Automation trends in room-and-pillar continuous-mining systems in the U.S.A.

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SYNOPSIS

About 90 per cent of the coal mined underground in the U.S.A. today is mined by the room-and-pillar system. The productivity of the system dropped from about 14,1 t per man-day in 1969 to about 7,3 t per man-day in 1978. Since 1974, the U.S. Department of Energy (formerly the U.S. Bureau of Mines) has been engaged in research to improve the production and productivity of the room-and-pillar system. The effort involves the development of integrated, automated, and remote-controlled equipment and systems including remote-controlled continuous miners, automated miner–bolters, automated extraction systems, continuous haulage systems for use behind miners, and remote-controlled equipment for miners, bolters, and shuttle cars. These systems are discussed briefly, the discussion being related primarily to coal winning, although the concepts could be utilized in room-and-pillar systems in mines other than coal mines.

SAMEVATTING

Ongeveer 90 persent van die steenkool wat teenwoordig ondergronds in die V.S.A. ontgin word, word volgens die pilaarafboustelsel ontgin. Die produktiwiteit van die stelsel het van ongeveer 14,1 t per mandag in 1969 tot ongeveer 7,3 t per mandag in 1978 gedaal. Die Amerikaanse Departement van Energie (voorheen die Amerikaanse Buro van Myne) is sedert 1974 besig met navorsing om die produksie en produktiwiteit van die pilaarafboustelsel te verbeter. Die poging behels die ontwikkeling van geintegreerde, geotomatiseerde en afstandsbeheerde toerusting en stelsels, insluitende afstandsbeheerde aaneendelwers, geotomatiseerde delwers–bouters, geoutomatiseerde pilaarsloopstelsels, aaneenvervoerstelsels vir gebruik agter delwers, en afstandsbeheerde toerusting vir delwers, bouters en spoelwaens. Hierdie stelsels word kortliks bespreek en die bespreking staan in die eerste plek in verband met steenkoolwinning, hoewel die begrippe ook in pilaarafboustelsels in ander myne as steenkoolmyne toegepas kan word.

INTRODUCTION

The room-and-pillar mining system accounts for about 90 per cent of underground coal production in the U.S.A. The utilization of continuous miners in the mining system has increased substantially since their introduction in the late 1940s, and today continuous miners account for about 65 per cent of the underground coal produced and are expected to account for more in future. In addition, over 30 per cent of the longwall production in the U.S.A. is obtained from gate and tail entries, which are developed by use of continuous miners. The productivity in underground coal mining increased during the period 1950 to 1969 (Fig. 1) as the utilization of continuous miners increased, but it has declined in the past decade from a maximum of about 14,1 t per manshift in 1969 to about 7,3 t per manshift in 1978. This drop in productivity is attributed to several factors, including the Federal Coal Mine Health and Safety Act of 1969, collective bargaining and wage contracts, changing mining conditions, absenteeism, decreased worker skill, and wildcat strikes.

The U.S. Department of Energy (DOE) has had a major research effort under way for the past five years to improve the production and productivity of the room-and-pillar continuous-mining system. Most of the research on health and safety in production systems is being conducted by the U.S. Bureau of Mines. The DOE effort involves the development of integrated, automated, and remote-controlled equipment and systems. Some of the systems being developed and evaluated are the automated continuous miner, automated miner–bolter, continuous-haulage systems for use behind miners, and remote-control equipment for miners, bolters, and shuttle cars. These systems are discussed briefly in this paper, starting with a discussion of the continuous room-and-pillar mining system, the bottlenecks in production, and possible solutions. This is followed by a discussion of the trends in the automation and equipment systems that are under development.

CONTINUOUS ROOM-AND-PILLAR MINING

A continuous miner, a roof bolter, and shuttle cars are the primary equipment in a mining section. A continuous miner performs the functions of coal breaking and loading the coal into a shuttle car positioned behind the continuous miner. The loaded shuttle car then transports the coal to the section haulage, commonly a belt conveyor. As the loaded shuttle car moves outbye of the crosscut nearest the face being mined, an empty shuttle car moves in behind the continuous miner to be loaded. An entry 4,5 to 6 m wide is thus advanced through a distance of 6 m before the miner is moved (place change) to another entry for coal extraction. A roof bolter is brought to the mined entry for roof support. Roof bolts are commonly installed at 1,2 m intervals along and across an entry; their lengths vary from 1,2 to 1,8 m, and 16 to 20 are usually installed in an entry advanced through a distance of 6 m. After the roof bolts have been installed, the entry is ready to be advanced again by the continuous miner. Crosscuts are required by law at maximum intervals of 27 m. A typical sequence plan for cuts in a four-entry development section is shown in Fig. 2. At present, place change is necessary after a maximum advance of 6 m because the federal regulations do not permit persons to work beyond the last row of bolts (unsupported roof).

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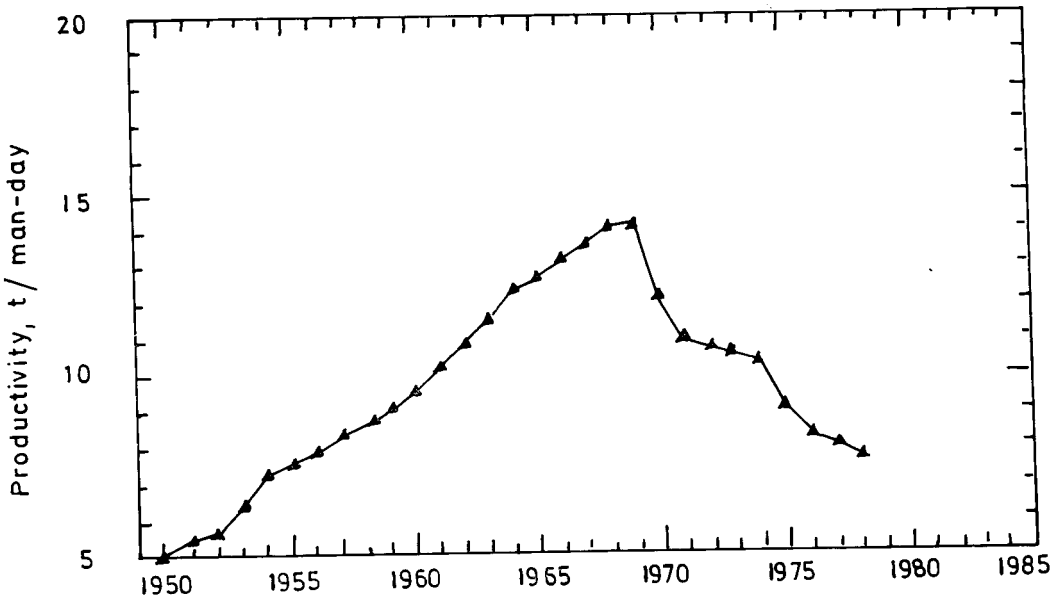

Fig. 1—Trends in the productivity of U.S. underground mines

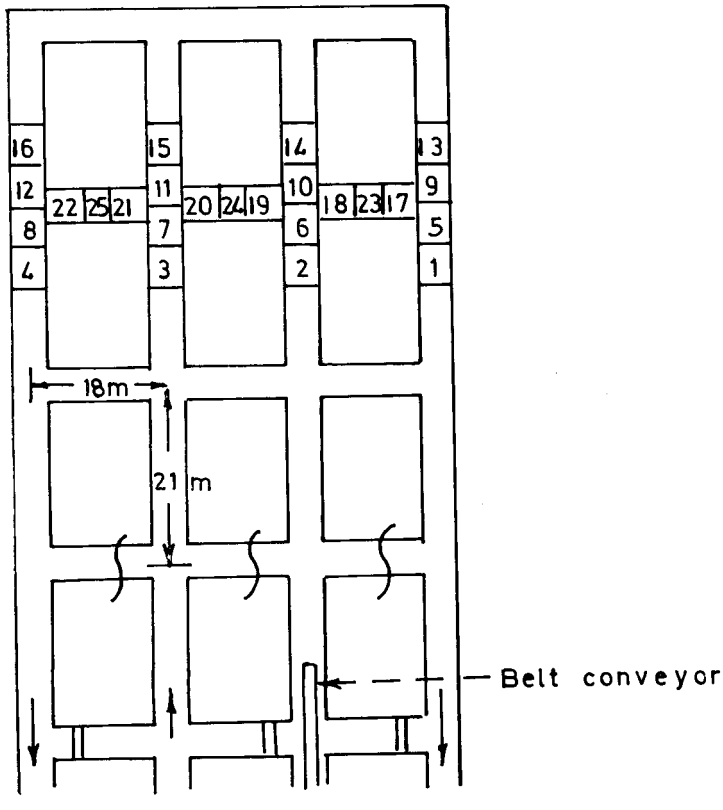

Fig. 2—Typical cutting sequence in a four-entry development section (1, 2, . . . , 25 cutting sequence)[4]

A continuous miner today can cut 3 to 5 faces through a distance of 6 m in an eight-hour shift, producing 300 to 400 t per shift, depending upon the thickness of the seam, the size of the entries and pillars, and the mining conditions. About ten workers, including the supervisor, are engaged in coal mining in a section.

Before concepts could be developed for improved production and productivity in the system, studies had to be made of the production bottlenecks in present-day continuous room-and-pillar mining sections. Studies conducted at a large number of mines throughout the U.S.A. indicate the following breakdown for the time utilized in a 480 min shift:

Travel to and back from working place	50 to 60 min
Lunch	20 to 30 min
Place change (3 to 5 cuts)	40 to 70 min
Advance ventilation, gas checks	15 to 25 min
Inspect and service equipment	25 to 40 min
Face inspection at the beginning of shift	10 to 20 min
Mechanical and electrical breakdowns	80 to 90 min
Actual coal winning and loading	70 to 100 min
Wait on shuttle car	50 to 70 min
Wait on bolters	30 to 40 min

A study by Davis[1] of continuous mining sections indicates that the available operating time for a continuous miner in a shift is about 34,2 per cent including tramming time, and about 20 per cent excluding tramming time. Thus, a continuous miner is actually winning coal about 20 per cent of the time, or 76 minutes in a shift. A continuous miner operates intermittently during a shift to produce coal: place changes are required because of roof-support requirements (8 to 15 per cent of the time), waiting on shuttle cars (10 to 15 per cent) results from a lack of continuous haulage, breakdowns of equipment during a shift (20 to 25 per cent) are the major cause of low availability, and advancing ventilation and frequent checks for methane (4 to 5 per cent) during production are required by law. The collective bargaining process has resulted in an increase in the size of face crews, leading to a loss of productivity.

In the above discussion it is assumed that the continuous miner always has a place to mine and that it does not have to wait for the bolting activity to be completed in an entry before it moves in to mine. In general, a continuous miner is unable to mine for 30 to 40 minutes of each shift when it is waiting for bolting activities to be completed in entries, although the use of dual-boom bolters in the past few years has considerably decreased this waiting time. In continuous mining, only a few places are worked at a given time to decrease the tramming time. Any delay or downtime on a miner directly affects production.

EQUIPMENT UNDER DEVELOPMENT

Some of the possible solutions to the production bottlenecks in a continuous-mining section are presented in Table I. The primary objective in the search for possible solutions is an increase in the available operating time of the equipment by the integration of several elements of a system into a single machine, thus reducing

TABLE I

IMPROVEMENT OF PRODUCTION AND PRODUCTIVITY IN THE ROOM-AND-PILLAR CONTINUOUS-MINING SYSTEM

	Delay element	Time lost %	Possible solutions	Concepts under development
1.	Place changes due to roof-support requirements	8 to 15	1. Larger advance of an entry beyond 6,0 m by remote operation of the continuous miner 2. Simultaneous mining and bolting 3. Temporary roof support integrated with mining machine	1. Remote-controlled continuous-mining systems 2. Automated miner–bolters 3. Automated extraction system
2.	Miner waiting on shuttle cars	10 to 15	1. Continuous haulage 2. Shuttle cars with larger payload 3. Remote operation of shuttle cars	1. Multiple-unit continuous haulage 2. Auto-track bridge conveyor train 3. Hopper feeder spillage cleaner 4. Automatic steering for low-seam shuttle cars
3.	Miner waiting on bolting cycle	8 to 12	1. Automated bolter 2. Bolting machine for holes longer than seam height 3. Reduction of bolt-hole drilling time by high speed drills	1. Bolter transfer module (BTM) 2. Flexible bolt bending with programmable automated drill 3. Water-jet assisted drill bit
4.	Larger face crew		1. Integration of different machine functions into one machine 2. Automation of machine functions	1. Automated miner–bolters 2. Automated extraction system
5.	Maintenance of equipment	20 to 25	1. Increased continuous-miner reliability 2. Development of hardware and improved machinery 3. Improved machinery maintenance	
6.	Inadvertent cutting of roof and floor		1. Coal interface detectors 2. Programmable automated cutting cycle	1. Programmable probe drill with optical scan 2. Swept frequency and impulse radar 3. Natural radiation 4. Sensitized pick 5. Automated continuous room-and-pillar mining with supervisory control

the time required for the performance of a job element. Under different or hazardous mining conditions such as in thin coal seams, retreat mining, or unstable ground conditions, remote-controlled equipment can help to increase production and productivity. The concepts, equipment, and systems discussed here can be utilized effectively with some modifications in room-and-pillar systems other than in coal mines.

Remotely Operated Continuous Miners

If roof conditions permit, an entry can be advanced beyond 6 m by the remote operation of a continuous miner. This is practised in thin seams, during pillar extraction, and under hazardous roof conditions. A radio-transmitter console is generally utilized for the remote-control operation, and the received signals on the machine operate the solenoid valves that control the machine functions. The radio device restricts the control of the miner to a distance of 30 m, and a maximum advance of 12 m without place change is possible. Beyond 12 m, the shuttle-car operator will be under unsupported roof. Such a remote-controlled operation considerably reduces the time required for a place change by continuous miners.

Bolting Systems

More efficient bolting systems are generally required in relatively thin coal seams where holes that are longer than the height of the seam must be drilled for bolts of the expansion-shell or resin type. Flexible shaft drills[2] and Ingersoll-Rand rod-changer–solid shaft systems have been developed for this type of drilling, and a system for the bending and insertion of bolts has been developed by Bendix Corporation for bolts that are longer than the seam height.

In addition, automated programmable bolter modules are being developed for the installation of resin and mechanical anchor bolts in thin (75 cm) coal seams.

Integration of Mining and Bolting Functions

The integration of mining and bolting functions into a single machine should permit the driving of long entries without a place change, thus resulting in an increase in production and productivity. Since the bolting is done immediately after the mining, this should result in better roof control.

Several new types of equipment have been developed under DOE sponsorship. These include the Joy automated miner–bolter, the Jeffrey miner-bolter, the Ingersoll-Rand/Lee-Norse miner-bolter, and the National Mine Service automated mine-extraction system.

Joy Automated Miner-Bolter

The Joy automated miner-bolter (AMB), which is shown in Fig. 3, is a full-face (4,8 m) ripper drum-type of miner that is similar in performance to a Joy 12-CM continuous miner[3]. The bolting system, which is an integral part of the machine, has automated roof bolters consisting of twin roof drills, storage for drill steel, bolts, plates and resin, and chock-type roof-support cylinders on each side of the machine. The bolting machines are controlled by a microprocessor, and can be fully automatic or sequenced for any of the four drills. The automated bolting cycle is monitored by the operator on the left side. The last row of bolts is about 3,9 m behind the face.

The mining cycle, which involves sump and shear cycles, is controlled by the operator on the right-hand side, and can be remotely controlled if so desired. The cutting drum can be slide-sumped 1,2 m hydraulically so that mining and bolting can be done simultaneously. The machine is capable of mining at a rate of 7 to 11 t/min. When fully automated, the production goal for the machine is 680 t per shift with a three-man crew (miner operator, bolter operator, and helper) on the machine. This represents an increase in production of about 60 to 70 per cent and an increase in face pro-

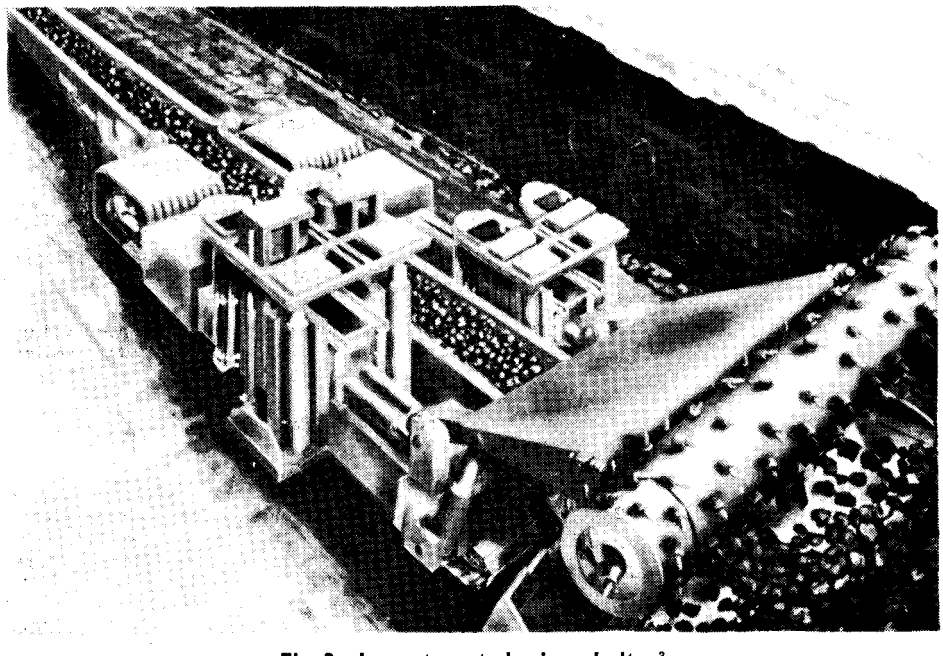

Fig. 3—Joy automated miner–bolter[3]

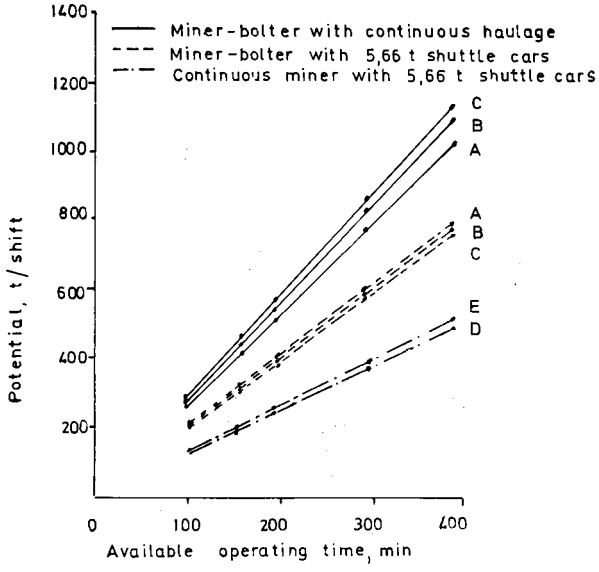

Fig. 4—Production potential of the Joy automated miner-bolter (A to E refer to different mine plans)

ductivity of 100 per cent. The minimum face advance before a place change is 30 m.

The results of a recent study[4] of the production potential of the Joy AMB are summarized in Fig. 4. With 5,44 t shuttle cars, it has the potential of increasing production by 50 to 60 per cent compared with the present-day system of place change, on the assumption that the available operating time is 240 min in both cases. With continuous haulage, the increase in production is expected to be between 110 and 120 per cent.

Jeffrey Miner–Bolter

The Jeffrey miner–bolter (Fig. 5) utilizes a remote-controlled continuous miner and a separate bolting machine called the bolter transfer machine (BTM)[5]. The BTM is capable of installing four bolts at 1,2 m intervals simultaneously, using remote-controlled automated drills. The BTM is attached behind a continuous miner, and can be detached to operate as an independent roof bolter. The last row of bolts is 12 m behind the face, and the roof conditions have therefore to be good enough to stand unsupported over this span. At the end of the shift, this 12 m span must be supported with an additional touch-up bolter.

Ingersoll Rand/Lee Norse Bolter Module

The Ingersoll Rand/Lee Norse bolter uses rotary–percussion drilling as compared with only rotary drilling in the Joy and Jeffrey bolting machines. Eventually this bolter module will be able to be used on the Joy AMB or BTM.

Automated Extraction System

The Automated extraction system (AES) is shown in Fig. 6. It is a full-face (4,8 m) machine that integrates most of the essential functions at the face, such as mining and bolting, self-advancing on-board ventilation, rock dusting, extensible conveying system, clean-up system in front, and scrubber system to deal with the dust generated during mining[6]. It has a programmable automated mining cycle, and the cutting head is sumped hydraulically so that mining and bolting can be performed simultaneously. The bolting modules are fully automated. Temporary roof support is integrated with the machine and is fully automated. The temporary support covers a distance of 3,3 m and is 2,4 m behind the face. Under relatively good roof conditions, this machine could mine an entry through 45 m without a place change. Just as for miner–bolters, the face area must be supported with an additional touch-up bolter at the end of a shift.

Computer simulation studies of the AES machine[7] indicate that the machine in its final stage should be capable of producing about 770 t per unit shift with shuttle cars, eight miners in the face crew, and 200 min of actual production time per shift. This is an increase in

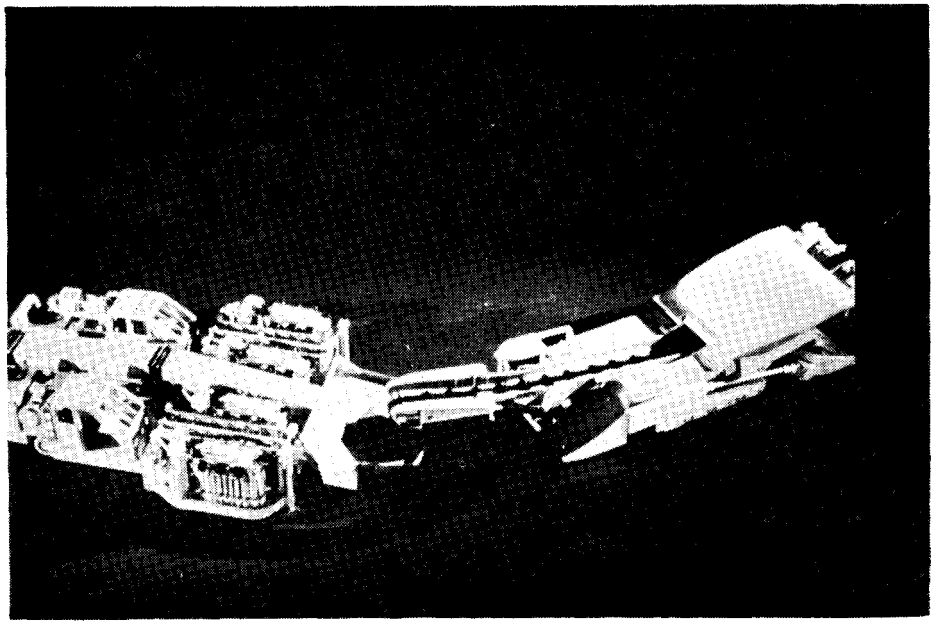

Fig. 5—Jeffrey bolter transfer machine[5]

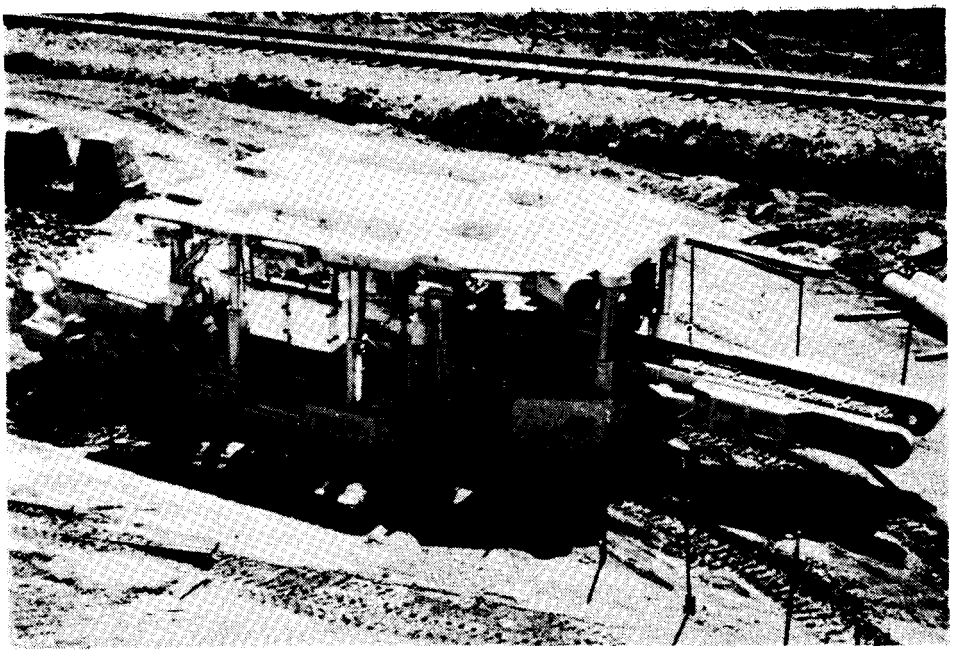

Fig. 6—Automated extraction system[6]

production of about 90 per cent over the present place-change mining system.

The integration of mining and bolting functions in a single machine requires that the mining and bolting cycle times should be properly designed and balanced if the full benefit of the integration is to be obtained. Commonly, the bolting time to install four bolts is longer than the mining time to advance an entry through 1,2 m. Based on the computer simulation of the Joy AMB[4], and on the assumption that 4 min is the bolting cycle time, it was concluded that the effect of delays in the installation of bolts on the production of the Joy AMB would be negligible for shuttle cars of up to 7,24 t. However, a loss of 3 to 5 per cent in production can be expected with continuous haulage behind the miner. Frantz and King[7], in their analysis of the AES, noted a delay in each shift of about 15 min in the installation of bolts.

In the miner–bolter and AES mining systems, even though the number of place changes are reduced, a place change generally takes longer. It is expected that the integration of mining and bolting functions into a single machine should reduce place-change time by about 50 per cent in a shift.

Fully Automated Remote-controlled Continuous-mining Section

Efforts are being made to develop a fully automated remote-controlled continuous-mining section[8,9]. An artist's concept of such a section is shown in Fig. 7. The section will have a remote-control station with supervisory control. Such a section may have continuous face haulage or shuttle-car haulage. Optical guidance is being considered for the shuttle-car haulage. The mining is done by a fully automated programmable full-face miner with simultaneous bolting that carries the face ventilation on it.

The entire section will be remotely controlled by a computer-based control system. A multitude of interfaces, such as cutting height, cutting rate based on environment (hardness of coal, methane emission, loading rate, etc.), guidance, and entry width will be utilized. A modular control concept is planned for the interfaces. The systems controller will automatically change the rate of mining to prevent crowding condition, will adjust the mining height, and will examine the mining environment to balance the mining performance with the environment. The machine, when fully developed, will have the potential of doubling the coal at present produced by a continuous-mining section.

Continuous Face-haulage Systems

A continuous miner loses approximately 60 min (12 per cent) in each shift waiting for the shuttle cars. This can be eliminated by the use of continuous face-haulage systems, which are now under development. These systems have the potential of increasing production by about 50 per cent in coal seams between 1,5 and 2 m thick; in coal seams of low to medium height, the increase in production may be 100 per cent. Some of the systems under development are briefly discussed here.

Multiple-unit Continuous Haulage System

The multiple-unit continuous haulage (MUCH) system is a train of rubber-tyred, self-propelled, vehicle-mounted cascading conveyors that transport coal from the continuous miner to the section belt[10], as shown in Fig. 8. The 10 h.p. chain conveyor on each unit is 76 cm wide and 23 cm high and, running at 84 m/min, can transport coal at the rate of 10,8 t/min. The system consists of three types of vehicles: a lead vehicle, a discharge vehicle, and a variable number of intermediate vehicles. Each intermediate vehicle is about 6,0 m long, 1,8 m wide, and 1,2 m high, and is powered by a 5 h.p. motor for tramming at 24 m/min. The discharge vehicle is about 13,5 m long, includes a bridge conveyor for transferring

coal to the section belt, and is trammed by a 7,5 h.p. motor. The bridge conveyor is about 6,6 m long, and the discharge end rests on a bridge dolly that rides on the section belt. The lead vehicle is about 6,1 m long and consists of a receiving hopper, an operator's cab, and a tramming motor of 7,5 h.p. It is not connected to the continuous miner. Suitable steering linkages between the vehicles allow for tracking and retracking, and for tracking-error recovery. The entire system is manned by one operator on the lead vehicle and one on the discharge vehicle. The two operators communicate by a page phone and light system.

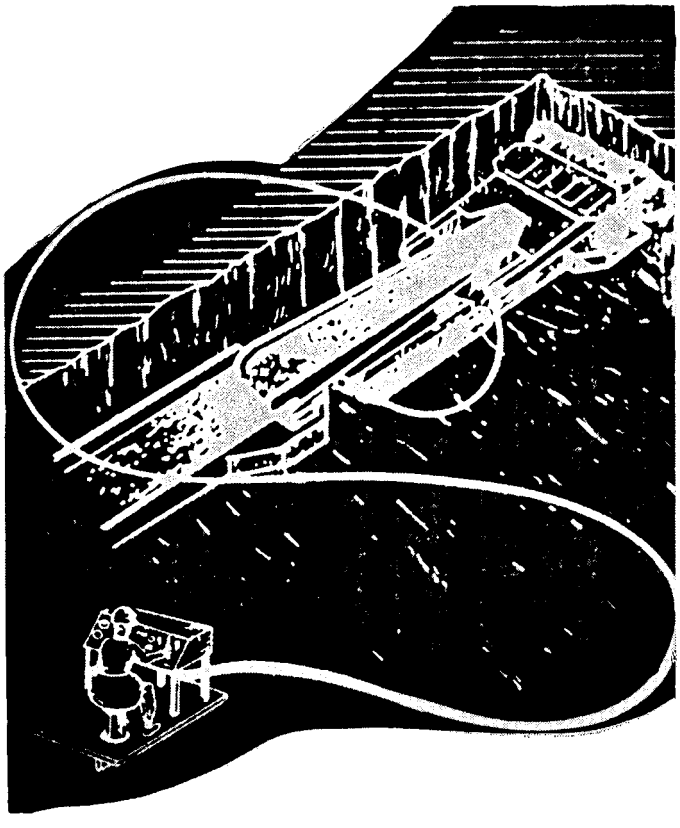

Fig. 7—Remote-controlled continuous-mining section with supervisory control[8]

Auto Track Bridge Conveyor Train

The auto track bridge conveyor train (ABCT), shown in Fig. 9, is designed primarily to facilitate the haulage of coal in thin coal seams. The conveyor system consists of alternating carrier and bridge-conveyor sections[11]. Each section, which is mounted on rubber-tyred wheels, is about 9 m long and is independently propelled. Scraper-flight dual-strand chain conveyors running at 90 m/min transport coal at the rate of 10,8 t/min. The coal from the continuous-miner conveyor is discharged on the first carrier section. At the discharge end, the coal is carried on a bridge conveyor to the section belt. Automated controls and a guidance system are provided on the system. The guidance cable on the floor carries a.c. current at a frequency of 10 kHz, and guides all the carrier sections so that they follow the same path as the first carrier. Sensors are located underneath each carrier to sense the magnetic field of the guidance cable, which is used to guide the conveyor through the mine. The guidance cable is stored on a reel during the retreat of the conveyor. Where necessary, intermediate transfer points are utilized. Initially, it is proposed that the ABCT should be developed to a length of about 150 m.

Hopper Feeder Spillage Cleaner

The hopper feeder spillage cleaner (HFSC), which is shown in Fig. 10, is not a continuous face-haulage system but an interface machine between the continuous miner and the continuous face-haulage system to improve production in a section[12]. The purposes of this equipment are to provide surge control, break large pieces of coal, meter coal to the continuous face-haulage system, clean up the floor, and act as the lead unit for the continuous face-haulage system. The addition to the unit of face ventilation, rock dusting, and additional roof support is also being considered.

The unit consists of a gathering table with a spinning-disc type of gathering mechanism for cleaning up, the surge control being provided by a 2 t hopper. A feeder breaker is provided on the unit for breaking large pieces of coal, and automated temporary support is provided so that the operator is under fully supported roof. Bolting units are provided on the equipment. The continuous miner is operated by remote control. This unit

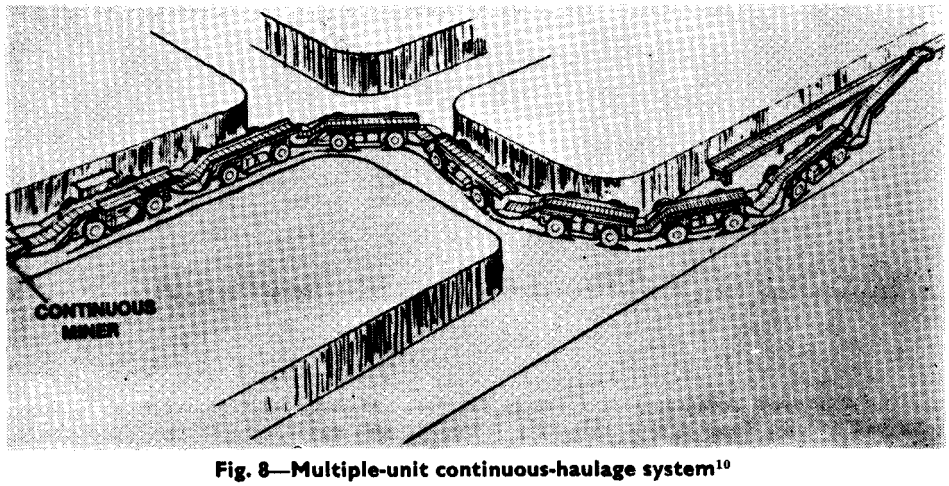

Fig. 8—Multiple-unit continuous-haulage system[10]

has the potential to increase production by 15 to 25 per cent in a shift. The unit being designed will be capable of interfacing with all the continuous face-haulage systems being designed and currently in use.

Automated Steering of Shuttle Cars in Thin Coal Seams

The steering of shuttle cars in relatively thick coal seams (thicker than 120 cm) has been automated successfully[13], and the concepts are now being extended to thin coal seams with considerable success.

Maintenance of Equipment

Breakdowns of equipment account for over 20 per cent of production delays, the breakdown of hydraulic systems being most common. With increasing automation, the reliability of the equipment may decrease, and considerable effort is being devoted to the improvement of continuous-miner reliability, the development of improved hardware, and the development of improved preventative procedures for the maintenance of machinery.

Development of Coal Interface Detectors

Automated and remote-controlled continuous-mining systems require the development of coal interface detectors (CID) for the adjustment of entry heights and the guidance and control of continuous miners. Electron-spin resonance, natural radiation, radar, and acoustic signals are most commonly utilized for this purpose.

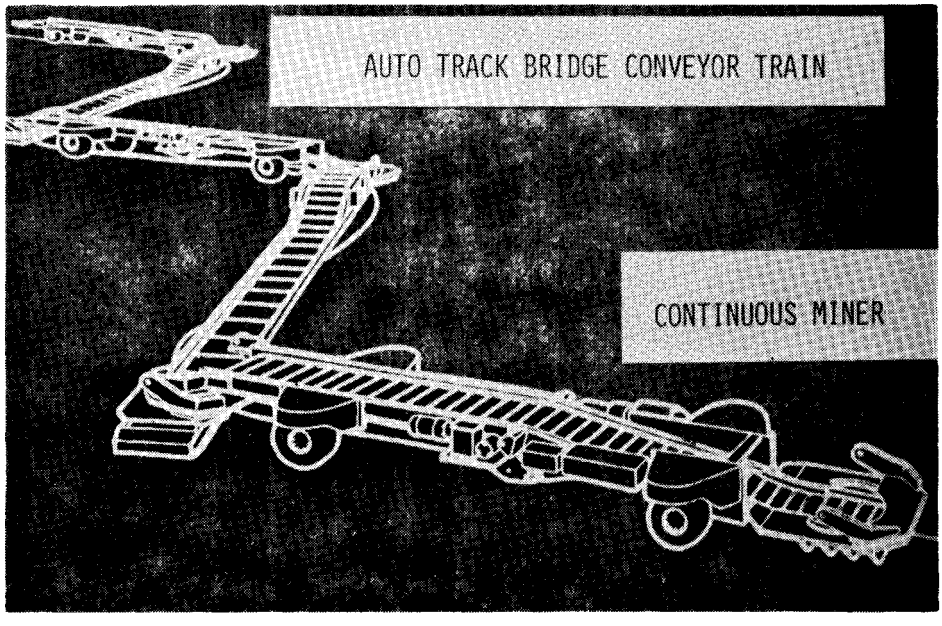

Fig. 9—Auto-track bridge–conveyor train[11]

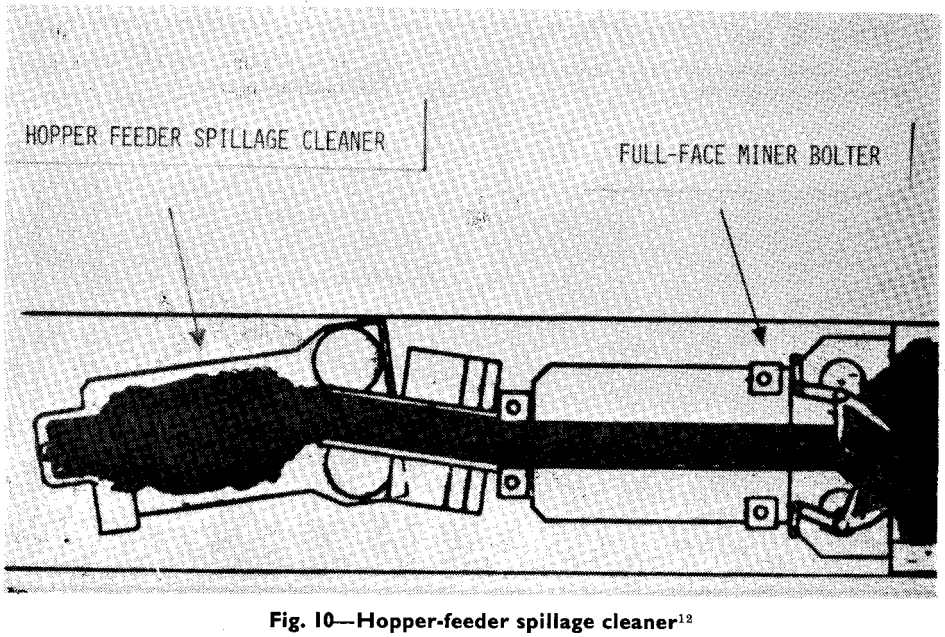

Fig. 10—Hopper-feeder spillage cleaner[12]

Research is also currently under way on the development of sensitized picks and vibration measurements for continuous miners. The sensitized pick measures the forces required to break or cut the material and uses the data to determine the interface, and the surface-recognition sensor utilizes data from a penetrometer and two dust reflectometers to identify the interface. The use of electromagnetic waves in the CID is also being considered. A gamma-ray backscatter gauge that was developed in the United Kingdom for the measurement of coal-seam thicknesses is being evaluated for use on continuous miners. A more comprehensive discussion of the CID development is given elsewhere[14].

Underground Communications

Automation and remote control of equipment should lead to higher production and productivity. The role of underground communications becomes more and more important with increasing automation. Good communications are also important from the safety point of view. A comprehensive review of the state-of-art and ongoing research in underground communications was recently published[15] and is not discussed here.

SUMMARY

The U.S. Department of Energy in developing the equipment and systems described here is trying to improve production and productivity in the room-and-pillar mining system, the ultimate goal being fully automated remote-controlled mining sections with supervisory control. Such equipment would not only improve production and productivity but should considerably improve health and safety because fewer people would be employed and they would be in a safer and healthier environment away from the face. Some of the equipment currently under development should be in commercial production by 1990, and should lead to increased productivities of between 50 and 100 per cent.

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