Evolution of Longwall Mining and Control Systems in the United States

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Abstract - this paper addresses the evolution of longwall mining in the United States from the initial "longwall" method, utilizing hand loading and manual haulage to the progressive mechanization of the face equipment. An analysis of accident information for specific benchmark dates in United States longwall evolution and a review of productivity (for the period of 1963 - 1973) are provided to demonstrate the impact of longwall mining advancements in these areas. It also addresses how the previous generation of machines and methods influenced the next, up to the present and addresses the introduction and advancements of automated control systems and the Mine Safety and Health Administration's safety concerns associated with them. Among the systems to be discussed are microprocessor controlled shearers and roof supports.

INTRODUCTION

Longwall mining is defined as a method of extracting any underground mineable mineral from its seam or vein in one operation, by means of a long (greater than 80 meters) working face or "wall".

The first extensive underground coal mining was done in the United Kingdom in the 13th century.[1] The first longwall mining is believed to have originated in Shropshire, England near the end of the 1600's,[2] approximately 70 years after the Pilgrims landed at Plymouth. We shall see how the United States mining industry has adapted European longwall mining technology to meet specific needs.

EARLY INSTALLATIONS

Successful use of longwall mining in the United States has been documented as early as 1899, when Alabama, Iowa, Missouri and Oklahoma had a total of 22 operational faces [3] (fig.1). These operations consisted of men hand loading coal shot from a solid face. into pieces of heavy burlap type material or wooden troughs with pole handles (hods). The coal was carried to a panel load point for transport to the surface in mine cars. Wooden props (timbers) were set to support the exposed roof, and were allowed to remain in place as the face advanced, This type of operation was the mainstay of longwall mining for many years. The progression of initial installations by state can be seen in figure 1.

By 1914, longwall mining was making a contribution to coal production in the United States and the number of installations was at the historical peak of 618. As can be seen in figure 1, of the 23 states with initial installations between 1899 and 1910, nine showed a decrease while the remaining 14 showed significant increases. This was especially-true for Alabama (+18), Kentucky (+39), Missouri (+71), Pennsylvania (+92) and West Virginia (+163). The total number of faces had increased by more than 500%.

By 1914, the mechanization of the mines had increased to the level where 52% of the coal mined was by machine. With the increased number of longwall faces, the use of undercutting (bottom) machines significantly reduced the practice of shooting off the solid. Also being introduced was the vibrator or shaker type conveyor to transport the coal along the face, after hand loading, to the panel load point for transportation to the main line haulage.

In the following fifteen years, the percentage of coal mined by machine increased by 24%, to 76% of the total [4] (fig.2). This was a result of further development of the undercutting machines and the introduction of chain type conveyors, as well as other methods of mechanically loading the coal. The increased availability of electricity in mines resulted in increased mechanization. As mechanization increased, hand loading and shooting off the solid decreased.

The longwall configuration most commonly used during the late 1920's is shown in figure 3 [5]. Props were still utilized with caps (crossbars) to protect the conveyor and men at the working face. Props with caps were also used in the intake and return airways, and were left in place to establish the return airway on the next (adjacent) panel to be developed. Because wooden props in other areas had been replaced by wooden cribs, one hazardous job working these panels was that of the crib puller. As the face was advanced, the rear row of cribs was recovered by the crib puller if possible. Some unique methods of longwall mining were initiated in the United States during the 1930's. The United States continued using these methods during the 1930's and 1940's. One particular method utilized a haulageway driven centrally into virgin territory. Mining arced out in a complete circle from the haulageway, thus creating a long circular-shaped face. Narrow pillars of coal (buffers) were left to maintain the haulageway until the area was mined out.

The European coal machinery manufacturers were introducing new generations of longwall equipment, with the first coal "plough" patented in Europe in 1912. This plough was a massive triangular shaped piece of steel sized to the height of the coal seam. The positions of the cutting bits, placed along its leading edges, could be varied manually by adjusting the plates on which the bits were mounted, The plough was pulled across the coal face by heavy wire rope.

Subsequent generations of ploughs have incorporated design modifications patented by various European and American inventors. These modifications have included more streamlined profiles and add-on bit decks (tiers) allowing conversion for use in varying seam heights.

The "shearer loader" machine was subsequently developed in Germany during World War II (1941-42) [6]. These shearer loaders were not shearers as we know today, but employed cutter bars with a long thin drum utilizing a cutter wheel and thin pick type fingers to extract the coal from the seam by moving up and down, as does a continuous miner cutter head. The falling coal was loaded onto the face conveyor by a gathering conveyor located behind the cutterbar (raking bar). The United States mining industry was not aware of these developments until the end of the war when the specifications were evaluated for feasibility of adaptation for United States mines.

POST WORLD WAR II INSTALLATIONS

In 1951, the first longwall system using the new techniques began production at Eastern Gas and Fuel Associates, Stotesbury #ll Mine, at Helen, West Virginia [7]. The installation was a joint effort between the Bureau of Mines, Eastern Gas and Fuel, and Mining Progress, Incorporated, the United States representative for Gewerkschaft Eisenhutte Westfalia, Lunen, Germany [figure 41. The system consisted of a Loebbe Hobel planer or plough; an armored face conveyor, powered by two 40 KW (53.6 HP) motors; approximately 20 lights; 18 pneumatic shifters; 328 steel face jacks; 10 aluminum entry jacks; 1 controller; and 1 generator to convert the incoming 2300 volt, 60 cycle, A.C. power to 50 cycle power for the European equipment. The motors and controls operated at 500 volts, and the lights operated at 220 volts. The conveyor drive motors also powered the plough, using 7/8" link chain at a speed of 75 fpm, while driving the conveyor at 150 fpm. The pneumatic shifters pushed the face conveyor toward the face. Compressed air was supplied from the surface through bore holes.

Roof control became important with the use of this technology. To maintain proper face loading, the roof was drilled and shot. After five shifts, the roof began working on its own and produced the desired caving - up to 20 feet in- height. This caving continued for the total length of the recoverable coal block (panel).

After the mining began, water collected along the face, causing some jacks to sink as much as 12 inches into the fire clay bottom. The jacks were initially set at least five rows deep with two or three jacks in each file (row). To alleviate this problem, wooden cribs were installed along the back rows of supports, spaced 8-12 feet apart. As the mining advanced, the cribs were recovered where possible.

A total of three panels were mined at the #ll Mine. The system was then recovered and installed at the Stotesbury #8 Mine of Eastern Gas and Fuel, where an additional eight panels were extracted from August, 1953 through July, 1956 [a]. During this period, experimental panels were set up in three other mines with varying conditions. All but one achieved expected recovery. Longwall mining in the United States continued to utilize this plough method for many years.

Technological advances spearheaded subsequent generations of improved equipment. The use of hydraulic jacks was introduced in 1960 at an Eastern Gas and Fuel Associates mine, using self-advancing rams attached to the conveyor. In 1963, the first shearer loader began production at an Old Ben Coal Company, Incorporated mine. In 1966, the first single ended shearer was purchased by Barnes and Tucker. The first "modern" double ended shearer was acquired by Eastern Associated Coal Company in 1968. In April, 1975, Consolidation Coal Company installed the first shield supports.

As the number of longwall systems grew, face lengths also were extended. Motor horsepowers were increased to handle the new loads being imposed on conveyors and coal mining machines. Higher operating voltages became necessary with Uthe higher horsepowers to allow use of realistically sized cables. The maximum voltage usable on these systems was limited to 650 volts A.C. by Part 18 of Title 30 Code of Federal Regulations. The promulgation of Schedule 2G in 1969 allowed the use of voltages up to 4160, with certain restrictions.

Longwall Mining Accident Analysis

The number of longwall installations steadily increased every year between 1963 and 1973, with a slight lull during 1970 and 1971. During these years the number of installations increased from 6 to 50, while annual production from these-systems increased from 800,000 to 9.5 million tons, The evolution of longwall mining and the increase in mechanization has had an impact on the number of fatal injuries through the years. Figure 5, shows a downward trend in the number of fatal injuries (fatalities) in the three reported years of 1914, 1929 and 1951, benchmark dates in the evolution of longwall mining. The three classifications for fatalities being reported are electrical, roof falls and face falls [9]. The figures reported are the total number of fatalities. The data available did not break down the specific causes, however, much of the data leaned toward the electrical fatalities which occurred on haulage equipment, or by contact with the D.C. haulage power lines. The roof fall statistics are for those fatalities which took place in the face areas. The face fall data includes gob thrusts (where the fractured immediate mine roof pushes through to flood the face area), coal face bursts, heavy sloughing, and rolls of the face. As can be seen, the number of accidents decreased over the period. The number of operating mines remained fairly stable between 1914 and 1929, and had increased significantly by 1951. Also, it cannot be derived as to what method of mining was being utilized, however seventeen of the twenty-three states reported in figure 1, were using longwall mining in 1914 and 1929. According to a report issued by the Department of Labor in 1983, fatal accidents in longwall mining were almost non-existent with six fatalities occurring on longwall face installations [10] for the period of 1978 - 1982.

AUTOMATED CONTROL SYSTEM

The mechanization of the longwall systems led to the development of more sophisticated control systems. The sophistication of control systems evolved primarily due to three factors. These factors are the desire for increased productivity, the overall cost of longwall mining equipment, and the safety and health concerns for the employees at the face.

Longwall mining was conceived and implemented as a means of increasing production. By providing roof support and concentrating a workforce along a continuous face length, longwall systems achieve a higher recovery rate than the traditional room and pillar method. While this was the primary focus of the early longwall faces, increased mechanization has increased the mining speed to further enhance productivity.

The initial longwall faces were labor intensive. As a result, these operations did not require sophisticated monitoring and control systems. A section boss overseeing the activities at the face and directing the crew was the primary control system.

The early mechanization of the longwall faces with the introduction of a plough to cut the coal along the face did not require extensive control systems. Limit switches installed at the head and tail provide indication of travel limits and make provisions for stopping and reversing the plough. Additional switches installed along the face length provide position indications showing the relative position of the plough along the face. Two speed motors allow for the acceleration and deceleration of the plough at either end of the face. The plough speed, when traversing the majority of the face length, is too fast to permit the plough operator to travel with it. Therefore, control from a single operating station at the headgate is used. The length and speed of travel are the only variables to be controlled in the operation of the plough. Because of this relatively simple operation and the decreasing use of plough systems, there has been little need to develop a sophisticated control system. The introduction of shearers utilizing ranging arms with the cutting drums and haulage motors for traversing the face created a climate for the application of sophisticated control system technology. The shearer can closely follow the undulations in a coal seam by varying the positions of the cutting drums, thereby achieving versatility in mining. Regulation of tramming speed compensates for seam conditions which often result in variations in cutting resistance. Controlling these functions results in more efficient use of the motors.

The desire to increase productivity and the expanded use of electricity in the mines has led to sophisticated mechanization of the longwall sytems. The electrical components, initially D.C. and later predominately A.C., employed in the mining process have enabled the mining and hauling of the coal much faster than is possible manually. Each succeeding generation of equipment has been designed to be more efficient and provide higher productivity.

Productivity gains have been accomplished through faster traversing speeds across the face and deeper cuts (webs) into the coal. Various shearer designs have incorporated one or both of these features to augment production. The increased cutting rate requires coordination of haulage and roof support for proficient utilization of the shearer's increased capacities. Because the increased capacity of a high speed, a high tonnage shearer is not beneficial if the shearer has to sit idle until the roof supports and face conveyor are advanced, the roof support system must be capable of advancing quickly enough to provide support for the newly exposed roof as soon after the cut as possible. This allows utilization of the increased cutting potential as well as contributing to the safety of the face area.

These needs, safety in the face area and better roof support, coupled with the lack of available manpower and timbers during World War II, led to the use of steel jacks for roof support. These jacks could be released, moved, and reset more quickly than wooden cribs or timbers. Subsequent generations of roof support systems incorporated hydraulic open-backed chocks and shields. The importance of control systems for the roof supports has increased due to the need to advance the roof supports as quickly as possible, the potential for controlling the hydraulics which operate the supports, and the task of advancing the face conveyor into the newly exposed face in preparation for the next cut. This increased importance resulted in the development of remote control and automated control systems.

The technological advances have been reflected in the purchase costs of the mining equipment. Current estimated purchase costs for a typical longwall mining system range from approximately 8.6 million dollars for a "basic" 500 foot face length to 15 million dollars or more for a fully equipped 1000 foot face length. Figure (6) provides typical purchase costs for various configurations of longwall mining systems. Productivity from these systems must be sufficiently high to provide a cost per ton competitive with alternative fuel supplies. During the period following World War II until the mid 1970's, alternate fuel prices, including coal from other countries as well as oil and natural gas, were low and supplies were abundant. Since that time, prices of oil and natural gas have increased dramatically though remaining somewhat unstable, and the price of coal from developing countries has remained low. The result has been that even with other fossil fuels commanding higher prices in the world market, coal producers in the United States must continue to mine as efficiently as possible in order to remain competitive. Therefore, as the price of longwall equipment increases, the need to fully utilize the higher production capabilities also increases. Since fulfillment of production potential has been the bane of longwall systems, better and more effective control systems are paramount for utilizing the capabilities available in modern longwall systems.

The other factor contributing to control system advancements is the concern for the safety and health of the workers in the face area. Longwall systems, by virtue of their extensive roof support, provide the maximum protection for miners from the number one cause of mine fatalities - roof falls. However, hazards still exist. Travel along the travelways of the roof supports for jacksetting and shearer operation is hampered by congestion from hydraulic lines, electrical cables, and the continual movement of the equipment along the face. Exposure to health hazards such as respirable dust and noise continues to be a problem.

Initial shearer designs included operator's stations incorporated into the machine's mainframe. The shearer operator has been required to travel the face length along with the shearer to oversee and control the cutting operation. Because of this, the shearer operator has been subjected to the safety and health hazards of the coal cutting operation more than any other longwall occupation. The introduction of umbilical and radio remote control systems on the shearers represented the first attempt to separate the operator from the mainframe, With this freedom of movement, the operator was able to position himself for better visibility of the shearer operation and reduce his exposure to the safety and health hazards.

Sophisticated remote control systems developed for longwall mining systems have progressively reduced the number of workers and the manhours spent in the face area. Continued improvement of longwall control systems is expected to result in further reduction of exposure to safety and health hazards. Major advancements are technically possible through increased utilization of equipment currently available. However, this evolution of control capabilities is not a panacea, and the associated drawbacks must be considered.

The use of technological advancements such as microprocessors have made the potential for truly remote controlled longwall mining systems a reality. With these developments, sensory devices have been incorporated into shearer designs to monitor the depth of cut, height of cut, speed of travel and relative location of the shearer along the face. Roof support systems are likewise utilizing the available technology to automate shield and conveyor advance into the face.

By the late 1970's, the beginning of price reductions for solid state electronic components made their use for control systems economically attractive. However, the harsh coal mine environment posed problems to the acceptable performance of these devices since they are heat, vibration, and dust sensitive. Due to concerns over the reliability of the components pre-initial use of solid state components and microprocessors was relegated to monitoring and display functions. No control functions were provided by these devices.

Manufacturers of longwall mining equipment, government agencies and engineering consultants have been involved in extensive research and testing of prototype devices and control systems. Government and industry research efforts have developed new control systems utilizing both innovative and traditional sensors. Sensors for control systems vary from traditional units, such as current and potential transformers (CT's and PT's) for current and voltage inputs, to sonic and radiation detection devices (coal interface) to determine the amount of cap coal remaining in the roof.

With proper coordination of the coal handling equipment with the shearer's cutting capabilities, the efficiency of the shearer's cutting operation becomes the critical factor to production. Shearers, which more than any other equipment on the longwall section dictate overall productivity, offer the best prospect for monitoring and control functions. The shearers were, therefore, the primary recipient of development work for introduction of microprocessor and solid state control.

The microprocessors are now programmed to allow maximal cutting rate of the shearer based upon the input data provided by the sensors. Cutting motor overload conditions are minimized by controlling the haulage speed (rate of traverse along the face). The signals from sensors monitoring the cutter motor's phase currents are used to limit the haulage speed, based upon the cutting conditions. Input to the microprocessor from position sensors (such as coal interface detectors and limit switches) have been used to control the relative positioning of the ranging arms and cutter-drums on subsequent passes along the face. This control minimizes discontinuities in the mine roof and floor, enhancing the operation of the roof supports in advancing the face conveyor, as well as supporting the roof.

Control of the shearer operation by a microprocessor-based system is dependent upon the decision-making capabilities of this technology. The decisions made by the microprocessor or central processing unit (CPU) in these systems are made in nanoseconds with constant and continual adjustments. By virtue of this rapid processing of input data and the decision-making capability, potential problems are identified and corrective actions taken, usually well before a human operator would perceive the situation.

After the introduction of microprocessor-based systems on longwall shearers, the next step was the incorporation of the same technology for the roof support system since the longwall “jack setter” is the longwall occupation with a hazard exposure level second only to the shearer operator. These electrohydraulic control systems possess the capabilities to activate and deactivate the solenoids to release, advance and set the roof supports automatically. Electrohydraulic sensors provide feedback signals from each support to enable a CPU to coordinate the advancement of the roof supports and face conveyor.

A CPU’s decision-making capabilities are used to control the operation of the supports. Pressure transducers, limit switches and similar devices provide input data to the CPU to determine the status of each support. In the automatic mode, the CPU signals its decisions to the appropriate solenoids on a support when all operational parameters are met.

With continued work in the fields of robotics, computer interfacing and telemetry systems, continued advancement of microprocessor control of longwall systems is anticipated. In addition to increased control over shearer-operation through the use of more refined sensors, increased interconnecting of roof support and shearer control systems are foreseen. By interfacing these two systems, all equipment movement on the longwall face can be controlled by an automated microprocessor system with computer monitoring at remote locations. Monitoring from the surface is envisioned, with few, if any, miners working in the face area.

Traditionally, electric face equipment has been attended while in operation; a major determinant in the approval criteria for the use of this equipment. Increased microprocessor control results in decreased human involvement . Microprocessors are capable of evaluating enormous amounts of input. data in nanoseconds and making rapid decisions based upon the data. However, microprocessors and sensors have not been able to duplicate human sensory perceptions and judgments. Microprocessor-based control systems are continuing to reduce the hazard exposure levels of employees at the longwall face. Use of these control systems exposes miners to non-traditional categories of hazards based on instrument malfunction. The quality of decisions rnade by a microprocessor is dependent upon hardware and software limitations. Decisions of the CPU are dependent upon the quality of the programming and the input data. The Mine Safety and Health Administration wants to ensure that any microprocessor control system installed on a longwall system incorporates repetitive self-diagnostic and supervisory (watchdog) operating parameters. The self-diagnostic checks employ a regulated signal simulating an input to ensure proper operation of circuit components used in the “conditioning” of the signals. This process is repeated within specific time frames to provide continued monitoring of these components. A supervisory circuit monitors for correct program sequencing of the microprocessor. This circuit monitors the sequencing and elapsed times between program steps for comparison to anticipated operation, By use of these checking procedures, accuracy of input information and proper functioning. of various components of the microprocessor and software are verified. Using repeated checks and "debugging" efforts diminishes, but does not completely eliminate, the risk of programming errors. The equipment is deenergized if any of these checks reveals a hardware or software malfunction. The Mine Safety and Health Administration has required all microprocessor-based control systems used on longwall mining systems to employ an emergency stop circuit which can be operator activated independent of the microprocessor, This emergency stop feature is intended to provide the machine operator with ultimate override control in cases of microprocessor or programming malfunction. This override control is essential since all possible malfunctions can neither be foreseen nor eliminated.

CONCLUSION

Longwall mining has evolved from sections using manual loading and haulage techniques to the mechanized systems currently being operated. The possibility of reduction in fatalities on faces, as well as the gains in productivity are reflective of the awareness and inclusion of safety features into the technological advancements incorporated into these systems. The innovative technologies used in control systems and increasing operating voltages offer the promise of continued progress in the areas of safety and productivity. Innovations do not necessarily benefit both safety and productivity and, in fact, may impact negatively on one while benefiting the other. Therefore, each innovation must be carefully reviewed for its overall impact. Future enhancements of control systems enabling the operator to be further removed from the equipment must be closely evaluated. While the operator may be removed from the hazards of operation, his ability to perceive and respond to potentially hazardous conditions will also been diminished. The result could be increased hazards faced by other miners due to malfunctions of equipment where an operator is not readily available to recognize and respond to the problem.

The Mine Safety and Health Administration is aware of the industry's need for the more efficient production of coal, and is empathetic with the efforts being made in an attempt to accomplish this goal. In concert with the industry's efforts, MSHA is attempting to familiarize its employees, including the inspectorate, with the new technology. With familiarization, MSHA employees can better appreciate, evaluate, and underscore the safety features of the technology being used to enhance the safety and productivity of the mines.

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