foot	pct	percent
ft/min	foot per minute	s	second
in	inch		

LONGWALL AUTOMATION: A GROUND CONTROL PERSPECTIVE

By Jeffrey M. Listak¹ and Deno M. Pappas²

ABSTRACT

This U.S. Bureau of Mines report describes the implications of in-mine ground control on the automated or remotely controlled operation of longwall mining equipment. Perhaps the greatest challenge to longwall automation researchers is the development of systems that will continuously function in the complex and unpredictable underground environment. The high degree of environmental variability, together with conditions brought about by the extraction process, makes complete automation of longwall mining a difficult task. The intellectual thought processes and split-second decision making required to avert disasters are lost when workers are removed from the face. As many mine operators can attest, minor problems, left unresolved, can eventually accumulate and lead to catastrophic consequences. The automation process will have to assess and manage various routine problems that are otherwise resolved through worker observation and experience.

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INTRODUCTION

In 1983, the number of operating longwall faces in U.S. mines peaked at 118 faces (1),³ producing an estimated 16 pct of the underground coal mined (figs. 1-2). By 1987, the number of faces had dropped to 101 (2), yet longwall mining produced over 21 pct of the underground coal mined. It is apparent that longwall productivity is increasing at an accelerating rate. Productivity statistics support this trend. In 1983, 64.7 face tons per worker day were being produced. By 1987, this number had doubled to 139 face tons per worker day (3-4). This marked increase in productivity may be attributed to improvements in longwall operation techniques, a leaner work force, and equipment sophistication. This trend will probably continue, especially with the development of semiautomated and, in the future, completely automated longwall faces.

With few exceptions, large mining companies have come to realize that the only way their mines can stay competitive in the domestic and world markets is to adopt

longwall mining methods (5). Consequently, underground coal mining is moving toward high-production longwall systems. Currently, much time and effort are being spent in the development of semiautomated and automated production longwall systems. Although advances have been made, several key factors related to underground conditions need to be integrated into the overall design of an automated longwall system. Adverse geomechanical conditions are one of the most debilitating problems faced by longwall operators in terms of both production losses and accidents. A seemingly insignificant ground control condition could eventually interrupt the activity of the shearer, shields, or conveyor, any of which interruptions would halt the production of coal. Therefore, the success of an automated longwall system will depend on the ability of all the automated components to overcome geomechanical problems encountered during the course of longwall panel extraction. The initial capital expenditure required for providing face support to a longwall system emphasizes the necessity of coping with ground control conditions. Figure 3 shows that over 70 pct of the total cost of longwall face equipment goes toward the cost of the longwall supports.

It is the intent of this report to review the state of the art in longwall automation and to identify ground control conditions that may affect the operation of an automated longwall system. This research is in support of the U.S. Bureau of Mines goal to develop longwall systems that allow for continuous and autonomous operation.

³Italic numbers in parentheses refer to items in the list of references at the end of this report.

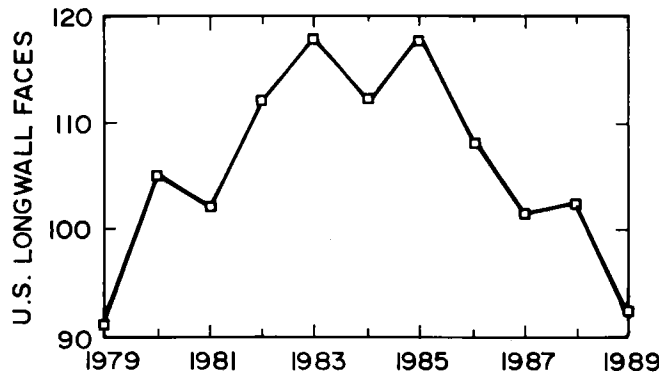


Figure 1.—Number of U.S. longwall faces.

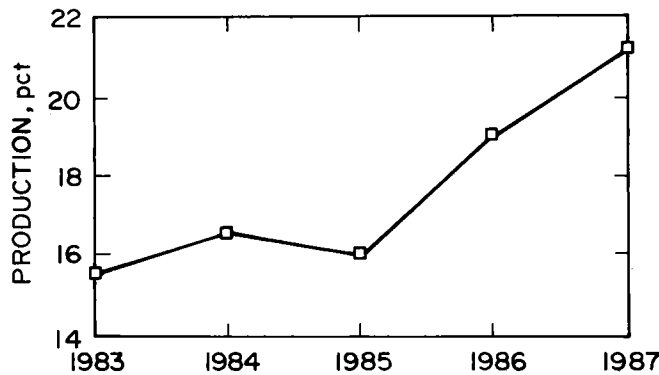


Figure 2.—U.S. longwall production.

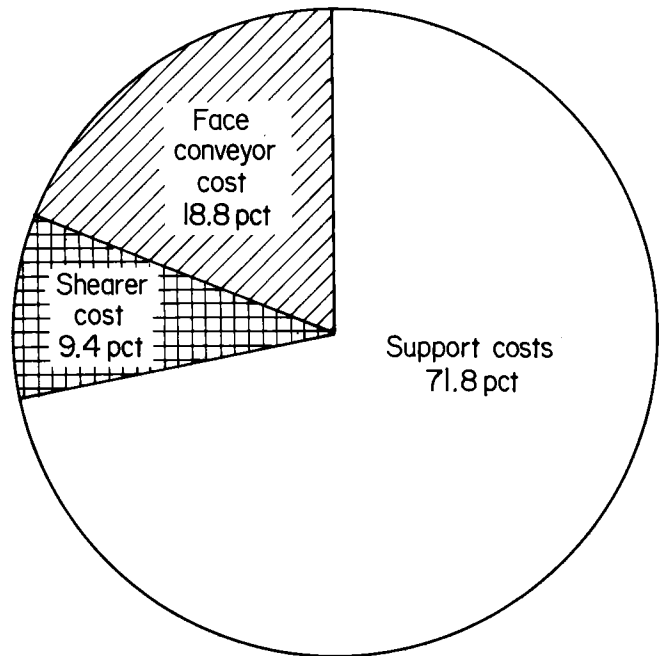


Figure 3.—Cost breakdown of longwall components.

BACKGROUND

The need for longwall automation was first recognized and addressed by the British in the early 1960's, with the Remotely Operated Longwall Faces (ROLF) program of the National Coal Board (NCB). This ambitious program attempted to automate the longwall system as a whole; however, at the time, mechanization was not developed to the level of reliability necessary to make automation feasible (6). By the end of the 1960's, the program was terminated; the lesson learned was that, for an automation program to be successful, a step-by-step approach of looking at each longwall component separately is required. The results of this work laid the foundation for the development of electrohydraulically controlled supports, which utilize an electrically activated compacted solenoid valve for controlling the hydraulic systems for the roof supports (7). Although it took nearly 20 years for the electrohydraulically controlled supports to become commercially available, this technology was a major contribution to automating the longwall mining system. A detailed description of electrohydraulic control of supports is presented later in this report, in the section "Roof Supports."

Another NCB initiative, known as the Advanced Technology Mining (ATM) program, was aimed at improving production and productivity on longwall faces by consolidating the reliability of proven equipment and moving in small steps toward automation (6-7). Out of this program developed two types of nucleonic sensors for detecting the coal-roof interface as the shearer is cutting. The first nucleonic probe basically consists of a transmitter with a radioactive source, usually cesium-137, and a receiver that detects the radiation. The gamma-ray backscatter device consists of a gamma radiation source that is directed onto the roof material and a method of radiation detection to monitor the backscattered radiation from the roof (8). As shown in figure 4, the sensor, known as the gamma-ray backscatter sensor, is enclosed in a housing positioned near the surface to be measured (9). A narrow beam of gamma rays is directed against the rock and is subject to scattering processes and attenuation. The amount of incident rays that are backscattered is inversely proportional to the density of the rock type. Figure 5 (10) illustrates the relationship between backscatter and coal thickness. In order for the probe to work accurately, it has to be in close contact with the surface of the roof; an air gap or void significantly reduces the accuracy of the results. In addition, the presence of a radioactive source in the probe was a major detriment toward further development. From these disadvantages evolved the second sensor, referred to

as the "natural gamma background sensor" (fig. 6A). This system allows the coal thickness above the shearer to be measured using the background radiation naturally emitted by most strata composed of shale (6). Radiation from the roof rock is attenuated exponentially by any coal left in place (8, 11-12). The coal thickness can be measured using an empirically determined attenuation curve, shown in figure 6B. Voids and air gaps are not a problem with the natural gamma background sensor; however, the probe does not work for nonshale strata.

By 1980, the second probe was refined and mounted on the shearer along with a computer-based control data transmission system and was termed the "System 70000" (6). This system has recently become commercially available as the Machine Information Display and Automation System (MIDAS)⁴ (13).

At the same time the NCB's ATM program was being developed, the U.S. Bureau of Mines began its longwall automation program focusing on shearer guidance sensors to detect the seam roof or floor interface. Three types of systems were developed (14):

- Vertical Control System (VCS).—VCS sensors include coal interface detectors, last cut height sensors, and interface connections to the shearer drum arm actuators and controls.
- Face Alignment System (FAS).—FAS sensors include coal face alignment sensors measuring the yaw and roll, and interface connections to the roof support and shearer tilt actuators.
- Master Control System (MCS).—MCS components include the software, controls, and information display necessary for operators to control the longwall operation from the headgate location.

When the U.S. Department of Energy (DOE) took over some of these Bureau projects, the VCS was field tested. Unfortunately, the trial run was discontinued owing to very severe ground control conditions. The DOE continued to work on surface recognition and coal depth measuring sensors. These sensors and detectors included nucleonic, electromagnetic, radar, and machine vibration types.

Recent developments in longwall automated systems are presented in the section "Longwall Automation State of the Art."

⁴Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

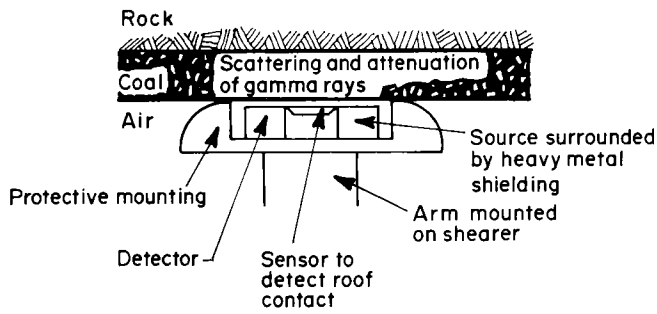


Figure 4.—Representation of gamma ray backscatter device. [Adapted from Wood (9)]

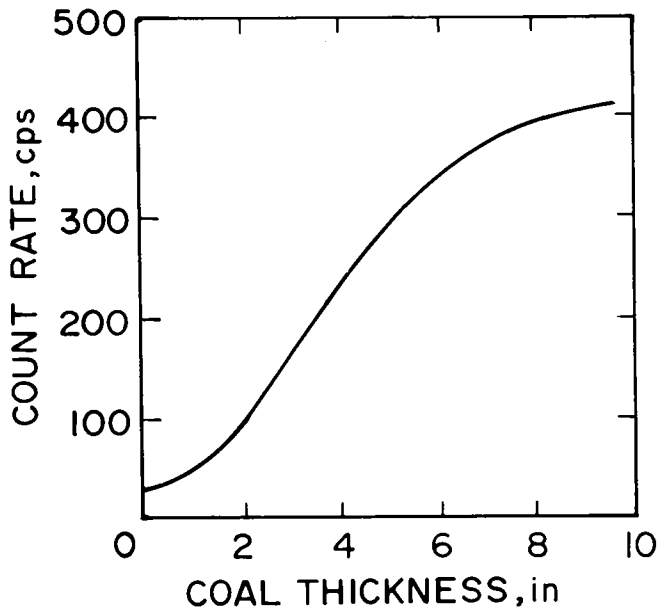


Figure 5.—Relationship between backscatter count rate and coal thickness. [Adapted from Clayton (10)]

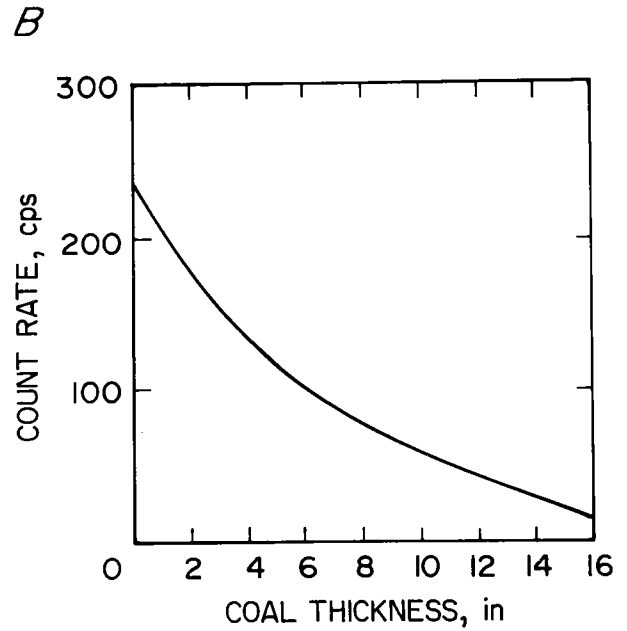
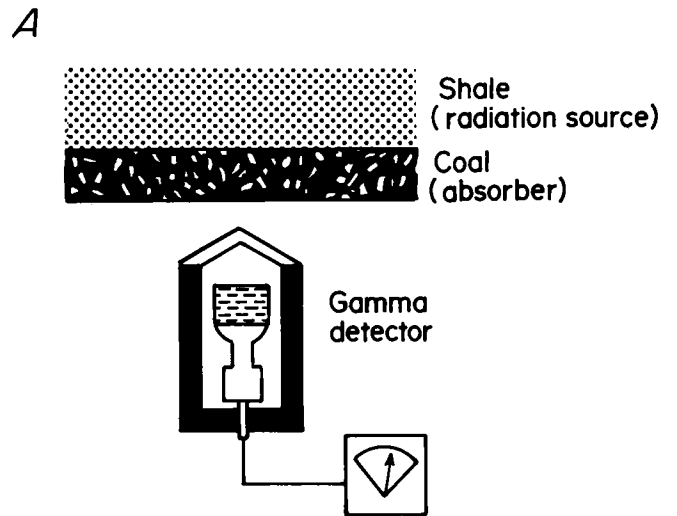


Figure 6.—Natural gamma radiation sensor. A, Schematic representation; B, calibration curve. [Adapted from Tregelles (12)]

LONGWALL GROUND CONTROL

Longwall ground control can be defined as a method of managing an unstable underground opening resulting from the redistribution to roof support elements of forces induced in the roof, rib, and floor during the mining process. Longwall mining ground control is of paramount

importance because effective strata control is to the coal operator's advantage in mining the coal, while ineffective control is to the coal operator's detriment in that bad conditions could result in the abandonment of the mine section or entire mine.

There are three major aspects of ground control that need to be considered when addressing the longwall automation program: the ground control problems inherent in the longwall method of mining, the ground control problems stemming from the changing geologic conditions found in all underground mines, and the unique ground control problems related to the different designs and layouts of longwall panels.

PROBLEMS INHERENT IN LONGWALL MINING

The longwall system of mining coal in 665- by 5,000-ft panels (average dimensions) with the roof caving behind the face and several gate road entries separating the panels presents ground control problems unique to underground mining. The total extraction of a large block of coal causes high stress concentrations, along the face and in the gate roads, and poses some difficult ground control problems depending upon the competency of the immediate and main roof rock. The following areas need to be considered for the successful design and implementation of an automated longwall system.

Pressure Distribution

When the mine entries are developed, the preexisting stress equilibrium is destroyed because of the extraction of the coal. The weight of the overburden previously supported by the excavated coal must now be carried by the neighboring solid coal in the panel and the pillars. These regions, where the vertical pressures exceed the average overburden pressure, are referred to as the "abutments" (15). Figure 7 shows a typical pressure redistribution pattern including the front and side abutment and the pressure buildup in the gob. In the overall design of an automated longwall system, the pressure distribution along the face and gate roads needs to be examined for the following reasons: (1) pillars must be sized to support anticipated loads, (2) roof falls are inevitable under some extremely poor roof conditions and the automated system must be protected from such events when they occur, and (3) system flexibility is required to respond to changing conditions.

Bumps

In some longwall mines the problem of mountain bumps or pressure bursts has become a major ground control concern. It is thought that bumps or bursts are triggered by the excessive loading of the pillars because of the massive overburden, which exceeds the bearing strength of the coal and results in a sudden and violent rupture of the face or supporting gate road pillars. Although bumps can occur in all types of mining methods, this phenomenon is usually more pronounced in deep mines with massive lithologic members present in the overburden (16) and to some degree is affected by the

physical properties of the coal being mined. Some bumps are so large they generate seismic waves that register between 3 and 4 on the Richter scale, cause tremors on the surface, and result in serious consequences underground (fig. 8). Research into bump phenomena continues, and although it is thought that the proper design of gate road pillars can guard against or control bump occurrence, a solution does not appear imminent.

Sloughing

One of the repercussions resulting from the weight of the overburden being transferred to the gate road pillars and longwall face is the sudden failure of portions of the outer skin of the pillar or longwall face (fig. 9). Although most rib sloughing incidents are minor, they may inhibit the movement of coal out of the headgate or halt the production of coal because large pieces of coal or rock fall and choke the conveyor at the stage loader. Consequently, these occurrences would have to be dealt with when considering an automated longwall system.

Cavities

During the longwall mining process, highly fractured roof may be encountered, resulting in falls between the face and support canopy tips (fig. 10). Consequently, these cavities cause the support to lose contact with the roof. If this condition persists, large roof voids develop above the longwall supports, disabling their movement and halting production. Correction of this problem often requires that miners climb on top of the supports and construct cribs to reestablish roof contact. If this condition occurs, it defeats the purpose of having an automated longwall since the miners are subjected to hazardous roof while constructing the cribs. Therefore, it is imperative that measures be taken to prevent the occurrence of cavities.

GEOLOGIC CONDITIONS

Whereas the first set of conditions affecting ground control is a result of the mining-induced stresses during coal extraction, the second set of conditions is a result of the geologic features already present in the coal measure rocks. These naturally occurring phenomena consist of major and minor geologic features and structures, including changing lithology, structural relief, faults, sand channels, slickensides, seam height, clay veins, joints, kettle-bottoms, seam undulations, and soft floor. The occurrence and implication of these features can vary greatly from region to region and often within the same coalbed and/or mine. The effects of these geologic features are magnified by the mining-induced stresses mentioned previously. These geologic conditions need to be confronted for longwall automation to be successful in the U.S. mining industry.

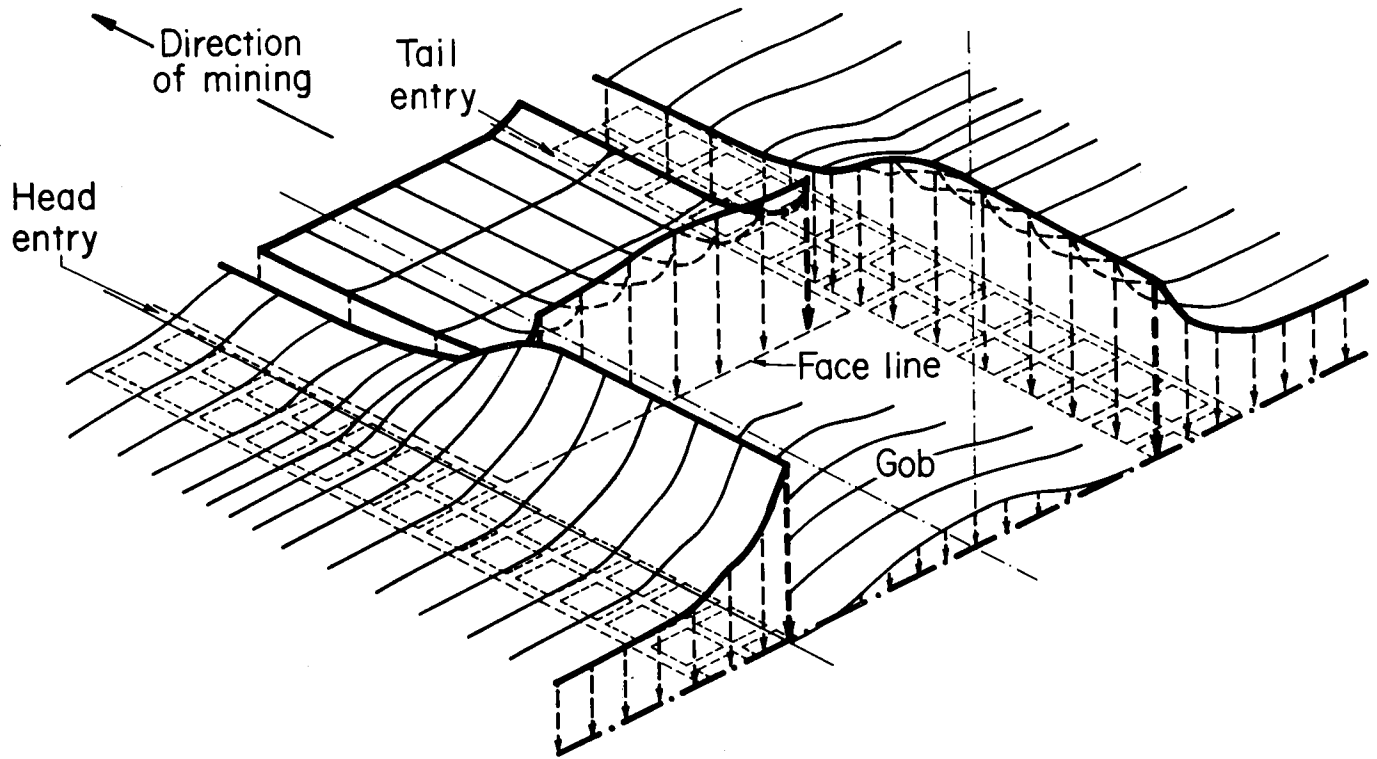


Figure 7.-Stress distribution profile in roof of typical longwall section.[Adapted from Whittaker (15)]



Figure 8.-Entry after bump occurrence.

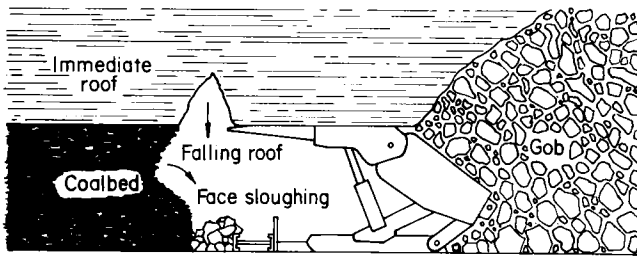


Figure 9.-Face sloughing.

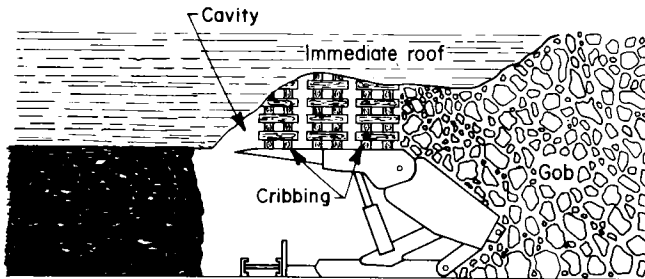


Figure 10.-Cavity or void along longwall face.

Lithologic Changes

Over the extent of a mine, it is not unusual to encounter coal measure rocks that vary in type, property, and thickness (fig. 11). Variation in lateral continuity of roof and floor strata present numerous problems to an automated system. As roof and/or floor rock gradually grade into other rock types, adjustments to equipment are required as the face advances. For example, floor rock that had sufficient bearing strength at the beginning of a panel can become soft as the panel is retreated and thus pose serious problems with the performance of face supports. Similarly, the immediate roof can change from being very uniform and stable to being fractured or friable and, subsequently, prohibitive to mining and damaging to equipment. In extreme cases, massive sandstone roof, which does not readily cave, can create conditions that can lead to excessive loading and, eventually, pressure bursts (bumps).

As the dimensions of longwall panels continue to increase, system flexibility will be required to control the different types of strata encountered throughout the length of the panel.

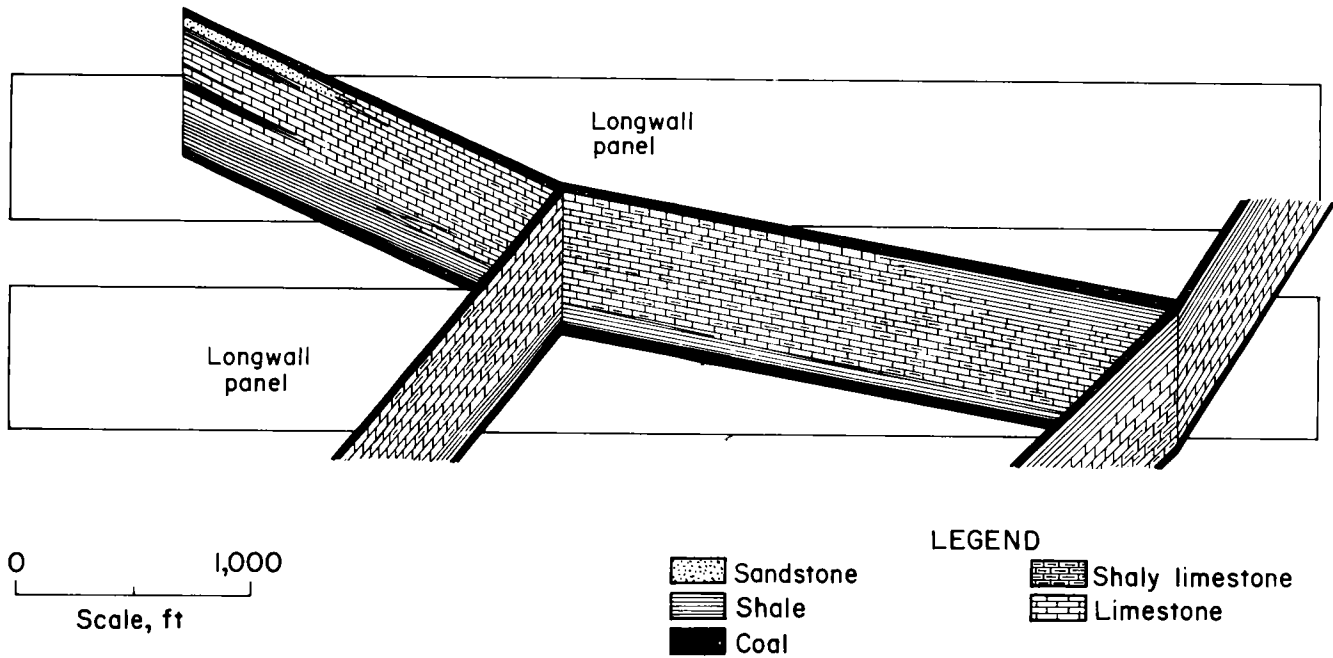


Figure 11.-Fence diagram showing changing lithology above longwall panel.

Structural Relief

Overburden thickness often varies over the length of longwall panels. Topographic relief from 0 to 2,000 ft over short horizontal distances (less than 1 mile) is not uncommon in drift mines located in mountainous regions. Extreme changes in overburden must be considered prior to selection of support equipment so that proper capacities of both face and supplemental support can be implemented to control changes in cover loads.

Stream valleys located above coal reserves also create a unique set of stress-related problems. Topographic relief, formed by years of normal erosion of weak, flat-lying sediments, creates a zone of lateral compression, as shown in figure 12 (17). These premining stress field concentrations beneath stream valleys are often the cause of roof failure brought about by the persistent shearing of the rock at the rib-roof interface. This type of roof failure, commonly known as cutter roof, is nearly impossible to support by conventional support methods.

Panel Continuity

Successful automation of longwall mining equipment is very promising because of the repetitive nature of the extraction process inherent in the longwall mining method and the fact that most coal seams are generally homogeneous and flat lying. However, geologic anomalies such as faults, clay veins, sand channels, kettlebottoms, seam undulations, interbedded seams, variation in seam height, and coal quality create challenges for developers of automation technology. For instance, sand channel and clay vein intrusions can occur periodically without warning and interrupt the otherwise uniform interface between the coal and the roof (fig. 13). In general, operators cut through the intrusion in order to maintain uniform roof height. On the other hand, a sensor that detects the coal-rock interface may attempt to follow the irregularity, causing inconsistencies in the roof and subsequent problems for roof supports. In the Western United States, the presence of faults can signify a sudden and complete loss of coal reserves, requiring complex mining adjustments (fig. 14). Fortunately, retreat longwall mining offers an advantage in that many of these features are recognized during the development of the longwall panel and prior to the setup of the face equipment. In addition, some of these conditions can be detected and managed with various devices (i.e., remote sensing and electromagnetic instruments).

LONGWALL LAYOUT AND DESIGN

Mines in existence prior to the use of longwall methods were limited subsequently in the use of longwall mining because of Federal subsidence laws, which restrict the

complete extraction of coal beneath surface structures (buildings, highways, cemeteries, etc.). This means careful planning, and oftentimes interruptions, of panel layout and projections to avoid populated areas. More recently, coal mines are being designed to include longwall practices, and as a result, wider and longer panels (super panels) are being developed away from populated areas. Super longwall panels have widths greater than 900 ft and lengths greater than 10,000 ft. The motivation behind this trend in super longwalls is to maximize the production of coal and minimize the long-term effects of surface subsidence. Mining larger panels and mining continuously using an automated longwall face could significantly increase production. For instance, as panel dimensions increase, the frequency of setup and transfer of equipment, a very time consuming process, decreases. However, at some point, equipment transfer to the next panel is required when the current panel is depleted of coal. Equipment recovery areas require special preparation near panel recovery points and have yet to be addressed by the automated process.

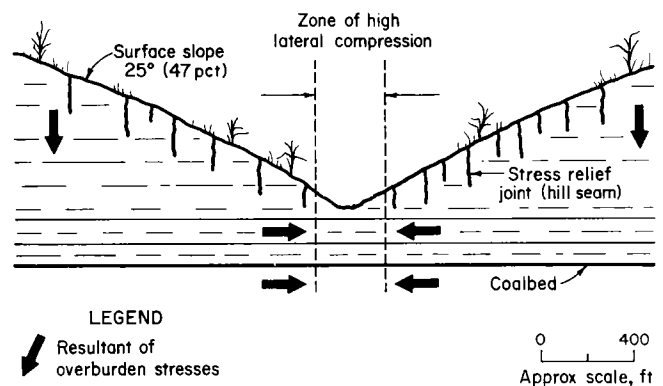


Figure 12.—Stream valley profile.

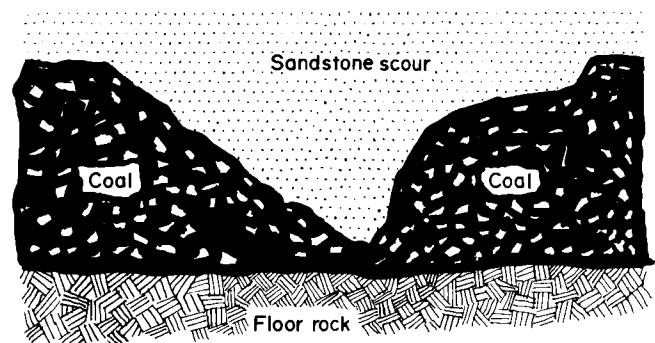


Figure 13.—Sandstone channel.

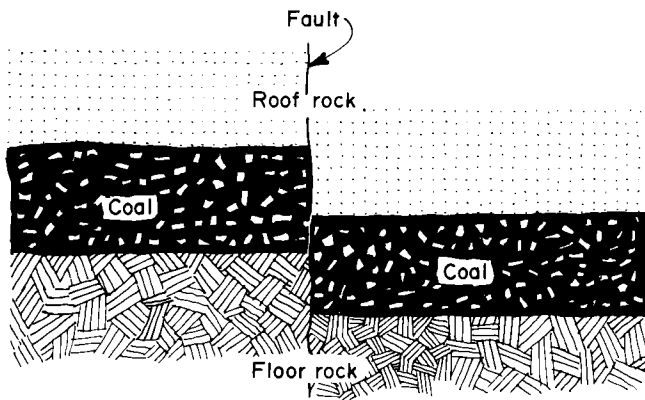


Figure 14.—Fault

Subsidence

Longwall mining allows the roof to cave quickly, uniformly, and completely, thus significantly reducing the long-term damaging and unpredictable effects of surface subsidence usually associated with room-and-pillar mining. Furthermore, a faster advance rate lessens surface deformations by reducing the magnitude of the inclination, curvature, and tension and compression zones ahead of the face, thus enabling the surface to settle with less damaging effects. An automated longwall system will allow for a

LONGWALL AUTOMATION STATE OF THE ART

Longwall mining is a repetitive process and one conducive to automation; however, the extremely harsh underground environment and unpredictable geologic conditions have seriously impeded automation progress. In general, the health and safety benefits that can be achieved from an automated longwall process are the removal of personnel from the hazards associated with immediate face exposure (i.e., dust, roof falls, noise, pinch points, etc.), while the economic benefits are a higher quality product, lower maintenance costs (less bit wear), increase in speed of operation, and better personnel utilization.

Various avenues of automation technology are being explored. Peterson (20) believes that the currently existing longwall component configuration is not the best basis for automation and that if a longwall system were designed specifically for automation, a differently designed system would be produced. However, other researchers (11, 21-24) and manufacturers are working within the currently available equipment specifications. As previously stated, automation of a longwall face is not a new concept; however, initial attempts failed because the technology was not available to make complete automation of individual components an integrated, error-free process. Today, positive technological advancements have been made in automation of individual components, particularly shield

faster rate of advance and tend to reduce the damaging effects of subsidence.

Multiple-Seam Mining

As mines expand, mining below or above previously mined-out areas or presently active mines will become more common, especially in the eastern U.S. coalfields. In West Virginia alone, there are over 50 minable seams in multiple-seam configurations (18). Analysis of ground control multiseam problems shows that factors contributing to interactions may be classified into variables that are fixed by the geologic environment and those that depend on engineering design (19). Although with proper design considerations automated longwall mining can be realized in multiple-seam situations, caution must be exercised when designing gate road and panel projections.

Gate Road Pillar Design Considerations

Another problem related to panel layout is that the design of gate roads often depends upon the prevailing roof conditions in a particular area during development, as well as supply, ventilation, and escapeway requirements. These conditions influence the number of entries and the type of pillar design, either desired or deemed necessary, in longwall gate roads. However, the best pillar configuration for developmental purposes does not always coincide with the most effective ground control methods for maintaining entry stability during longwall retreat mining.

supports. Although advances in shearer automation have been realized, no current breakthrough can be reported.

ROOF SUPPORTS

Shield supports now make up 98 pct of the longwall face support installations in the United States (1). Two major groups of shield manufacturers have clearly influenced the development of shield support application in the United States. The basic structural design parameters of the caliper and lemniscatic shields were introduced by West German manufacturers, and the hydraulic and later electrohydraulic auto-control concepts were innovations of the British (25). Perhaps the most significant advance toward automation has come from the development of electrohydraulic control systems for shield supports. The earlier pilot-operated valve systems have been superseded by electrohydraulic control systems. Electrohydraulic shields were introduced in the United States in 1984. Since then, the technology has been readily adopted by longwall operators (fig. 15). Initially, the move to an electrohydraulically controlled support was made because electrohydraulics provided the ability to move a group or batch of supports from one dustfree location. Also, these types of supports were able to achieve a uniform set

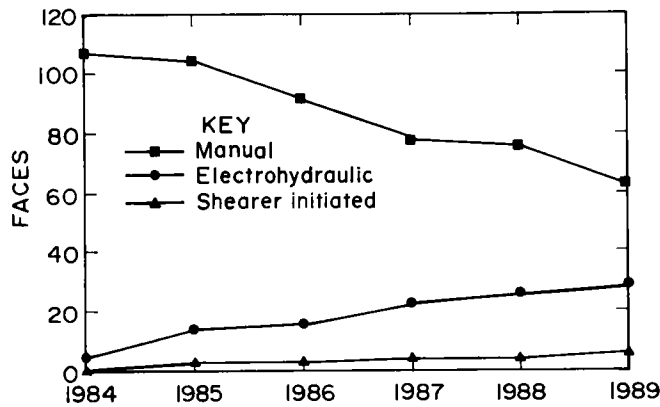


Figure 15.—Trends in longwall shield controls.

pressure against the roof and a much faster cycle time (6 to 10 s per support). Base lifting to overcome soft floor, which had been available on hydraulically controlled supports, has been successfully incorporated into the electrohydraulic systems.

In general, the four major components of an electrohydraulic control system are (1) the hydraulic directional control valves, (2) the solenoid valves, (3) the electronic control unit, and (4) the headgate computer. General schematics of the two systems currently in use are shown in figure 16 (26). The major difference in the systems is the function of the microprocessor contained in each electronic control unit. In system *A*, the signals are sent to a master computer for interpretation. The commands are then issued to cycle the next support in the batch. Each of the supports in the system is dependent on the headgate computer for cycling. In system *B*, the microprocessor on each shield interprets signals and relays commands to the next support to initiate the support cycle. In this system each support is "smart," thus eliminating the need for a master computer.

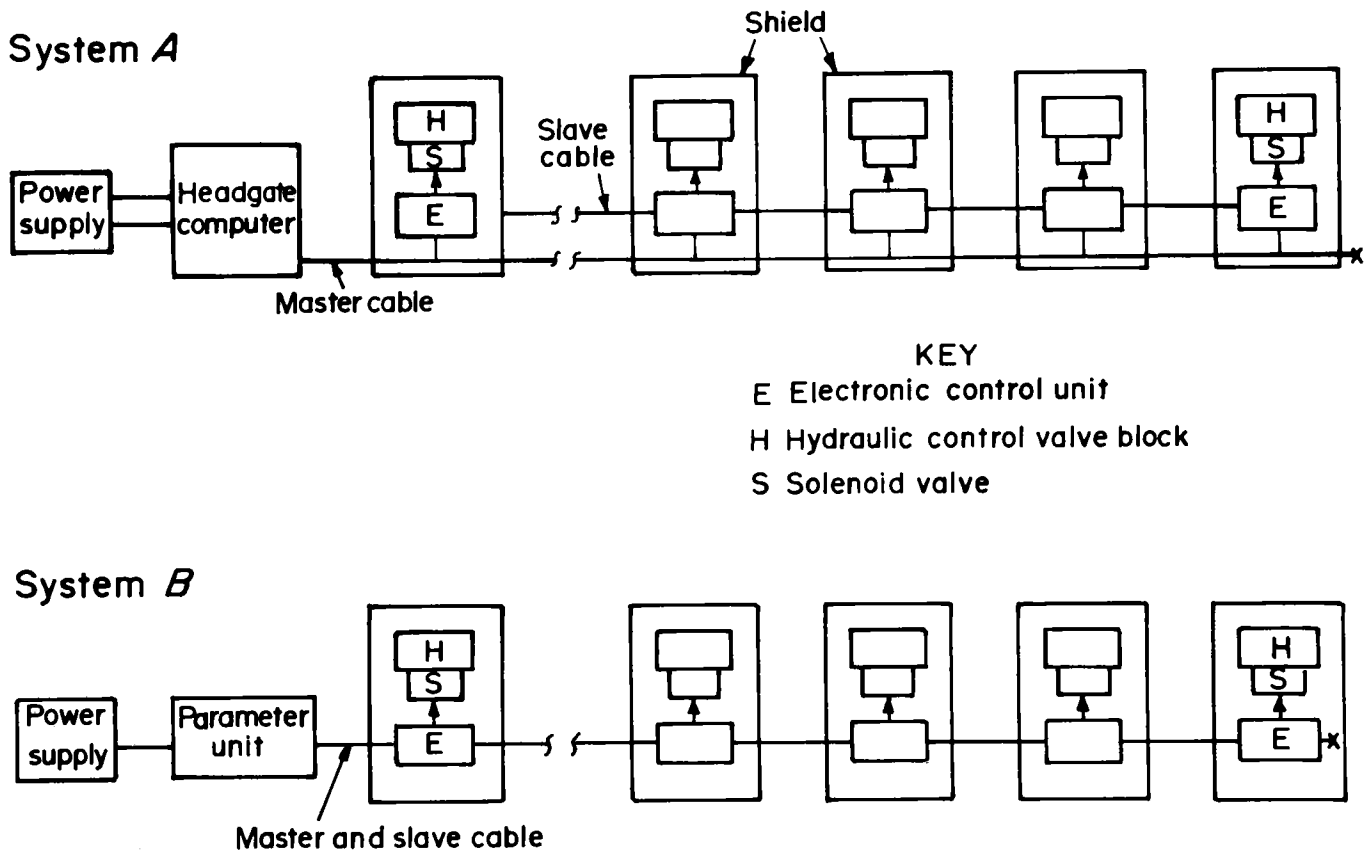


Figure 16.—Schematic showing two types of electrohydraulic systems for shield control. [Adapted from S. Peng (26)]

Initially, electrohydraulic control units were easily incapacitated by dust and moisture migration into the unit's electronics. As a result, supports, although equipped to operate in batch mode, were being activated singularly from an adjacent support. However, reliability has greatly improved and batch advance of supports is now the rule rather than the exception for installations utilizing electrohydraulic control. Support manufacturers agree that, although there is room for improvement, the dependability problems first encountered with electronic components have been sufficiently overcome so that today few, if any, support installations are purchased without electrohydraulic control technology.

The successful application of support advance technology is currently evolving into what eventually will become a completely automated longwall face. Currently, the use of automatic support advance by shearer initiation is gaining in popularity, and there are several installations with this capability. However, the use of shearer initiation for the automatic advance of face supports is at the same stage as that of batch control several years ago (i.e., mines have the technology but are not utilizing it). Two mines that have installed shearer-initiated support advance are reluctant to use it, for different reasons. One operator recognizes its benefits, but mine officials fear that miners are threatened by its presence; they are therefore allowing for an extended training and breaking-in period. The other operator does not see production advantages over its current method of mining. In general, operators are able to meet their contractual obligations by employing methods that do not require the added expense of automated equipment. In addition, some operators are reluctant to adopt technology that is not yet fully proven and thus will wait for the development of more reliable systems.

SHEARER AUTOMATION

To manage the complex conditions that will be encountered underground, it is not enough for shearing machines to be automated. Instead, machine "intelligence" will be required, not only to perform normal operations, but to detect, interpret, and respond to possible changes in normal operations (many of which are ground control related). Computerization has provided the integration of once stand-alone electronic components, enabling on-board intelligence. With the existence of a proven interface on the machine, the addition of feedback sensors can allow for the use of on-board intelligence (27). Some of the early technical endeavors that were the basis for the current state of the art are presented in the "Background" section of this report. A synopsis of the Bureau's robotics and automation research program, by Schnakenberg (28), lists the critical path technology categories for intelligent mining machines (table 1).

Three important areas must be addressed before shearer automation can become practical (9): (1) cutting horizon, (2) face alignment, and (3) shearer position.

Table 1.—Intelligent mining machines critical systems and technologies (28)

<i>System</i>	<i>Dominant components and issues</i>
Basic machine	Mechanical, electrical, and hydraulic systems.
Computer systems . .	Processor boards, operating system; communication networks for real-time, multiple-processor operations.
Machine control	Position, electrical, and hydraulic sensors; computer data acquisition, closed-loop control algorithms, and command language.
Guidance systems . .	Position and heading sensors and systems, obstacle and mine rib detection and registration to map data, computer software for data fusion and filtering.
Coal interface detection.	Coal-strata properties and differences, multidisciplinary systems for real-time sensing of cutting position, artificial intelligence data interpretation.
Diagnostics	Sensors of machine condition, expert system interpretation and analysis, human interfacing.
Planning	Data interpretation, knowledge representation, artificial intelligence, and human interfacing.

Cutting Horizon

The automated shearing machine will replace the machine operator and therefore must execute the functions a human operator would perform using sensory perception. Machine operators maintain horizon control by observing the position of the cutting drums and making adjustments according to the coal-rock interface or the desired thickness of the cut. Shearing can take place at the coal-rock interfaces of the roof and floor, or coal may be left unmined either at the roof or at the floor depending on the competency of the rock or the seam height desired. Sensors have been developed to maintain cutting horizon in a variety of ways; however, the primary purpose is either to differentiate between coal and rock or to determine the thickness of coal left at the roof.

These sensors are in various stages of development, and thus far, no one sensor has been a total success. The sensitized pick transducer uses pick force to guide the ranging drum along the correct horizon by maintaining a continuously updated hardness profile of particular bands within the coal seam (6). The vibration transducer discriminates between the coal-rock interface, while other sensors, such as the natural gamma radiation, doppler radar, and electromagnetic wave sensors, can be used to detect coal thickness left at either the roof or floor. Maintaining horizon control at the floor presents problems for

many of the sensors because there is no way to mount sensors on either the shearer or face conveyor to transmit signals into the floor. The type of sensor utilized on a particular shearing machine would depend on the application desired or on ground control conditions either present or expected.

Face Alignment

During the retreat of a longwall panel, it is not unusual for face equipment to gradually wander out of alignment (i.e., the longwall face is no longer perpendicular to the head and tailgate entries). To correct this occurrence, shearer operators make angle or wedge cuts to straighten the face. British Coal is developing sensors to maintain face alignment (24). Transducers on the support advance rams and distance measurements using a cord transducer located in the gob are two promising face alignment techniques.

Shearer Position

As the shearer traverses the face, cutting coal, the shields are advanced to support the exposed roof, followed by the push or advance of the conveyor, which in turn enables the cycle to begin over again. Since the latter two operations (shield advance and conveyor push) depend upon the position of the shearer along the face, timing during the cycle is critical. An automated system must continually monitor shearer position so that effective advance of supports and conveyor can be performed in proper sequence.

Two types of systems have been developed and successfully implemented to monitor shearer direction and position along the face. One system employs the shearer haulage drive gear as an odometer. As the drive gear rotates, pulses are generated, incremented, and relayed to a central control unit in the headgate at regular distance intervals along the face. The control unit is linked to the roof supports and, by recognizing the position of the shearer, is able to relay commands to activate the support advance and conveyor push at a preset distance behind the shearer.

The other system utilizes an infrared transmitter mounted on the shearer and receivers located on each of the supports (fig. 17). As the shearer moves along the face, the infrared signals are received by the supports and relayed to the headgate control unit. The control unit defines the position and direction of the shearer and conveys commands to initiate support advance and, subsequently, conveyor push.

A summary of shearer system readiness, as compiled by one automation researcher, is shown in table 2 (21).

COMPONENT INTEGRATION

The various sensors being developed for an integrated automated system are presented in table 3. The continual development and reliability of individual components along

with the introduction of microprocessors (computerization) has enabled some degree of successful automation. The successful interfacing of supports and shearer has been achieved through the use of electrohydraulics and shearer position technology. Although advances are being made, the shearer remains the final obstacle in achieving total longwall automation.

Table 2.—Status of shear automation devices (21)

Ready	Shearer face location sensor. Pitch and roll sensors. Coal thickness sensor. Computer and electronics. Digital communications. Error condition reporting. Ability of equipment to withstand environment. Auto floor slave and robotic roof control. Roll stability on floor cut.
Partially complete	Evaluation vibration sensor. Addition of high-performance coal thickness data. Cut control using coal thickness data. Shearer turnaround control.
New work	Integration tests with self-advancing shields. Optimizing shearer and pan designs. Maintenance procedures, documentation, and training.

Table 3.—Summary of longwall automation monitoring devices (9)

<i>Parameter monitored and device used</i>	<i>Function</i>
Cutter position:	
Odometer	Measure shearer position along face.
Infrared transmitter . . .	Do.
Cutter roll:	
Tilt transducer	Measure shearer roll.
Inclinometer	Do.
Horizon control:	
Natural gamma radiation sensor.	Measure roof coal thickness.
Doppler radar sensor . . .	Do.
Sensitized pick force sensor.	Differentiate between coal and non-coal. For locating interface or for horizon control by using marker bands.
Vibration sensor	Measure roof coal thickness, locate coal-rock interface.
Memory pass	Recall preprogrammed cut profile to be duplicated on successive shearer passes.
Electromagnetic wave.	Measure roof coal thickness.
Face alignment:	
Cord transducer	Measure straightness of face, determine angle of face with roadways, and measure advance of face.
Advance ram transducer.	Measure advance of face.

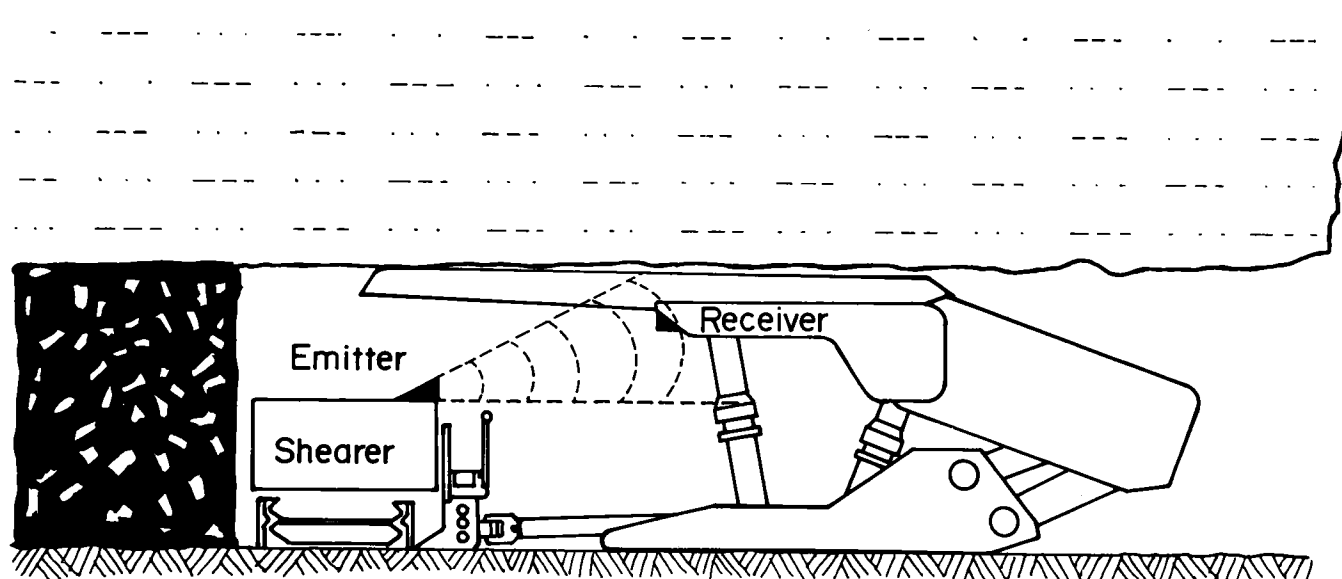


Figure 17.—Infrared technique used for shearer-initiated face advancement. [Adapted from S. Peng (26)]

CONSTRAINTS AFFECTING LONGWALL AUTOMATION

The authors visited several longwall operations throughout the United States to observe the various degrees of automated face equipment in use and to discuss with operators constraints that may limit the further development of automated operations. In general, constraints affecting equipment (shearer, roof supports, conveyors) as well as the mine atmosphere (ventilation, dust, methane) emerge as impediments to an automated system. Ideally, automated face equipment will isolate mine personnel from face hazards while providing significant increases in production; however, compliance with regulations regarding dust and methane concentrations must still be enforced to guard against catastrophic mine explosions. In addition, large production capacities at the longwall face are limited by the capacity of the conveyor, as well as outby haulage systems that transport coal to the surface.

Since the two major active components of a longwall system are the shearer and roof supports, the following sections present ground control and other general constraints to automation that affect these two components.

GROUND CONTROL CONSTRAINTS

Shearer

When personnel are present along the face, problems that arise are immediately diagnosed and remedied. Consequently, by the routine recognition and correction of small problems, major production-stopping problems are averted. The key to successful automation will be the

ability of the equipment to overcome problems routinely associated with daily operations.

Frequent production delays due to shearer stoppages, not related to equipment failure, along the face can usually be attributed to rocks on the face conveyor on the tail-gate side of the shearer that are too large to pass between the shearer and conveyor. These rocks usually fall from the unsupported roof span between the face and the support canopy and must be broken into smaller pieces by a sledgehammer in order to pass beneath the shearer (fig. 18). Large rocks that fall on the headgate side of the shearer also have to be broken to pass from the face conveyor to the stage loader.

Events such as pressure bursts (bumps) and gate road roof falls occur with less frequency but are major production hindrances and, in the case of bumps, pose serious safety hazards. The magnitude of a bump is dependent upon the amount of stored energy in an area. In one mine, a large bump damaged shield supports so severely that extreme measures (blasting) had to be employed to remove one-third of the supports from the face area. In another case, a bump near a shearer twisted and bent the ranging arms of the shearer, requiring costly repairs (about \$1 million). Some western U.S. longwall faces frequently experience small coal bumps along the face as the shearer cuts. These bumps hurl fragments of coal out into the walkway where longwall crews work. Miners protect themselves from flying debris by walking between support legs or by hanging lengths of belt from shield supports in bump areas. The shearer operator, however, must remain in the walkway unprotected.

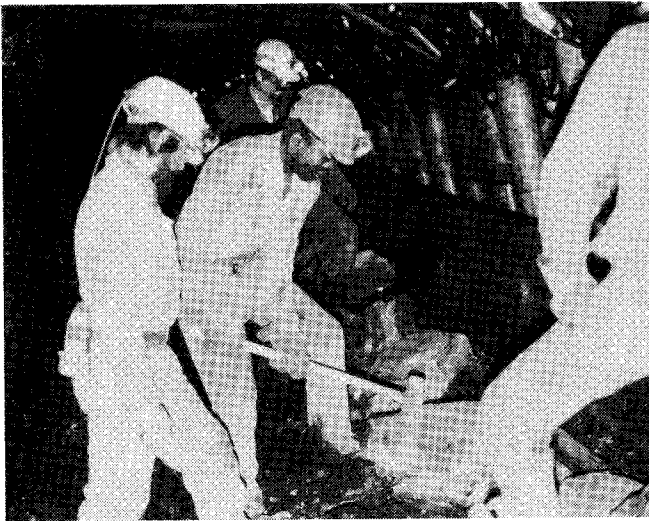


Figure 18.—Rock on face conveyor being broken up into smaller pieces with sledgehammer.

Roof falls in gate road entries also inhibit production and provide the potential for the development of dangerous situations. Tailgate falls block aircourses for ventilation, which can lead to the buildup of dust and methane concentrations. Extensive maintenance is required to reestablish airflow for face ventilation.

Roof Supports

Successful control of the roof and problem-free cycling of longwall face supports are the basic principles required for a productive longwall. However, there are situations that require the constant attention of longwall personnel to prevent support-related production stoppages. The most common ground-control-related occurrence that hinders support functions is soft floor. Floor rock is often composed of shale or fire clay. The properties of the rocks vary and may be adversely affected by water. On competent, level floor rock, supports slide forward during the advance cycle. However, support bases penetrate soft rock and dig into the floor, which requires that the base be lifted out of the depression.

The reaction of the floor to the support is also dependent upon support operation. For better control of the roof, support operators bias support force toward the tip of the canopy. This shifts the immediate roof loads toward the front of the base and reduces the bearing area of the support base, causing the base to break and penetrate the floor, resulting in advance problems or, worse, support instability. Support manufacturers have designed support bases to overcome soft floor and, as previously stated, have successfully incorporated this technology into the automatic advance of supports.

A situation of seemingly less importance but one that requires constant maintenance by face crews is the pushing or plowing of debris (loose coal and floor rock) ahead of support bases. Continuous shoveling of this material is required to allow for unimpeded advance of supports.

Another roof-support-related problem is that support loads across the face may not be uniform and may require different setting pressures depending upon the location of increased load. Nonuniform loading is determined through observation, and support setting pressure is adjusted accordingly. By incorporating support leg pressure transducers into the automated system, support leg pressures can be continually monitored and adjusted automatically to achieve an appropriate setting pressure.

Shearer tram times across the face continue to increase and are currently rated at about a 40- to 45-ft/min maximum (29). On a 600-ft-wide face utilizing 120 shield supports, a shearer, moving at 40 ft/min, would take 15 min to cut one direction. The shields, cycling at 10 s, would take 20 min to advance the entire face. This procedure would require the shearer to wait 5 min every cutting pass. However, by cycling shields simultaneously, advance times are dramatically increased. The ground control implications of moving two or three adjacent supports at the same time are obvious; however, manufacturers have designed electrohydraulic controls to systematically advance nonadjacent supports simultaneously and thus allow for roof control between advancing supports.

GENERAL CONSTRAINTS

Other problems facing complete longwall automation, not necessarily related to ground control, must also be considered. In general:

- More complex machinery requires more maintenance to keep it functional;
- More highly skilled personnel will be required to perform remedial maintenance measures when equipment malfunctions;
- The type of sensors utilized may depend upon the specific application desired or geologic conditions present or expected;
- Electronic devices will have to be rugged to endure continual abuse from machine vibration, dust, and moisture;
- Control and articulation of cutting drum cowls has not been successfully accomplished;
- Integration of sensor detection, computer interpretation, and machine response must occur nearly instantaneously;
- Work force attitudes toward automation are negative.

BUREAU RESEARCH

The Bureau's research has been directed to develop automation technology for continuous mining machines, because 75 to 80 pct of underground production (room-and-pillar) is mined by continuous miner and because continuous miners provide development for longwall retreat, shortwall, and highwall mining. The Bureau is actively involved in the development of intelligent machine control technology. The major thrust of the research is concentrated in the area of coal interface detection (CID) and machine guidance. Several promising CID techniques are currently being investigated, including machine vibration and adaptive signal discrimination, natural gamma radiation, thermography, X-ray fluorescence, and radar (22). The subsystems being developed can be utilized individually in the near term as aids to remotely controlled

continuous mining. These sensors, in turn, can be extended to automation of longwall mining systems.

Bureau research is divided into three categories: (1) a fundamental or core program of research that explored and developed the fundamental knowledge and hardware, (2) an applied research program that brings the pieces or integrated systems to a demonstrable, reliable, and fieldworthy stage, and (3) ad hoc solutions to mining industry needs (28).

The Bureau is committed to research that will increase coal extraction efficiency by increasing machine availability time and utilization. This goal will be accomplished by developing and integrating systems that will allow for continuous and autonomous operation of mining machines.

CONCLUSIONS

Although most technologically advanced automated machinery operates in a highly controlled environment, this is not possible in the underground coal mine. Therefore, the success of an automated longwall system hinges on the ability of the system to handle routine environmental constraints, including dust and methane, and ground control limitations that all mines cope with on a day-to-day basis. Ground control constraints include mining-induced stresses inherent in longwall mining (e.g., bumps, sloughing, cavities), geologic conditions (e.g., lithology, structural relief,

geologic anomalies), and longwall layout (e.g., panel size, setup, recovery room) that must be considered and incorporated into the overall operating design of an automated longwall.

While the various components needed to automate a longwall face are at various stages of maturity, it is evident the mining industry will gradually integrate all of these components into a totally automated longwall system such that they are designed to function within the environmental limitations of an underground mine.

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