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LONGWALL MINING OF THIN SEAMS

by

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ABSTRACT

An estimated 49 billion tons or 29 percent, of the coal reserve base to a depth of 1,000 feet in the eastern United States fall in the 28- to 42-inch range. Often left out as a consequence of selective mining, it is a paramarginal source that will become increasingly important. At present, all active thin seam longwalls are located in the Eastern Coal Province, and a number of operations have been suspended due to the erosion of the market for metallurgical coal.

Extensive premining studies, appropriate mine planning, reliable equipment that is designed with ergonomics in mind, adequate roof support, intensive training, and strong face discipline are the ingredients that provided a measure of consistency in production for the last 10 to 16 years, particularly in the Pennsylvania bituminous coalfield where single drum shearers dominate. Plows, which were found to be very productive in suitable strata in Europe, are used in the Pocahontas field. Low seam four- and six-legged shields have been introduced recently. The future holds automation at progressive levels. The first step is batch control with the benefits of quickly applied roof support and reduction of workmen exposure to environmental hazards.

INTRODUCTION

In the eastern United States, 49 billion tons, or 29 percent, of a coal reserve base of 169 billion tons minable by underground methods fall in the 28 in. to 42-in. range (1). The underground reserve base includes bituminous and anthracite coalbeds more than 28 in. in thickness to a maximum depth of 1,000 ft. The tonnage in the low coal range is now of less economic importance than reserves in the above 42 in. category. Some of it is currently mined and all is considered a paramarginal source that will become of increasing interest in the future.

As a consequence of selective mining, thin coalbeds are often left out in favor of thicker overlying or underlying beds. But mining thin coalbeds in sequence from top to bottom in the strata profile makes use of what resources are available and extends the life of mines that age economically as extraction moves away from openings. Another advantage of such planned mining is a better control of rock mass behavior and methane emission.

In thin coalbeds, large areas must be extracted to maintain a high rate of production. To produce 1,000 tons of material per shift, a 500-ft face must advance 10 ft per shift in a 60-in. coalbed; 12.5 ft in a 48-in. bed; and 17 ft in a 36-in. bed. Entry development must keep pace with such face advances; therefore, retreat is the preferred mode of mining because entries driven with or ahead of the face cannot be developed fast enough, neither can face ends be formed in the available time. Most efficient thin seam longwalls in Europe are retreating, and in the United States, the Code of Federal Regulations standards make multiple entry development for retreat mining mandatory.

The human factor is of the highest importance (2). Personnel movement should be restricted to a minimum. Ergonomics, the human aspect of machine design, enters into consideration in assembling, taking apart, moving, maintaining, and operating equipment. Automation at progressive levels may be attempted to remove the workman from the face. Obviating valve manipulation, roof support units can be controlled individually by push buttons or in batches by manual or shearer initiation. Remote control from the entry presents a high level of roof support automation.

The first longwalls in the United States were introduced in the fifties with the specific purpose of mining coal in the 30- to 40-in. range by a plow. Gains in productivity by this method versus room and pillar mining by low seam continuous miners or even hand loading on conveyors were negligible, and roof control by single friction or hydraulic props was often precarious, so that the last of these walls was phased out in 1958. Longwalls with powered roof support were successful but operated in coalbeds of at least 50 in. when introduced in the sixties. Presently, 12 longwalls of a total of approximately 100 active faces extract coal, 42 in. and less, in the Lower Freeport and Upper Kittanning of Pennsylvania, Pocahontas No. 3 of West Virginia, Hazard No. 4 (Fireclay) Rider of Kentucky, and Lower Jewell coalbeds of Virginia.

¹Numbers in parentheses refer to items in the list of references at the end of this report.

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GEOLOGY

In Pennsylvania, the D-Seam (Lower Freeport) and C Prime-seam (Upper Kittanning), mined by longwall methods, belong to the Allegheny series (fig. 1) (3). The Allegheny series is overlain by the strata of the Conemaugh or "Barren" formation, which forms the surface. The minesites are in the Appalachian physiographic province, which is structured in a series of low northeast to southwest trending anticlines and synclines with dips of 2 to 8 degrees. The coalbeds are 41 to 47 inches in thickness, and the coal is of medium volatile rank and of good utility or even metallurgical quality (4). The immediate roof is mostly formed by a sandy shale, which caves behind the canopies when the roof support is moved ahead.

West Virginia is also part of the Appalachian Plateau province. Pocahontas No. 3 coalbed of high rank and quality is the most valuable seam of the Pocahontas formation. The thin-seam longwall operations are located in the southern region near Beckley and Pineville, where the Pocahontas No. 3 seam measures 36 to 44 inches in thickness. Operations in the Powellton and Hernshaw coalbeds of the Kanawha series have been suspended.

The Raven coalbed, locally called Lower Jewell in Buchanan County, Virginia, is high to medium volatile coking coal and is 36 inches thick. It belongs to the Lee formation which may be the equivalent of the New River series in West Virginia and overlays the Pocahontas series. The coal-bearing strata are generally flat lying to gently dipping.

In eastern Kentucky, the longwall mining is conducted in the Hazard No. 4 (Fireclay) Rider coalbed near Hyden in Leslie County. Coal thickness ranges from 26 to 42 inches. The immediate roof is shale, and the overlying rock formation is classified as channel sandstone, shale, and sandstone. The area is part of the Hazard reserve district, and the coal is ranked as high-volatile utility fuel. Operations in the Elkhorn No. 2 coalbed of the Big Sandy reserve district near Jenkins have been suspended.

MINING SYSTEM AND PANEL GEOMETRY

Figure 2 is a diagram of a typical retreat panel and its ventilation system. The longwall panel is blocked out by bleeder entries that provide gob ventilation during retreat mining by directing the airflow across the gob and moving any body of gas which may accumulate into the bleeder system. Intake air is coursed along the face from the maingate to the tailgate before it enters the gob. The tailgate is an additional intake to bring the tailgate face end area in compliance with Mandatory Standards.

Many companies prefer homotropical face ventilation, that is, air and coal flowing in the same direction from the tailgate to the maingate. It keeps dust concentration lower compared with the conventional antitropical ventilation, where high relative velocities between air and conveyors may initiate aerodynamic entrainment of respirable dust (5).

The objective of panel design is to maintain ground stability in the gateroads under the following considerations:

1. Leaving large chain pillars of 80 to 100 ft in width. The rationale is to create conditions for each sequence of panels similar to those obtained on the first panel, where the least adversity is expected (6, 7). This design results from the findings of Salamon and Munro (8) who determined a Factor of Safety S by the following formula:

$$S = 1320 \times w^{.046} / h^{.066} \times (1-e) / 1.1H$$

where w = pillar width, feet
 h = mining height, feet
 e = extraction ratio, decimal
 H = depth of overburden, feet

The extraction ratio considers the whole area, including longwall face and chain pillars.

2. Choi, Dahl, and Von Schönfeld recommend that the large chain pillars be located at the maingate entry of a panel and that the small yield pillars be located at the tailgate entry of the next panel. This configuration will provide reduced deformation and improved stability around the tailgate; it should also induce a cleaner break at the edge of the gob and improve overall opening stability by transferring a significant portion of the overburden weight to the gob. Figure 3 shows a finite element model designed to determine loads on the chain pillars (9).

Ventilation requirements may dictate a minimum of four development entries for retreat longwall that is in compliance with MSHA Mandatory Standards. Three-entry development, which is quite common, is subject to exemptions from State and Federal Laws, and double entry and single entry (with appropriate dividers) gate systems were approved for several western mines prone to bumps during multi-entry development.

High losses of water gage in low-height and heavily timbered and cribbed entries of 4,000- to 5,000-ft-long panels may pose a problem in coursing 12,000 to 15,000 cfm through the longwall faces. Air travel can be cut in half by having the air flowing in at one end and out at the other end of the panel (10).

Figure 4 shows a panel operation plan that seeks to minimize resistance to the airflow during extraction. The plan includes the gob area of the first panel, longwall face extraction in the second panel, and panel development in the third panel. During the development, one entry is the combination belt and track entry on a split with limited air velocity; the adjacent entry is the air intake; and the third entry is the return aircourse. The panels are connected to a bleeder entry system. During panel extraction, both entries, adjacent to the belt entry, which is now the maingate, are on intake air; and at the tail end, all three entries are on return.

In addition to the spray water applied for dust control and amounting to as much as 25 gal/min on some faces, water influx from other mines and from the surface will wet and muddy the mine floor, cause extreme inconvenience to the workmen, and may ground out electrical equipment. Longwall panels should possibly be projected to provide grades for drainage from the faces to the gob. Otherwise pumps with permissible drives or powered by air or hydraulic motors are needed in the face area.

The effect of face length on strata control is uncertain. Therefore, selection of face length is guided largely by economic and technical considerations. Cost of equipment ownership increases with face length, but the cost of panel development per unit of mined coal decreases as face length increases (fig. 5). Also, conveyor chain reliability sets a limitation to face length. A face length of 600 ft was determined to be the most economic length compatible with conveyor reliability (11).

Factors with affect panel length are the following:

- Surface effects
- Local geology
- Interaction with previous mine workings
- Oil and gas wells
- Boundaries
- Gateroad maintenance

Longwall panels in the United States average 4,000 ft in length. A few exceed 5,000 ft. Several new coal mines have been developed for longwall mining with panel blocks as large as limiting factors allow. They are projected to have two active longwall faces and as many continuous mining units as are required for development and extraction.

Roadways are 16- to 20-ft wide to accommodate belt conveyor, track, hydraulic powerpack, and electric power centers. In addition to mechanical and resin anchored roof bolts, belt entry roof support by resin anchored trusses has been introduced lately. During development by continuous miner, roof or floor is brushed to provide 50 to 60 in. of clearance in the maingate. Often tailgates are driven with the same height as maingates to add to the transportation and escape facilities.

Critical ground stresses may develop at the face ends, where abutment forces along the face combine with those along the gateroads. They impose a heavy load on the roof support system. Therefore, single hydraulic props, by virtue of early bearing capability, are used to control convergence in gateroads. They are set, in addition to cribbing that relies on rock deformation for building up support strength. Most props function with a self-contained pump and manual operation. They yield at 22 tons. There are also props that are connected to the hydraulic face supply system and can extend to exert a thrust of 30 tons if properly blocked. They are rated to yield at 44 tons.

MINING EQUIPMENT

The shearer loader is the predominant mining machine in thin seam longwalls in the United States. Only three plow faces were operating in thin seams in 1980 in spite of obvious advantages of plow versus shearer, such as simplicity, control from the maingate, coarser cuttings, better methane control, and less dust. But shearers can cut rock inclusions and firm coal that is not plowable, and offer a better horizon control where the coalbed is undulating, the floor is soft, or bed separation between coal and adjacent rock is not distinct, though manufacturers of novel plows claim adequate horizon control and cutting performance in firm coal. Plowability also depends on the attitude of the cleats in the coal and is best if the longwall face runs roughly parallel to the main cleats. Panels should be designed accordingly. Plows operate on numerous economically viable faces in 40 in. of coal and less in Germany where plowing is the predominant mining method below 64 in. of mining height.

Two types of plows, the hook plow and the "Gleithobel," are used in the United States. The hook plow is the older version (fig. 6). It is fitted with a stabilizer base plate that reaches under the pan line. The plow chain, guided along the gob side of the face conveyor, engages the stabilizer plate and, thus, pulls the plow whose picks are turned into the coal. The hook plow, passing along a face in firm coal, causes the face conveyor to "breathe," sometimes associated with blocking of the conveyor and chain breakage due to the high forces exerted by the advancing rams of the roof supports.

The "Gleithobel" is the more recent version of the plow that eliminates the stabilizer plate of the hook plow with its associated problems such as power losses due to friction and harmful "breathing." The plow is guided by ramp plates and propelled by a plow chain installed on the face side of the conveyor (fig. 7). Its upright position is maintained by a portal riding atop the pan line (figs. 8-9). A novel version of a plow without a portal is stabilized by a slide shoe that rides on a tubular guide, attached to the face side of the conveyor (fig. 10). Horizon steering of a "Gleithobel" is

achieved by outrigger-mounted hydraulic cylinders along the pan line that elevate or lower the gob side of the conveyor and, conversely, steer the plow to drop or to climb relative to the face. At the face ends, block anchorage cylinders maintain and steer the system in the horizontal plan.

High-speed or overtake speed plowing at plow speeds of 300 to 400 ft/min with conveyor speeds of 100 to 150 ft/min is the plowing technique most frequently used in Europe. This technique was developed to put an even load on the conveyor and, thus, improve the production potential of the system as the plow runs at high speed. The low plow speed is used in grading work or near the terminal points. Plow speeds of fast running plows approach pick speeds on the perimeters of revolving shearer drums (12). Two- and three-speed plows and conveyor drives are available to permit a number of combinations for the best results with cutting depth ranging from 2 to 6 inches. A disadvantage of high-speed plowing is that frequent switching and reversing causes heating in the large plow motors and the circuits of the control system (13).

Plows are advanced into the coal by maintaining constant pressure with the advancing rams of the roof supports. Plow chains usually measure 26 x 92 mm. Larger chains, 30 x 108 mm, are now quite common. Modern plows are powered by water-cooled two-speed plow motors at each end, rated up to 200/75 hp.

Originally plow drives had to be installed in the gateroads outside the face panel block. However, the "Gleithobel" can be rigged to bypass the drives by having its center section connected to the plow chain so that part of the tail drive can be cut free (figs. 12-13).

Effective dust control on most plow faces is provided by sectional sprays, distributed along the pan line on 20-ft intervals and playing water on the plow track through slots in the spill plates. The sprays can be triggered manually, but automatic initiation by the passing plow is preferable because it properly apportions the quantity of water ejected under high pressures. Some "Gleithobels" are equipped with trailing hoses to feed water to sprays directly placed on the plow bodies. Water infusion of the coal from the entries through holes drilled parallel to the longwall face can be very effective to raise moisture in the coal by 2 to 3 percent by injecting 0.1 to 0.5 gal/min under 200 - 400 psi pressure (12, 5).

Two plow faces operate in the 40-in Pocahontas No. 3 coalbed. One is a hook plow and the other is a "Gleithobel." Another "Gleithobel" is used to mine the 36-in Lower Jewell seam. There are plans to substitute plows for shearers on two Pocahontas No. 3 faces.

Most shearers in use in thin seams are single drum bi-directional machines of the fixed drum or ranging arm type. Drum diameters should approximate mining height, and the ranging arm gives some flexibility in cutting by drives and in grading (fig. 14).

Cutting efficiency is achieved by sharp picks and a drum lacing pattern that provides failure of coal in tension and breakout towards a free face in the direction of coal flow across the drum (14). Most shearer drums have two-start spiral vanes, are 30 in. in width and cut a 27- to 28-in web. Three-start spiral vane drums with forward attack picks have been introduced recently. A wider web is desirable where roof control can be maintained.

Loading doors or cowls are needed to support the loading function of the drums in connection with static ramp plates mounted along the face side of the conveyor. Loading doors are used with single drum shearers. They are actuated by hydraulic cylinders, and following the direction of shearer travel, they are either held parallel to the shearer body or swung out 90 degrees in a position parallel to the drum shaft (fig. 15).

Cowls are used with both double and single ranging shearers. They need a vertical clearance of 12 in. in addition to the drum diameter to swing them around the drum when the direction of the shearer travel is reversed.

Shearer haulage chain live tensioners are mounted on the main and tail terminals of the face conveyor and are connected to the hydraulic pressure system of the roof supports. The tensioners compensate for the elastic stretch of the chain, which may amount to as much as 2.1 ft for a 470-ft face and a 26-mm chain. They are to provide uniform chain loading regardless of the position of the shearer along the face. Chainless haulages promise benefits in both safety and efficiency but have not found application in thin seams yet except for one prototype unit that did not give satisfaction.

The well known Bretby cable handling system is used with most shearers, but is not applicable in very restricted vertical clearance. Therefore, a system for thin seam operation has been developed. Shearer cable and water hose are laid into the cable trough along the pan line by a shoe riding atop the roll top of the spill plate and kept from lifting out by spring loaded arms (15).

The control of respirable dust often constrains the production. Fewer picks, slower drum rotation, and picks as long as 4 in. are favorable factors in dust control. Wetting of the dust at the point of origin is achieved by pick face flushing through water sprays integrated with the drum and ejecting water under high pressures up to 600 psi (fig. 16). Hollow drum shaft ventilation by water-driver venturis is recommended where methane liberation is high. Additional methods available to allay dust at the source include water with a wetting agent and homotropical ventilation. Having the drum in the shadow of the coal to be mined also reduces propagation of dust (12).

Shearers no longer ride on the pan line but on heavy structural elements of the furniture, ramp plates, and tubular guides. The single drum shearer must enter the tailgate and, if roof or floor deterioration or heavy timbering and cribbing makes that impossible, a machine stall must be provided, often driven by blasting and hand loading. Face end

formation can also be achieved by having a second tail end shearer cut out into the gate. This system is quite common in the United Kingdom and practiced in a few faces in the United States.

Double-ended ranging-drum shearers provide face end formation without entering the gates but do not operate in heights less than 50 in. The in-web shearer, a low double ended ranging-drum shearer version, which rides on the floor ahead of the face conveyor, is designed to cut coal as low as 36 in. and to contain the equipment within the panel block without extending into a vulnerable tailgate (fig. 17). The debut of this machine in the United Kingdom has been heralded as quite successful compared with single drum on-pan machines (fig. 18). The following advantages are claimed:

1. Reliability due to high horsepower.
2. Face end formation with stall elimination.
3. Minimum cutting height and, hence, less reject due to effective horizon steering by both ranging arms and roll control.
4. Ample vertical clearance above the pan line.
5. Adequate dust control.

The following disadvantages have been noted:

1. The turnaround maneuvers to sump the shearer into the next pass at the face ends amount to 33 percent of the cycle time, with associated loss of production (fig. 19). For instance, each shearer pass on a 600-ft block is equivalent to cutting an 800-ft face. Turnaround time with a single drum shearer is minimal because it is moved into the new cut at each face end without snaking the conveyor.
2. The ranging arms may block the flow of coal onto the pan line, causing recirculation of the material.
3. The haulage chain, if installed on the face side, may also pose an obstacle to the coal flow.
4. Accessibility to the control gear may be difficult.
5. Spindles of manual control may be easily damaged and fouled.
6. "Crabbing" occurs when shearer and pan line diverge, with associated excessive power loss by friction.
7. Length of the machine is 25 ft, which causes difficult maneuvering on undulating floor and at the face ends.
8. The high price of the machine.

Experience with in-web shearers in the United States has been negative so far. One machine was removed, because coal dust was uncontrollable. Another machine came equipped with chainless haulage. However, the chainless haulage system was not adequate to operate in the severe conditions on the face, where the machine had to cut its own floor to provide 36 in. of vertical clearance in a 30-in. coalbed. With the chainless haulage, the main problems were breaking of the driving chain, frequent tripping and breakdown of the solid state haulage force limitation device, and fouling of the captivation shoes. The shearer was then converted to chain haulage. Substituting a haulage chain for the chainless haulage brought on other problems, notably breaking of the haulage chain. The machine was removed from the mine after a cutting module broke down.

A third in-web shearer is still in operation. Frequent tripping of a mechanical haulage pull force limitation device causes very slow cutting. There are plans to replace the shearer with a plow.

The first in-web shearers were brought on the market in the early seventies by a German manufacturer and similar machines were made in the United Kingdom. A more mature type of in-web shearer has chainless haulage on the face side of the pan line and two drives to provide a steady pull with evenly distributed load. Such a machine may find application on high production faces (fig. 20).

Profiles of heavy duty face conveyor pans are 30 by 5-1/4 in and 30 by 7-1/2 in. Each standard pan is 59 in. long to accommodate one roof support unit so that the middle of the pan can be attached to the double-acting ram, thereby minimizing the stress at the pan connections due to eccentric forces when pushing the conveyor forward or pulling up of the roof support unit.

The conveyor snaking procedure that sumps the shearer into the face and involves about 12 pan lengths or 60 feet also stresses the pan connections. Damage to pan ends can be avoided by having connectors attached to the conveyor furniture rather than placing them on the pans. The furniture includes ramp plates on the face side and spill plates with the guide tubes, the cable handling trough, and the brackets for attaching the rods of the double acting rams on the gob side (figs. 21-22).

Conveyor chain speed is 200 to 220 ft/min except for some plow faces. The conveyors are powered by 125-to 150-hp main and tail drives. The power is transmitted through fluid couplings and must be adequate to haul the coal away from the cutter loader. Hydraulic or pneumatic auxiliary chain tensioners facilitate splicing and tensioning of heavy conveyor chains. The conveyor chains are vulnerable to martensitic hardening through the combined effect of fine debris in the pan races and ample spraywater originating from the dust control systems (16). The chains become brittle and break. Older faces still have 18-mm twin outboard and triple chains. Newer conveyors come equipped with single and twin center chains of 30-, 26-, and 22-mm size, and DIN (German Engineering Standards) quality. Twin center chains accommodate low profile drives in thin coalbeds. Short drives and low type returns cause additional wear to chains due to sharp reflection around the sprockets (figs. 23-24).

Stage loaders bridge the gap between the face conveyor and the panel belt by providing flexibility at both the receiving and the delivery end. The stage loader must be wide and running at a velocity of 300 ft/min or more to take the coal away from the face conveyor. The receiving end of a swivel beam type stage loader is hitched to the face

conveyor terminal. It moves with it and must be designed to prevent spillage from being carried back under the return strand of the face conveyor, where accumulation of debris can cause stoppage and chain breakage. The delivery end rests on a swivel dolly that rides on the belt tail piece and allows an overlap of 10 to 13 ft, equivalent to four or five shear passes. A lump breaker can be integrated into the stage loader where space is available. In limited vertical clearance, the stage loader drive is placed at the low receiving end and powered by one or two motors of 25 to 75 hp (fig. 25).

Coal clearance from the face affects production directly. Therefore, the use of high capacity, 42- or 36-in-wide retractable panel belt conveyors are common. They are equipped with mobile tail pieces and have solid or rope structures suspended from the roof by chains (fig. 26).

Track is installed in entries in most mines to accommodate men and supply movement. Low seam man-riding battery locomotives have been developed recently. A few mines use belt and rubber-tired transportation for men and supplies.

ASPECTS OF ROOF CONTROL

The objective of roof control is to avoid bed separation and to prevent convergence in the excavation. In brief, the status in the preextraction condition should be ideally retained by offering infinite numbers of support points with identical resistance (18). Accordingly, the following features are vital in the design of roof support:

1. A large hydraulic extension range so that roof cavities can be supported quickly.
2. An adequate mean load density to support a rock column, considering strata separation and cantilever action. Wade developed the following formula for mean load density (17):

$$MLD = (1 + \sum_{n=1}^5 C_n) \times 4gh \text{ tons/ft}^2$$

where h = mining height, ft

g = specific weight of rock, tons/ft³

C_n = magnification coefficients

Magnification coefficients are identified as hanging of immediate roof, local face activity, bridging of immediate roof prior to the first fall, main roof weight, and extended downtime.

3. A working pressure equalling 80 percent of the support yield pressure to maintain a strong thrust against the roof immediately after exposure to prevent bed separation. The hydraulic system must have sufficient capacity to coordinate the speed of the roof support advance with the shearer haulage speed and, thus, to minimize the delay of supporting the roof after exposure.

A modern powerpack consists of three units, two operating and one on a standby basis, of 75 hp each. Each pump is capable of supplying 25 gal/min to a dual pressure system of 4,350 psi for leg setting and 2,000 to 3,000 psi for all other functions. A mixing and storage tank holds 240 gal of 5-percent oil-in-water emulsion. Usually a powerpack is kept near the longwall face in the headgate area and must be moved outby with the retreating face. But the use of stationary powerpacks is on the increase. They are located in the mainline entries where they can supply pressurized hydraulic fluid through 2-in. pipelines to several inby faces without relocation.

4. Depth of web.
5. Short span of exposed roof.
6. Short time of roof exposure.
7. Efficiency of cleanup. Compression of a cushion of debris will cause excessive yield and, hence, bed separation because roof supports yield only 0.5 to 1 inch (18). A self-cleaning base will allow debris to pass through into the gob.
8. Load redistribution by "tramping." German miners use this expression to describe roof deterioration above powered supports caused by frequent setting and lowering. For instance, shields with short canopies take fewer steps from gob to the face than chocks with longer canopies.
9. Rate of face advance. A fast face advance is beneficial for maintaining roof control.
10. Mode of operation. The one-web-back mode provides a wider travelling space and immediate forward support by advancing the roof support after the shearer has cut by and before the conveyor is moved. The non-web-back mode minimizes roof exposure in front of the front props. This mode is often used in thin coalbeds in connection with a crawl pan.

11. A safe travelway. Crawl pans should not be narrower than 24 in. so that injured persons on stretchers can quickly be moved out of the face area. Five- and six-legged chocks provide a most convenient and protected travelway between front and center legs.

Five- and six-legged chocks are in use on four D-seam longwall faces in Pennsylvania and offer adequate roof support. They are spaced on 39- to 48-inch centers to provide a high load density. This type of roof support is also the preference in British thin seam longwalls. The hydraulic travel ranges from 30 to 53 inches. Legs are rated to yield at 55 to 85 tons. Setting load is less than half of the yield rating. The canopies are articulated between the center and front props. These chocks operate in the non-web-back mode and feature a relatively short prop-free front. They can be equipped with spring steel extensions to provide immediate forward support (fig. 27).

Four-legged chocks with a hydraulic range of 29 to 49 inches and canopies, articulated between the front and rear legs, are used in the Pocahontas No. 3 coalbed in West Virginia under firm roof strata. Each leg yields at 175 tons. Chocks with lower yield ratios are used in thin seam longwalls in Pennsylvania and Virginia (fig. 28).

Shields have been gaining preference over chocks since their introduction into America in 1975. Determining factors for favoring shields over chocks are the following:

1. Sheltered working space requiring minimum cleanup work.
2. Structural stability that allows advancing without delay even with brushing roof contact.
3. Wide hydraulic range of mining height.

However, a mechanical disadvantage, caused by the inclination of the shield legs, reduces the vertical force exerted against the roof, particularly in low mining height.

Figure 29 shows how the support forces can be evaluated for two-legged caliper and lemniscate shields. The canopy tip of the caliper-shield describes a circular arc when the shield is raised or lowered. Hence, the critical span between the canopy tip and face widens with increasing height of the shield unless compensated by an extension. Caliper shields also develop a horizontal thrust towards the face when yielding. On lemniscate shields, the span between canopy tip and face barely changes during vertical travel. Figure 30 illustrates how the joint between the gob end of the canopy and the gob shield has been redesigned to eliminate the dead corner where debris could accumulate. A large ram between the canopy and the caving shield stabilizes the joint. Figure 31 shows a four-leg shield with two rear legs supporting the gob shield and thus stabilizing the joint. These shields provide a high tip load and achieve a more even floor loading than two-legged shields (fig. 32). Another design features all four props supporting the canopy directly (fig. 33). Thin seam designs with arrangement of props in an X-fashion are also on the market (fig. 34). Six-legged shields combine a safe and convenient travelway with a minimum of prop-free front (fig. 35).

Having the double-acting ram mounted in an inclined position counteracts the tendency of the shield to dig into the floor. The ram acts through reverse linkage to raise the base slightly and to exert the full force of the piston end when the shield is pulled up to the conveyor.

Automatic sprays mounted on the canopies are to control dust originating from the gob during shield advance, and the working space is sealed against dust by sideplates fitted between the shields and kept tight by springs and hydraulic rams (fig. 36).

Unidirectional control of each roof support from the adjacent unit shelters the operator and keeps him on the upwind side of the ventilation current. Figure 37 shows a piano-key selector for adjacent push button control. Some roof support systems are controlled by adjacent bidirectionally acting valves (fig. 38).

Remote control in batches of 10 units was introduced recently (19). It is designed to locate the shield operator in intake air in both directions of cutting (fig. 39). The shearer initiates the automatic cycle of shield movement when he pushes a batch-initiating valve attached to a shield. The shield operator then activates a selector valve, and the shield movement begins. Each shield, one by one, goes through the cycle of advancement. Movement of a shield starts only after the preceding shield has reached full working pressure. This is a factor favoring safe roof control. Another important safety feature is that it takes the action of both shearer and shield operator to actuate the batch movement cycle and, in an emergency, a stop valve can interrupt the automatic sequence and bring it to a halt.

Roof supports should be equipped with load indicators to measure hydraulic pressures and, thus, to trace the loading profile in the roof support system. Redistribution of load through moving adjacent roof supports has proved more significant than exposing roof when the shearer cuts by (18).

High air velocities in the restricted longwall cross-sectional area can cause physical discomfort to miners and initiate aerodynamic dust entrainment. Research in dust elutriation carried out in England by the National Coal Board indicated the threshold velocity lies at about 450 ft/min, above which the aerodynamic entrainment increases very rapidly.

The ventilation cross-sectional area A is a function of mining height according to an empirical formula developed in Europe (20):

$$\begin{aligned} A &= 12.5 (M-1) \text{ for chocks and four-legged shields, ft}^2 \\ A &= 10(M-1) \text{ for two-legged shields, ft}^2 \\ M &= \text{mining height, ft} \end{aligned}$$

Obviously, in terms of face ventilation, faces with two-legged shields are at a disadvantage relative to those with chocks or four-legged shields.

Recovery of longwall roof support is always a difficult task and requires a game plan with forward planning and skillful execution. Shield recovery poses an unusual problem because part of the structure is under the caved rock. Therefore, during the last 10 passes across the face, wire mesh is stretched over the top of the shields. The wire mesh sections, 5 ft in width, are spliced together by steel clips and 3/16-in. wire rope, leaving 6-in. overlaps. After the shield line has reached its terminal position, the shearer completes 2 or 3 more passes to make space for maneuvering the shields out of the shield line, turning them by 90 degrees, and hauling them out. The face conveyor is pushed ahead by means of crib blocks inserted between the advancing ram rods and the pan line.

The exposed roof is quickly supported by wire mesh and planks bolted to the roof. Roof bolts are installed either by column-mounted compressed-air or hydraulic drills, or by rubber-tired roof bolting machines of narrow design. The shearer or plow, the face conveyor drives, the pan line in lengths of three pans, and the stage loader are then removed. Figure 40 and 41 show a shearer moved by rail and a shield on a flat car.

The recovery space is secured by a movable bulkhead formed by two shields, moving side by side along the recovery room, while a shield is pulled from the shield line and taken off the face. This is an important safety feature. Another precaution taken is to build cribs in place of a removed shield. Compressed air or hydraulic hoists anchored to roof bolts or scoop-mounted are used to pull the shields out from the line of supports and to turn them for transportation on sleds or special scoops, fitted with platforms instead of buckets. A precaution, taken in recovery under hazardous roof, is to advance shields from the line of supports under their own power. Shields can then be set quickly, should immediate support be needed (fig. 42).

Where conditions allow, one or several recovery chutes are driven-dead ended for a length of 80 to 100 ft (fig. 43). The recovery room, generated by the terminal position of the face, will cut into these chutes. Hauling pans and roof supports through the chutes will accelerate the recovery procedure.

Presently, three thin seam longwall faces are equipped with shields. Six-legged shields are installed in a D-seam longwall in Pennsylvania. Four-legged shields with X-arrangement of legs are used in the Pocahontas No. 3 coalbed in West Virginia and the four-legged shields with V-type arrangement of legs are used in the Fireclay Rider coalbed in Kentucky.

Face lighting greatly enhances the convenience and safety of the longwall environment. Lighting systems must meet mandatory standards and be approved by a MSHA Statement of Test and Evaluation. The required luminous intensity is 0.06 fL (foot Lambert). Systems with fluorescent or high intensity luminaires have been developed. The components including luminaires, lamp ballasts, and powerpacks should not obstruct the travelway. The luminaires should illuminate the required space but not cause glare to the miners.

Telecommunications systems include page units, spaced every 50 ft along the face, and a prestart signal. Emergency cut-off keys are placed every 25 ft along the pan line.

TRAINING

Prior to initiating the face operation, companies conduct an intensive longwall orientation program for face crews, supervisors, and maintenance personnel. Sequence of face operation can be demonstrated on three-dimensional models or on real equipment set up on the surface and consisting of a length of face conveyor with the terminals, roof support, and shearer or plow. Manufacturer's service personnel provide hands-on training. Hazards peculiar to longwall mining are identified, such as flying particles of coal and rock, and bursting hydraulic hoses and fittings.

On the longwall face, hands-on training is conducted for each crew member in the proper operation of each piece of equipment under one-on-one supervision. Safety and job skills training and retraining classes are held continuously.

OPERATION

Face production and, hence, productivity is a function of the rate of face advance; in thin seams, large areas must be extracted to maintain a high rate of production. The severely restricted space constrains ventilation and taxes the miners' stamina in installing, operating, maintaining, and moving equipment, sometimes under adverse ground conditions that require rock handling. Forward planning from the premining stage to the equipment face-to-face move, reliable equipment, and a high degree of discipline and skill are required to control hazards and provide a safe environment.

All the same, reports from overseas indicate that operations in thin seams are among the most productive ones. The following table lists results from four plow faces in Germany (21):

Mine	Coalbed thickness inch	Tons per day
Niederberg	28	2,100
	36	2,000
Rheinland	31	1,900
	43	2,800

In the United States, the shearer faces in the Lower Freeport and Upper Kittanning coalbeds have scored a record of consistency since the middle sixties. They produce now in the 1,800 to 2,500 ton range of daily output on three shifts with 11 to 13 men crews, each consisting of a shearer operator, a snaker, jack setters, maingate and tailgate men, utility men, and a mechanic, and supervised by a foreman. A record production of 7,920 tons of raw coal was achieved in 24 hrs in October 1977 in one of these mines by completing 47 shearer passes in 42-in coal (22).

Variation in the number of face men is explained by the varying effort involved in the face end formation under different conditions depending on whether a tail end stable must be advanced by hand or whether roof conditions require additional timbering or cribbing.

Plow faces in the high rank metallurgical quality Pocahontas coalbed operate with roughly the same number of face men as the shearer faces, though the plow is remotely controlled from a console in the maingate. Again it is the effort in the gateroads that affects the numbers of face personnel. Production is somewhat lower than the above-mentioned shearer faces due to restricted cutting height under firm roof strata.

Face operations are monitored, and some companies prepare the following documentation:

- Longwall Foreman's Daily Report
- Longwall Operating Summary (monthly)
- Longwall Maintenance Report (monthly)
- Monthly Longwall Manpower Analysis
- Longwall Operating Analysis

The "Longwall Operating Analysis" was developed to tabulate the time of machine availability for cutting and the actual length of cut in feet achieved during each shift versus the potential length of cut calculated for various assumed haulage speeds.

CONCLUSIONS

In the quest for energy, the need for mining thin seams will be pressing and increasing. Thin seam operations pose a challenge to the ingenuity of mining engineers to overcome the factor of human inconvenience in the restricted environment and associated high cost production. Surprisingly, low seam longwalls in the Federal Republic of Germany in an average thickness of 35 in. and dipping less than 18 degrees come close to achieving the average production rate of all German longwall operations. They are all plow faces, and a consistent production of 3,300 tons per day and a productivity of 40 tons per man shift are reported from one of the thin seam longwalls.

These results were attained by reliable high-capacity equipment and roof support by shields that can be collapsed to as low as 22 inches. Maximum mining height for plow operated faces lies at 31.5 inches. Technology for mechanized mining of flat lying coalbeds less than 31.5 inches in thickness without rock cutting is not available, and firmness of coal, undulation of the strata, coalbed thickness variation, and the necessity of cutting rock, particularly through faults, set limits to plow application.

The in-web shearer can be used in firm coal to a minimum mining height of 40 inches, and a daily production of 1,650 to 2,200 tons is reported from a longwall in the Saar district of Germany equipped with such a shearer and shields. Numerous in-web shearers are employed in the United Kingdom; reports as to their success are contradictory. Also, experience in the United States, though limited, has been negative.

The steady increase in output from single drum shearer faces in Pennsylvania is a remarkable achievement, and occasional record breaking peaks in production indicate the potential of such mining. Technology development for the future is aimed at achieving the following goals:

1. Automatic horizon control of plows or shearers.
2. Automatic alignment of the face conveyor to keep the longwall straight.
3. Remotely controlled shearer that is passed along the face.
4. Reduction of slack coal that accumulates in the travel space before it passes into the gob.
5. Improved reliability of a high-capacity low-seam face conveyor.
6. Shields flexible enough to follow floor level variations.
7. Automatic control of roof support.
8. Improved control of respirable dust.

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ACTIVE LONGWALL OPERATIONS IN THIN SEAMS IN THE UNITED STATES

Coalbed state	Thickness inch	Panel block feet	Cover feet	No. entries	Cutter/ loader hp	Face conveyor hp chain mm	Stage loader hp chain mm	Roof support hydr. range inch
Lower Freeport (D-Stream) PA	40 - 50	450 x 4500	400 - 600	3	SDR 200	TS 18 2 x 150	TS 18 75	Check 5/275 32 - 46
do	40 - 50	450 x 4500	400 - 600	3	SDR 200	TS 18 2 x 150	TS 18 75	Check 5/275 32 - 46
do	42	540 x 2800	400	3	SDR 200	T18 26 2 x 150	TS 18 75	Shield 6/450 28 - 50
do	41 - 47	460 x 5000	600	3	SDR 230	SS 26 2 x 125	SR 2 x 25	Check 6/510 28 - 53
do	41 - 47	460 x 5000	600	3	SDR 230	SS 26 2 x 125	SR 2 x 25	Check 6/510 28 - 53
Upper Kittanning (C Prime) PA	42 - 55	600 x 2500	790	3	SDP 270	TS 18 2 x 125	TS 18 75	Check 4/780 22 - 52
Pocahontas No. 3 WV	36 - 46	400 x 2500	650	4	G1 2 x 200	T18 26 2 x 125	TOS 19 75	Shield 4/440 27 - 57
do	36 - 46	400 x 3000	650	4	HP 2 x 125	TS 18 2 x 125	TS 18 75	Frames 4/560 28 - 46
do	44	480 x 5500	800 - 1000	4	SDP 270 SDP 200	TS 18 2 x 150	SR 40	Check 4/700 22 - 49
do	42	490 x 5000	800 - 1000	4	DO 300	SS 26 2 x 150	SR 40	Check 4/700 22 - 49
Lower Jewell (Barnes) VA	36	380 x 3300	600	4	G1 2 x 125	TS 18 2 x 125	TS 18 75	Check 4/460 28 - 46
Hazard No. 4 (Pineclay) KY	36 - 42	600 x 4000	150 - 500	3	SDP 270	TOS 19 2 x 150	SR 40	Shield 4/360 26 - 37

KEY: Cutter/loader: SDF single drum shearer; SDR ranging single drum shearer;
DD double drum shearer (in-web)
G1 Gleithobell; HP hook plow.
Face conveyor: SS Single strand; TOS twin outboard; TIS twin inboard;
4 stage loader: TS triple strand; SR single roller
Roof support: Number of legs/summation of yield ratings.

FIGURE 1 - Active Thin Seam Longwalls

FIGURE 2 - Retreat Longwall Panel

Finite Element Mesh

FIGURE 3 - Finite Element Model

FIGURE 4 - Longwall Retreat Mining Plan

FIGURE 5 - Face Length in Terms of Ownership and Development - Costs

FIGURE 6 - Hook Flow

FIGURE 7 - Gleithobel

FIGURE 8 - Gleithobel

FIGURE 9 - Gleithobel

FIGURE 10 - Gleithobel Without Portal

FIGURE 11 - Block Anchorage

FIGURE 12 - Plow Face Layout

FIGURE 13 - Plow Face

FIGURE 14 - Single Drum Shearer

FIGURE 15 - Single Drum Shearer

FIGURE 16 - Pick Face Flushing

FIGURE 17 - In-web Shearer

- FIGURE 18 - Face Layout

Longwall mode of operation

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-FIGURE 19 - Longwall Mode of Operation -

FIGURE 20 - In-web Shearer

FIGURE 21 - Face Conveyor

FIGURE 22 - Face Conveyor

FIGURE 23 - Main Drive

FIGURE 24 - Main Drive

FIGURE 25 - Stage Loader

FIGURE 26 - Winch for Belt Retraction

NOTE: Dimensions are inches

FIGURE 27 - Six-legged Chock

FIGURE 28 - Four-legged Chock

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FIGURE 29 - Shield Diagrams

Lemniscate - 2

FIGURE 30 - Lemniscate - 2

FIGURE 31 - Four-legged Shield

FIGURE 32 - Roof Shield

FIGURE 33 - V-type Shield

FIGURE 34 - X-type Shield

FIGURE 35 - Six logged Shield

FIGURE 36 - Side Shield

FIGURE 37 - Piano Key Selector

FIGURE 38 - B1-D1 Rotary Valve

FIGURE 39 - Remote Batch Control (12)

FIGURE 40 - Shearer on Wheels

FIGURE 41 - Shield on a Flat Car

FIGURE 42 - Movable Bulkhead

FIGURE 43 - Recovery Chutes