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# Rotary Drilling Holes in Coalbeds for Degasification

UNITED STATES DEPARTMENT OF THE INTERIOR

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# Rotary Drilling Holes in Coalbeds for Degasification

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# ROTARY DRILLING HOLES IN COALBEDS FOR DEGASIFICATION

by

Joseph Cervik,[1] H. H. Fields,[2] and G. N. Aul[3]

ABSTRACT

Coal is a soft and brittle material. Drilling rates in the Pittsburgh coalbed using a drag bit exceed 3 ft/min at 2,500-pound thrust. However, maintaining the bit on a horizontal trajectory or parallel to bedding planes to attain lengths of 1,000 feet is difficult. This Bureau of Mines report presents a drill string configuration that can be guided through the coalbed. The angle of the borehole is measured periodically and by proper combinations of bit thrust and rotational speed (r/min), bit trajectory can be lifted or dropped to keep the bit in the coalbed. An example of a hole drilled to 2,126 feet is presented to show levels of thrust and rotational speed used to lift or drop the bit, the seemingly unexplainable events that occur, and the strategy used during drilling. Thrust levels during drilling range from 600 to 2,500 pounds. Hydraulic motors powered by a 30-hp, 440-volt motor provide ample power for drilling horizontal holes 2,000 feet long.

## INTRODUCTION

Experience has shown that methane flow rates from horizontal holes drilled into coalbeds are directly proportional to length. For holes drilled from underground locations in a coal mine in the Pittsburgh coalbed (Fairview, W. Va., area), a characteristic flow rate is 25,000 $ft^3$/d per 100 feet of hole. However, in areas of the coalbed remote from mining, such as in shafts located 1 mile or more from an underground mine, initial flow rates are much greater and approach 65,000 $ft^3$/d per 100 feet of horizontal hole. The lower flow rate is the result of partial degasification of the coalbed along the periphery of the mine.

Maintaining a bit on a horizontal trajectory or inclined to follow the dip of a coalbed is difficult. The natural tendency of the bit during horizontal drilling is to arc downward because of gravity. Changes in hardness of the coalbed or hard inclusions such as pyrite balls may deflect the bit in an unpredictable manner.

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[2]Mining engineer.
[3]Geologist.

A bit deviating from a given trajectory by 1° will intercept the top or bottom of a 7-foot-thick coalbed in 200 feet, and in a 4-foot-thick coalbed, within 115 feet if started in the center of the coalbed. Hence, precise control must be maintained on the trajectory to keep the bit in the coalbed and to attain lengths of 1,000 feet or more.

Starting in 1957, the British conducted experimental drilling studies to develop tools and equipment for drilling horizontal holes in coal to depths of 450 feet (1).[4] Procedures were developed for inducing the bit to rise or fall; no information was published on bit thrust and rotational speed. A state-of-the-art study on horizontal drilling in 1970 (5) concluded there are no reliable published data on horsepower, thrust, rotational speed, bit configuration, and the effects of these factors on hole trajectory. In the Pittsburgh coalbed (2), horizontal degasification holes have been drilled ranging in length from 500 to 850 feet. Hole trajectory was controlled by close-fitting stabilizers (packed hole) that ranged from 2 to 10 feet long. Torque, drilling speed, thrust, and rotational speed were not measured. At a demonstration in a strip pit (4), a horizontal hole was drilled to a depth of 1,034 feet. Drilling parameters and a drill-string configuration were developed experimentally to control hole trajectory.

Holes in excess of 1,000 feet expose a large area of the Pittsburgh coalbed to degasification and, therefore, fewer holes are required along the mine's periphery to reduce significantly methane flow into the mine. In addition, four or five horizontal holes (1,000 feet long) produce about 1 million $ft^3/d$ of methane, which can be piped to the surface through an underground system of pipelines. Reduction in methane flow into mine openings improves safety, results in a savings in ventilation costs, and improves the potential for increased coal production.

The objectives of this Bureau of Mines report are to describe the demonstrated methods of maintaining a bit on a predetermined trajectory and to provide data on drilling parameters and equipment. This report provides guidelines and reviews concepts for (those who are contemplating) a horizontal drilling program. Drilling procedures and parameters have been developed for the Pittsburgh coalbed. Although procedures and parameters may require slight modifications in other coalbeds, the principles of horizontal drilling are unchanged.

## ACKNOWLEDGMENTS

The cooperation of Eastern Associated Coal Corp., Pittsburgh, Pa., is greatly appreciated. The authors thank William Laird, vice president--research and development, for his cooperation in conducting some of the work described in this report and for his continued interest and support. We acknowledge the work of Fenix and Scisson, Inc., Tulsa, Okla., on horizontal drilling, which was sponsored by the Bureau of Mines (contract No. H0111355).

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[4]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

## DRILLING HARDWARE

Coal is a soft and brittle material in comparison to a sandstone and, therefore, presents no special problems in drilling. However, hard inclusions such as pyrite concretions do cause drilling problems (3, 5). Certain bit designs will not penetrate a large pyrite mass, and if the bit is not deflected by the inclusion, drill pipe must be pulled and the bit changed.

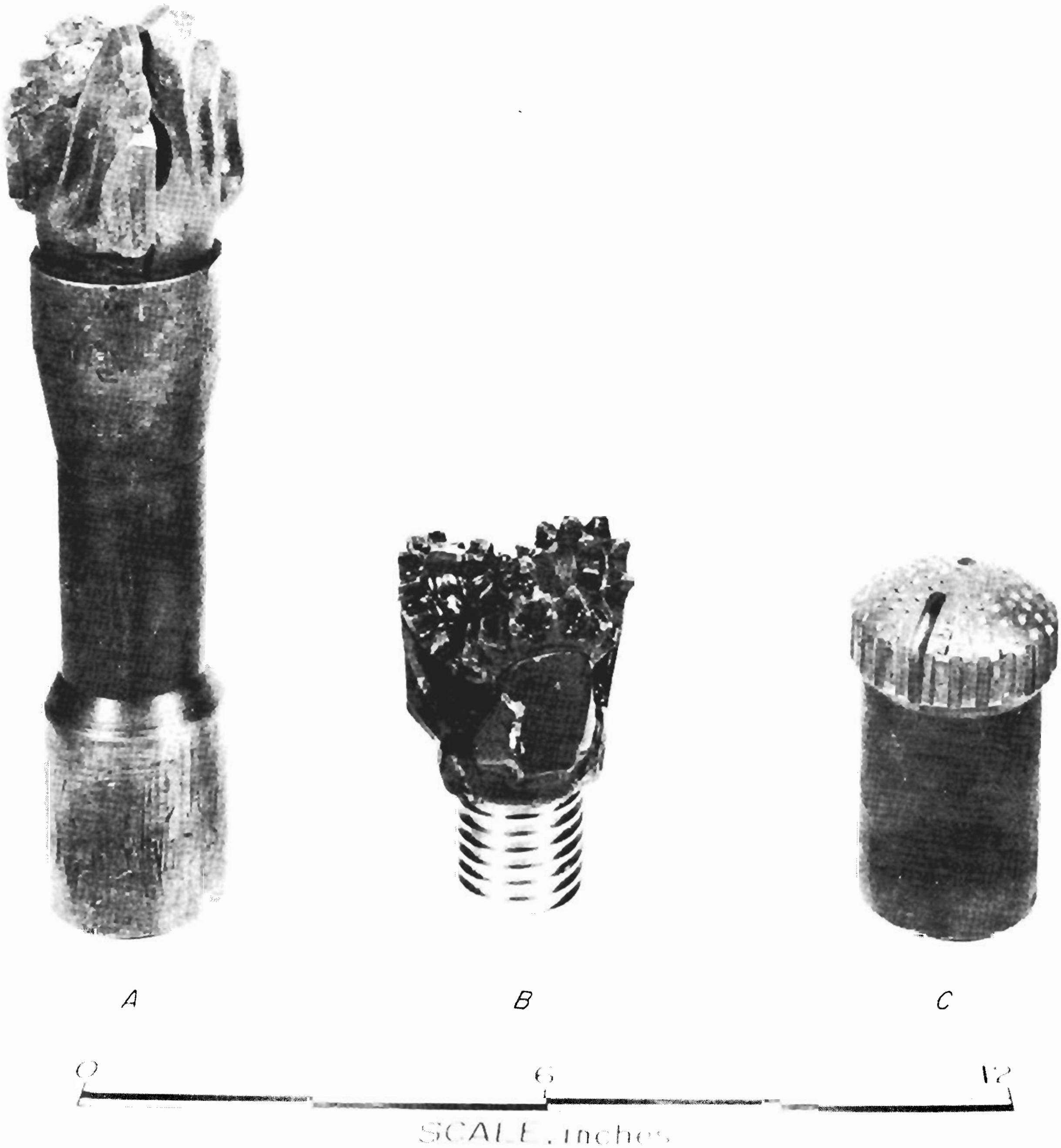


FIGURE 1. - Drill bits. *A*, Three-blade drag bit; *B*, three-cone roller bit; *C*, plug bit.

Water at flow rates of 15 to 20 gal/min is effective in removing drill cuttings and preventing blockage at penetration rates of 3 ft/min. In some underground drilling locations, disposal of drill water is a problem and a recirculating system must be used. Air as a circulating medium is not permitted. An explosive air/methane mixture will form, and sparks from drilling could set off an explosion.

## Bits

There are a variety of bits that can be used to drill coal (3-5). These include a three-blade drag bit, plug bit, and a three-cone roller bit (fig. 1). Choice of the type of bit used will be governed primarily by cost and performance of the bit. For fixed levels of bit thrust and rotational speed, the drag bit by far has the highest penetration rate in coal and is the least costly. Table 1 shows comparative penetration rates of the various types of bits (4). The drag bit has one disadvantage. It will not penetrate a hard inclusion such as a pyrite ball. When this occurs, the drill pipe is pulled and a three-cone roller bit is used. If pyrite balls are prevalent in a coalbed, the three-cone roller bit is used throughout the hole-drilling program even through penetration rates are lower than the drag bit by factors of 3 to 4. Use of the three-cone roller bit circumvents frequent pulling of drill pipe during drilling. Bit diameters used in the Bureau's hole-drilling programs range from 3 to 3-5/8 inches.

TABLE 1. - Bit penetration rates, (Ohio strip pit) (3,000-lb thrust, 200 r/min)

| Bit type | Penetration rate, ft/min |
|---|---|
| Drag.......................... | 11-12 |
| Three cone roller............. | 3- 4 |
| Plug.......................... | 2- 5 |

## Drill Rod

Flush joint casing is used for drill rod in horizontal drilling programs conducted by the Bureau (3, 5). Specifications of casing are shown in table 2. Generally, for holes drilled 500 or more feet, BQ flush joint casing is used. Ten-foot lengths are used for ease of handling in underground locations.

TABLE 2. - Casing specifications

| Casing | EW | BQ |
|---|---|---|
| Outside diameter.................inch.. | 1-13/16 | 2-3/16 |
| Inside diameter...................do... | 1-1/2 | 1-13/16 |
| Threads per inch...................... | 4 | 3 |
| Weight.............pounds per 10 feet.. | 28 | 40 |

## Centralization of Drill String

The primary objective during drilling is to maintain the trajectory of the hole parallel to bedding planes of the coalbed. If the bit deviates from this course, some means of correcting its path must be applied to prevent the hole from intercepting the floor or roof.

Experience has shown that the trajectory of a hole being drilled with a bit and flush joint casing only (fig. 2) is unpredictable. Rotating this assembly at 500 r/min and low levels of thrust causes the bit to wear the bottom side of the hole and arc downward. However, as thrust levels are increased, the hole may arc upward or downward and the trajectory is unpredictable generally.

If a short centralizer (fig. 3) (4-5) is placed directly behind the bit, the trajectory of the hole will follow an arc into the roof. The centralizer is about 8 to 10 inches long, and its diameter is 1/16 inch less than the diameter of the bit. This drill string is shown in figure 4. The weight of the drill string is borne by the centralizer. However, the drill casing, which lies on the bottom of the hole, tends to tilt the centralizer and bit slightly upwards, and consequently, the bit follows a trajectory into the roof. The spirals on the centralizer (clockwise or counterclockwise) do not affect the performance of a drill-string configuration (4). Clockwise spirals are used because of the tendency to assist in the removal of cuttings.

Shifting the centralizer from a position directly behind the bit to a position one casing length (10 feet) from the bit causes the trajectory of the hole to follow a curved path downward (fig. 5). The flexibility of the casing and the weight of the bit bends the drill string downward slightly and, consequently, the trajectory of the hole will be downward. If two lengths of drill casing followed by a centralizer are used, the trajectory of the hole into the bottom is steeper.

Based on the trajectories of the drill strings (figs. 4-5), one would assume logically that the use of two centralizers--one directly behind the bit, and another 10 feet behind the first centralizer (fig. 6)--would keep the bit on a horizontal trajectory. However, this is not so. Experience has shown that the trajectory of this drill string is a downward path. There is no satisfactory explanation for this behavior. Separating the two centralizers by two joints of drill casing (20 feet) does not solve the problem either. The joint between the two centralizers and the flexibility of the drill casing causes the drill string to bow upward between the two centralizers; consequently, the trajectory of the hole is upward (fig. 7).

The drill string that gives the best overall results is the configuration shown in figure 8 (4). This configuration is similar to that in figure 7, except the BQ drill rod is replaced by a heavy NW drill rod (fig. 9). This rod is 2-5/8-inch-OD, 1-3/4-inch-ID, and weighs about 205 pounds. The equivalent length of BQ drill rod weighs about 80 pounds in comparison. The heavy NW drill rod stiffens the drilling assembly and adds weight to the

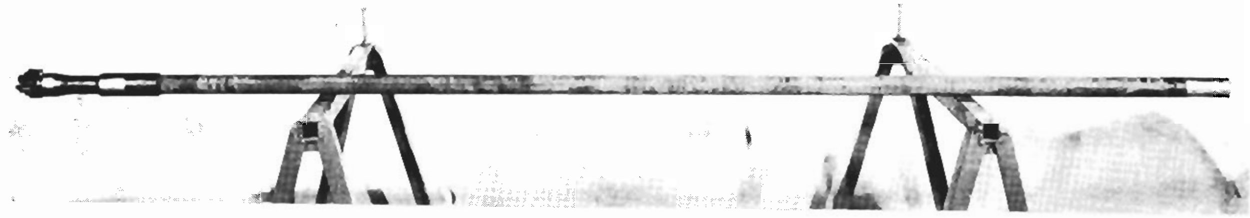

FIGURE 2. - Drill string with bit and drill casing.

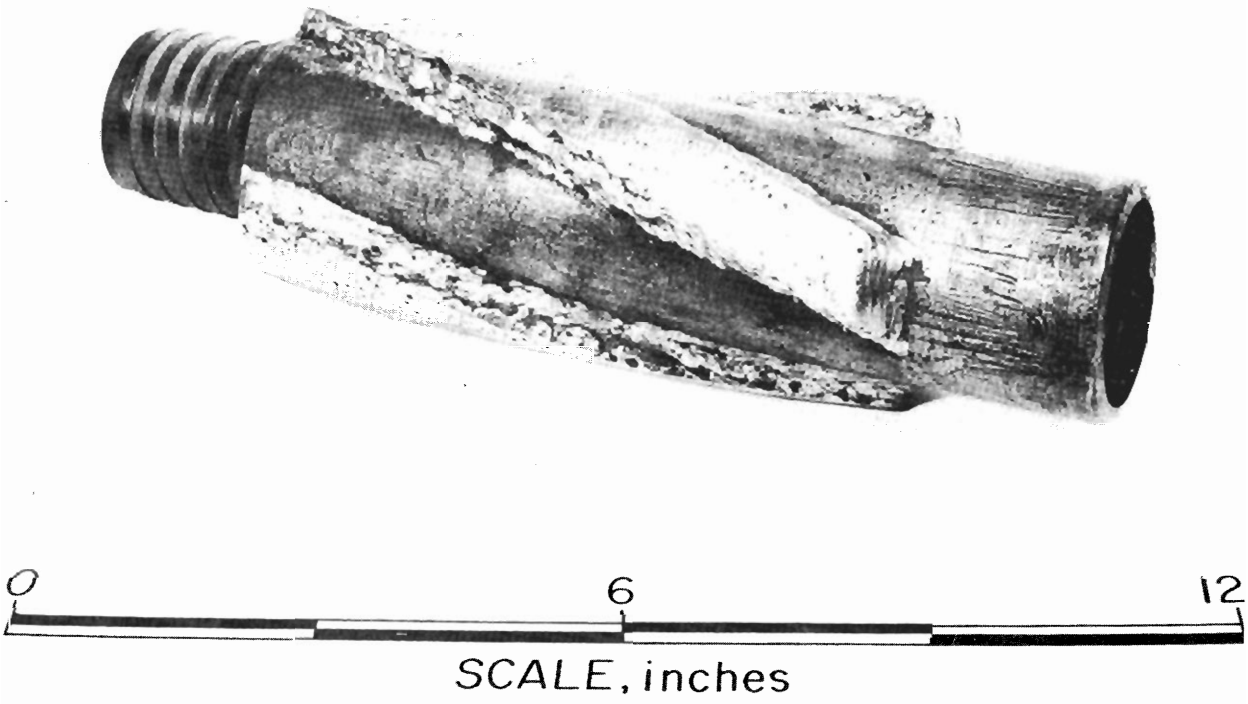


FIGURE 3. - Centralizer.

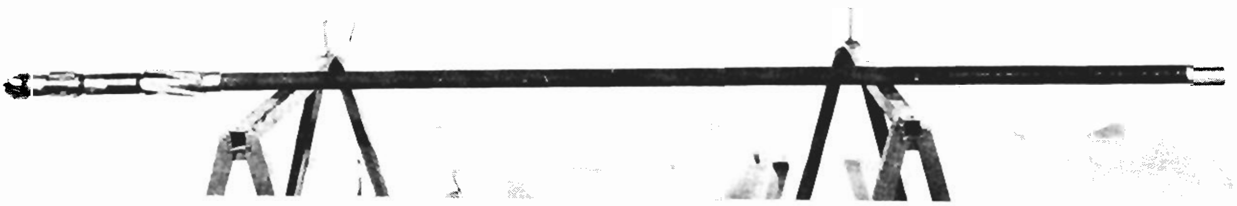

FIGURE 4. - Drill string with one centralizer behind bit.

FIGURE 5. - Drill string with one centralizer 10 feet behind bit.

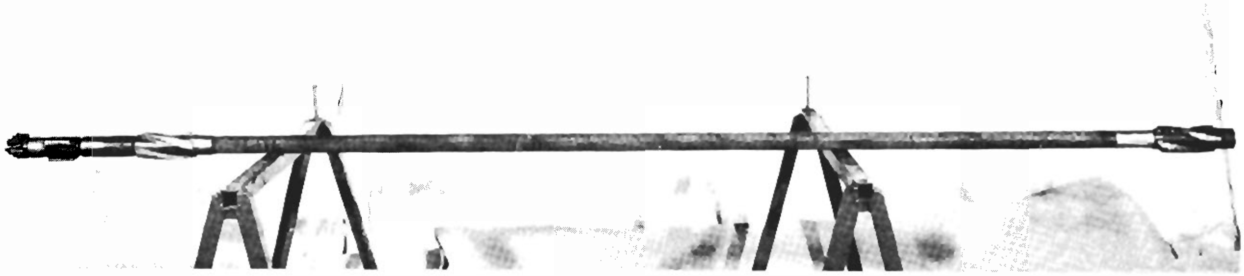

FIGURE 6. - Drill string with two centralizers 10 feet apart.

FIGURE 7. - Drill string with two centralizers 20 feet apart.

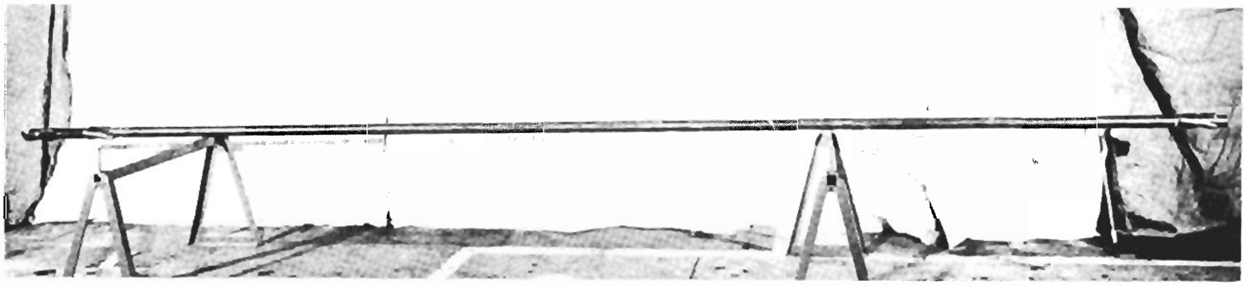

FIGURE 8. - Drill string with two centralizers separated by a 20-foot-NW drill rod.

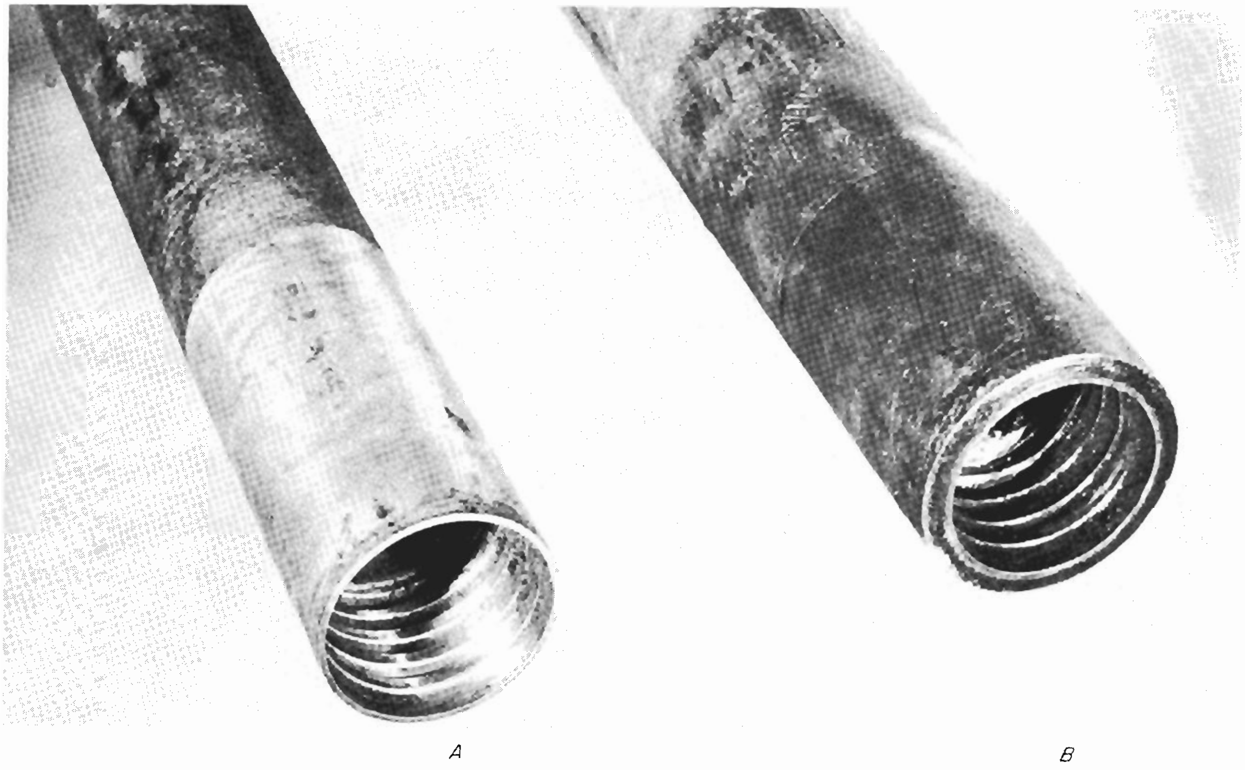


FIGURE 9. - Drill rod. *A*, BQ; *B*, NW.

bottom side of the bit. The drilling assembly (fig. 8) can be made to drill upward, downward, or horizontally.

## CONTROL OF HOLE TRAJECTORY

There are two drilling parameters that affect the trajectory of a drill string and are controlled by the driller. However, before changes are made by the driller, he must know beforehand the path the bit is following with respect to a programed trajectory. This information is obtained with instruments such as Sperry-Sun or Eastman Well Surveying Co. single-shot survey instrument.[5]

### Hole Surveying

Figures 10 and 11 show the single-shot survey instrument and its protective case, respectively. This instrument contains electrical components; therefore, it must be made permissible and approved for use in coal mines. Only the path of the bit in a vertical plane is measured and controlled. Control of the path of the bit in an azimuthal direction will be discussed in succeeding paragraphs.

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[5]Reference to specific equipment does not imply endorsement by the Bureau of Mines.

FIGURE 10. - Single-shot survey instrument.

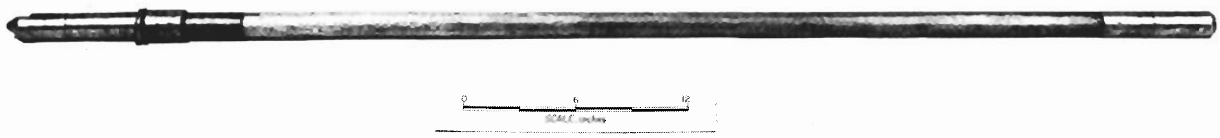
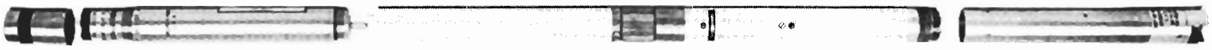


FIGURE 11. - Protective case for survey instrument.



A B C

FIGURE 12. - Survey instrument. *A*, Timer; *B*, batteries; *C*, inclination unit.

The essential elements (fig. 12) of the single-shot surveying instrument are the inclination unit, which is in the form of an inverted plumb bob, batteries to furnish electrical power, and a timer, which controls the electrical circuits and illuminates the angle unit at a preset time to record the inclination on a film disk. Special loading and developing tanks permit handling of the photographic record disk in daylight or without turning off cap lamps underground.

When the inclination of the bit is to be determined, the surveying instrument is placed in its protective casing, which is then inserted into the drill casing and pumped with water to the end of the hole. At a preset time, the film disk is exposed and, subsequently, the instrument is retrieved by wire-line, which is attached to the protective casing. The film disk is removed, developed, and read. The determination of the inclination of the bit takes about 1 hour for a hole at a depth of 1,000 feet. Initially, the hole is surveyed every 30 feet. If the bit maintains its programed trajectory, surveys are extended to 50-foot intervals, then to 100-foot intervals. When the bit begins to deviate, the surveys are made again at 30-foot intervals.

## Drilling Parameters

Two drilling parameters that affect the path of the bit in a vertical plane are bit thrust and rotational speed. Table 1 shows that the penetration rate of the drag bit is 11 to 12 ft/min using 3,000-pound thrust and 200 r/min. At higher thrust levels, penetration rates of 19 ft/min are obtained, providing the fluid return rate is 25 gal/min or more. However, the high penetration rates potentially obtainable in coal are never attained during controlled drilling (fig. 8). Thrust levels normally used during drilling range between 500 and 2,000 pounds. Bit rotational speed ranges from 200 to 900 r/min.

The thrust applied determines not only the penetration rate but also the path of the bit. Table 3 summarizes the effect of thrust and bit rotational speed on bit trajectory (4). Levels of thrust and rotational speed shown in table 3 are meant as guidelines and may vary from one coalbed to another.

TABLE 3. - Effect of thrust and bit rotational speed on hole trajectory

| Thrust, pounds | Bit, r/min | Effect on bit trajectory |
|---|---|---|
| 800............................ | 700-900 | Downward or dropping. |
| 1,200.......................... | 400-600 | Holds angle. |
| 2,000 or greater............... | 200-300 | Upward or lifting. |

## Drilling Procedures

Experience in drilling holes in the Pittsburgh coalbed shows that the bottom 3.5 feet is relatively soft and free of pyrite inclusions. However, the top 3.5 feet is much harder and contains numerous streaks and bands of pyrite. No difficulty was encountered in lifting or dropping the bit, when necessary, in the lower 3.5 feet. However, when the hole was in the upper 3.5 feet, considerable difficulty was experienced in attempts to drop the bit because of the resistance to penetration due to hardness of the bands of pyrite in the coalbed.

The procedures for dropping the bit are to reduce thrust to about 800 pounds and increase bit rotational speed to about 800 r/min. At the end of each 10 feet of drilling, several slow reaming passes are made to wear the bottom of the hole. This procedure was repeated for each 10 feet of penetration for distances of 50 to 100 feet. In many cases, these procedures dropped the bit; however, in several cases, the bit did not drop fast enough and, consequently, the roof rock was encountered. The procedure then is to pull the drill pipe and remove the centralizer behind the bit. The bit is backed off the end of the hole 20 to 30 feet, and slotting runs are made for each 10 feet of drilling. Removing the front centralizer shifts the weight of the heavy NW drill rod to the blades of the drag bit. The bottom of the hole is quickly and effectively worn and a new hole started slightly below the old one. The new hole is surveyed every 20 feet until the desired angle is obtained, and the drill pipe is pulled, the front centralizer replaced, and drilling is continued.

The procedures for lifting the bit are easier and more effective, generally. Thrust is increased to 2,000 to 3,000 pounds and bit rotational speed is reduced to about 200 r/min. A hole deviating by 1° is brought back on course within 30 feet of drilling. Penetration rates are higher also because of the higher thrust levels. In some cases, such as a hole that is dropping 2° to 3° below its programed trajectory and approaching the bottom of the coalbed, removal of the back centralizer turns the hole more rapidly and may prevent the bit from entering the bottom. To do this, the drill pipe must be pulled twice.

## Human Factors

There is presently no substitute for experience in long horizontal hole drilling. The driller must be familiar with the tools, equipment, and their response to drilling parameters. He must make frequent hole surveys, which detracts from actual drilling time. At depths approaching 1,000 feet, survey time requires about 1 hour. Therefore, the driller tends to drill for longer periods before surveying. Consequently, a hole may have diverted from its programed trajectory by more than 1° when finally surveyed. Considerable time may be lost redirecting the hole to its proper trajectory. No serious delay time will occur providing the bit is maintained within 1° of its programed trajectory.

The driller must react immediately to rod chatter sounds from his drill, which indicate hard spots in the coalbed. These hard spots tend to deflect the bit in an unpredictable manner. The driller should reduce thrust until the zone has been drilled. Soft spots in the coalbed are a problem also. Penetration rates are extremely high (5 ft/min at 1,000-pound thrust and 300 r/min), and the bit tends to arc downward rapidly. When soft spots are intercepted, the driller should reduce the rotational speed as low as possible and increase thrust to prevent the bit from wearing the bottom of the hole excessively and arcing downward.

## Azimuthal Control

Thrust and bit rotational speed do not appear to affect the path of the bit in an azimuthal direction when drilling with the assembly (fig. 8). Surveys of holes drilled to depths of about 1,000 and 1,100 feet showed that the holes were 13 and 22 feet left, respectively, of the original bearing lines at depth (4). For degasification purposes, generally this distance is not critical, and no attempt is made to control the bit in a azimuthal direction. However, precautions are taken when pyrite balls are encountered because the bit can be deflected both in the vertical and azimuthal directions.

## Methane Control

Methane flow rates from horizontal holes drilled in virgin coal areas increase at a rate of 45 $ft^3$/min per 100 feet of hole in the Pittsburgh coalbed. At horizontal distances of 1,000 feet, the flow rate is approaching 450 $ft^3$/min and sufficient air must be circulated to reduce concentrations of methane to levels below 1 pct at the drilling site. Therefore, at least

45,000 $ft^3$/min of air is required. The large quantities of air required are not available generally; therefore, other means of handling methane during drilling must be used.

Figure 13 shows the method used in coping with large quantities of methane. Drilling is conducted through a Bureau designed and fabricated stuffing box attached to a 20-foot length of 6-inch-diam pipe grouted into the coalbed. Water and drill cuttings drop into the bottom of the box, and methane is drawn off the top of the box. Flexible tubing is used to connect the top of the stuffing box to a vertical 8-inch-diam borehole, which is maintained at a slightly negative pressure by a surface exhauster or natural draft. This method is a safe and efficient means of handling flows of methane during drilling.

The stuffing box does not solve all methane problems. When drill pipe is being pulled or during hole surveys, gas pressure at the back of the horizontal hole clears the drill pipe of water and methane begins to flow into the mine opening. A one-way check valve placed in the drill string either directly behind the bit or behind the second centralizer eliminates this unsafe condition (fig. 14).

## Drilling Example

Figure 15 shows a partial plot of the trajectory of a horizontal hole drilled with a 3-1/2-inch drag bit and the drill string configuration (fig. 8). This example shows the response of the drill string to drilling parameters (thrust and rotational speed), the strategy used, and the seemingly unexplainable events that occur during drilling operations. The dip of the coalbed in the direction of drilling averages +0.25°. The designation +0.25° indicates the dip of the coalbed is 0.25° above horizontal. The designation -0.8° indicates 0.8° below horizontal.

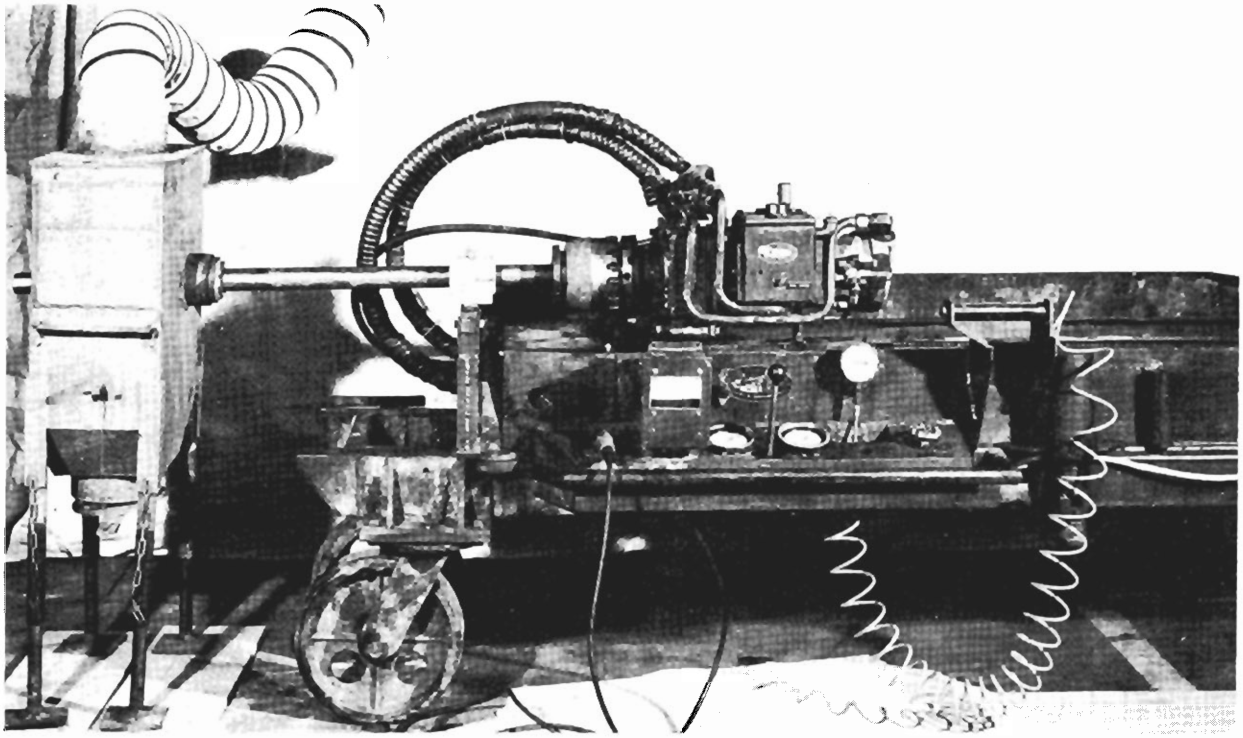


FIGURE 13. - Stuffing box for methane control.

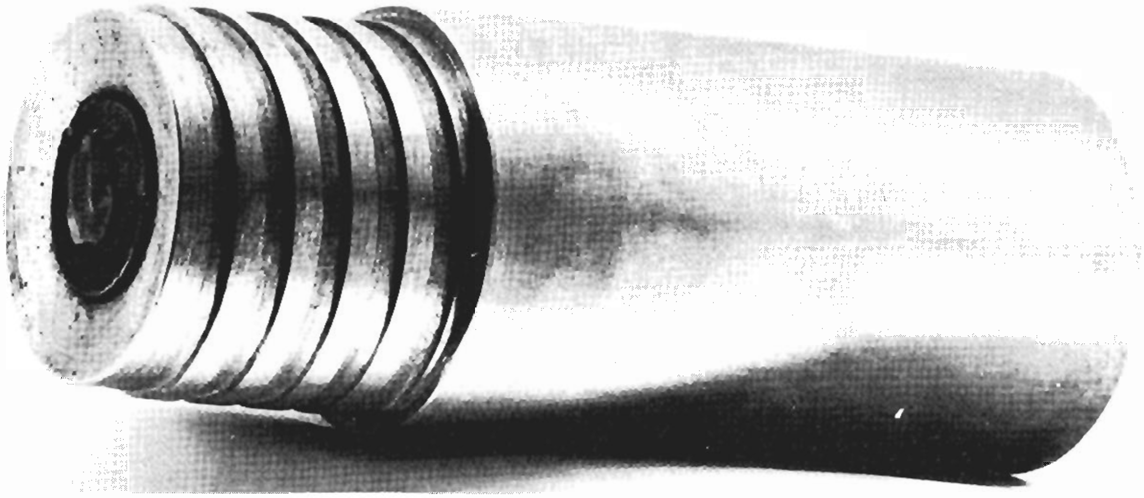


FIGURE 14. - BQ one-way check valve.

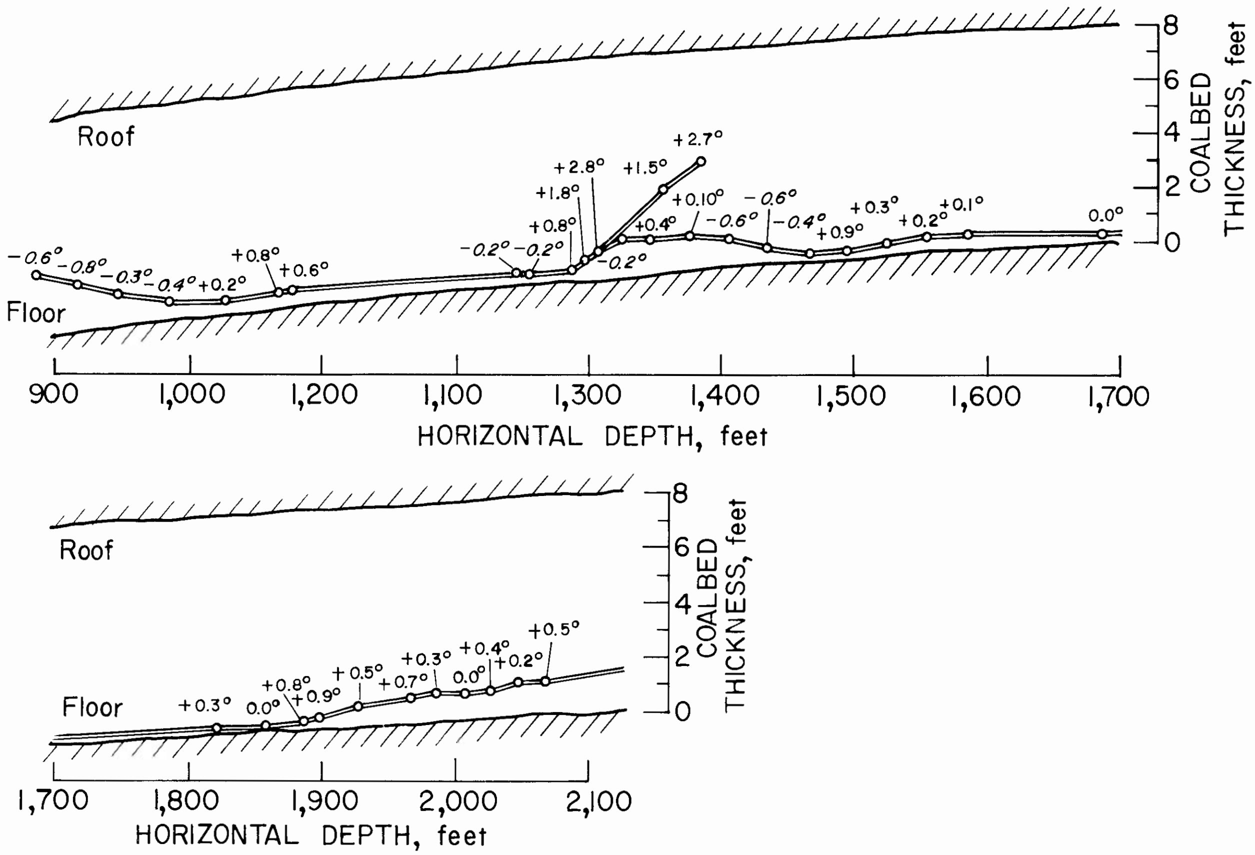



FIGURE 15. - Plot of hole trajectory.

During the drilling operation, a plot is maintained of the trajectory of the hole. The location of the bit relative to a horizontal plane is known at all times. If the coalbed undulates, another unknown is introduced. Table 4 summarizes the drilling parameters used during each interval drilled and the survey angles at the end of each drilling interval; the strategy used for the next drilling interval is provided under remarks.

TABLE 4. - Summary of drilling parameters

| Drilling interval, feet | Drilling parameters | | Survey | | Remarks |
|---|---|---|---|---|---|
| | Thrust, pounds | Rotational speed, r/min | Angle, deg | Depth, feet | |
| 886-916.... | 1,900 | 345 | -0.8 | 916 | Continue drilling next interval with upward parameters. |
| 916-946.... | 1,950 | 270 | -.3 | 946 | Trajectory beginning to level out. Continue drilling with upward parameters. |
| 946-986.... | 2,100 | 270 | -.4 | 986 | Continue drilling with upward parameters. |
| 986-1,026.. | 2,000 | 270 | +.2 | 1,026 | Bit trajectory turned. Reduce thrust and increase rotational/speed. |
| 1,026-1,066 | 1,200 | 345 | +.8 | 1,066 | Reduce thrust to break upward path of bit during next interval of drilling. |
| 1,066-1,076 | 600 | 330 | +.6 | 1,076 | Bit angle is decreasing. Continue drilling with downward parameters. |
| 1,076-1,116 | 600 | 330 | ([1]) | ([1]) | Increase thrust level slightly during next interval. |
| 1,116-1,246 | 1,000 | 335 | -.2 | 1,246 | Continue drilling with downward parameters for 10 feet to confirm previous survey. |
| 1,246-1,256 | 1,000 | 335 | -.2 | 1,256 | Continue drilling next interval with slightly dropping parameters. |
| 1,256-1,286 | 960 | 335 | +.8 | 1,286 | Continue drilling with slightly downward parameters for 10 feet to confirm survey at 1,286. |
| 1,286-1,296 | 960 | 335 | +1.8 | 1,296 | Continue drilling with slightly downward parameters for 10 feet. |
| 1,296-1,306 | 960 | 335 | +2.8 | 1,306 | Continue drilling with dropping parameters. |
| 1,306-1,356 | 960 | 335 | +1.5 | 1,356 | Angle decreasing. Continue drilling with dropping parameters. |
| 1,356-1,386 | 600 | 330 | +2.7 | 1,386 | Pull drill pipe. Remove front centralizer. Restart hole at 1,306 feet. |

[1]No survey made.

TABLE 4. - Summary of drilling parameters--Continued

| Drilling interval, feet | Drilling parameters | | Survey | | Remarks |
|---|---|---|---|---|---|
| | Thrust, pounds | Rotational speed, r/min | Angle, deg | Depth, feet | |
| 1,306-1,326 | 300 | 340 | -0.2 | 1,326 | New hole started. Bit trajectory near horizontal. Pull drill pipe and replace front centralizer. Continue drilling with slightly lifting parameters. |
| 1,326-1,346 | 1,440 | 330 | +.4 | 1,346 | Continue drilling with slightly dropping parameters. |
| 1,346-1,376 | 900 | 340 | +.1 | 1,376 | Continue drilling with dropping parameters. |
| 1,376-1,406 | 1,080 | 340 | -.6 | 1,406 | Increase thrust to lifting parameters for next interval. |
| 1,406-1,436 | 1,440 | 370 | -.6 | 1,436 | Continue drilling with lifting parameters. |
| 1,436-1,466 | 1,500 | 340 | -.4 | 1,466 | Trajectory beginning to level out. Continue with lifting parameters. |
| 1,466-1,496 | 1,500 | 340 | +.9 | 1,496 | Bit trajectory turned. Decrease thrust to dropping parameters. |
| 1,496-1,526 | 900 | 340 | +.3 | 1,526 | Continue drilling with slightly dropping parameters. |
| 1,526-1,556 | 1,080 | 340 | +.2 | 1,556 | Do. |
| 1,556-1,586 | 1,080 | 340 | +.1 | 1,586 | Do. |
| 1,586-1,686 | 1,080 | 340 | 0 | 1,686 | Do. |
| 1,686-1,826 | 1,080 | 340 | +.3 | 1,826 | Hole near bottom of coalbed. Drill with lifting parameter to bring hole up. |
| 1,826-1,856 | 1,440 | 300 | 0 | 1,856 | Continue drilling with lifting parameters. Increase thrust. |
| 1,856-1,886 | 2,160 | 220 | +.8 | 1,886 | Decrease thrust, but continue drilling with lifting parameters. |
| 1,886-1,896 | 1,740 | 225 | +.9 | 1,896 | Decrease thrust, but continue drilling with lifting parameters. |
| 1,896-1,926 | 1,440 | 225 | +.5 | 1,926 | Increase thrust level. |
| 1,926-1,966 | 2,160 | 225 | +.7 | 1,966 | Continue drilling. |
| 1,966-1,986 | 2,160 | 230 | +.3 | 1,986 | Do. |
| 1,986-2,006 | 2,500 | 225 | 0 | 2,006 | Do. |
| 2,006-2,026 | 2,500 | 225 | +.4 | 2,026 | Do. |
| 2,026-2,046 | 2,160 | 225 | +.2 | 2,046 | Do. |
| 2,046-2,066 | 2,500 | 234 | +.5 | 2,066 | Do. |
| 2,066-2,126 | 1,440 | 310 | - | - | Stop drilling. |

The interval of drilling between 1,246 and 1,296 feet provides an example of an unpredictable event. Drilling at 1,246 feet is progressing with hole-dropping parameters. However, a survey at the end of the drilling interval at 1,296 feet shows that the bit trajectory has reversed sharply. Drilling is continued with dropping parameters, but the bit trajectory angle continues to increase. Past drilling experience shows that if the bit deviates by more than +2° from its programed path, pulling drill pipe, removing the front centralizer, and restarting a new hole are procedures to be used instead of attempting to turn the hole using 600-pound thrust and high rotational speed (>500 r/min). The only logical explanation for the hole angle reversal is that the bit encountered a hard spot at a glancing angle and was deflected upward.

The interval between 1,926 and 2,126 feet is an example of drilling in soft coal. Penetration rates ranged from 30 to 40 in/min at thrust levels of 2,160 to 2,500 pounds. Normally, the hole trajectory would turn upward at a sharper angle. Drilling was terminated at 2,126 feet because of a lack of drill pipe. The only mechanical problem with the drill was a worn hydraulic motor driving the spindle. Spindle rotational speed could not be increased beyond 350 r/min. Generally higher rotational speed is needed when hole trajectory is to be dropped.

Similar data have been obtained in the drilling of five additional holes in the Pittsburgh coalbed. The experience derived from those tests substantiates the data in table 4 and are not provided here because the purpose of this report is to describe a proven method for rotary drilling degasification holes in coalbeds.

## ALTERNATE DRILLING ASSEMBLY

The preceding discussions were applicable to the drilling assembly (fig. 8). The diameter of the centralizers is 3-7/16 inches, which is 1/16 inch less than the diameter of the bit (3-1/2 inches). Typical drilling parameters and associated penetration rates in the Pittsburgh coalbed are shown in table 5.

TABLE 5. - Penetration rates using a 3-1/2-inch bit

| Thrust, pounds | Bit rotation, r/min | Effect on bit trajectory | Penetration rate, in/min |
|---|---|---|---|
| 800............. | 700-900 | Downward..... | 4- 7 |
| 1,200........... | 400-600 | Holds angle.. | 10 |
| 1,500 or greater | 200-300 | Upward....... | 15 or greater |

Increasing the thrust level to more than 1,200 pounds causes the bit trajectory to follow a curved path upward. Dropping a hole requires thrust to be reduced to the 800-pound level; accordingly, the penetration rate decreases to about 5 in/min. Certainly the full potential of the hydraulic drilling unit is not being utilized.

To improve the performance of the drill unit, the bit diameter of the drilling assembly (fig. 8) was increased to 3-5/8 inches. The centralizer diameter is 3/16-inch less than bit diameter. Under this condition, the bit tends to wear the bottom side of the hole and, consequently, arcs toward the bottom more rapidly than the 3-1/2-inch bit. To overcome the tendency to drop, thrust levels were increased to about 1,700 pounds to maintain the bit on a horizontal trajectory. The drilling parameters and associated penetration rates are shown in table 6.

TABLE 6. - Penetration rates using a 3-5/8-inch bit

| Thrust, pounds | Bit rotation, r/min | Effect on bit trajectory | Penetration rate, in/min |
|---|---|---|---|
| 800............ | 350 | Downward..... | 7- 8 |
| 1,700.......... | 250 | Holds angle.. | 17-20 |
| 2,000.......... | 200 | Upward....... | 22 or greater |

Increasing the bit diameter improves the performance of the drilling assembly. There is a general increase in penetration rate, changing bit trajectory especially downward is easier, and bit rotational speed is reduced, eliminating much of the drill rod vibration that occurs over 400 r/min. The only disadvantage to the larger bit diameter assembly is bit wear. Normally, a 3-1/2-inch bit will become dull after drilling 1,000 to 1,200 feet. The points or corners of the blades become rounded and penetration drops slightly. The sides of the blades and corners of the 3-5/8-inch bit become rounded in about 800 feet of drilling. This is due to the weight of the heavy NW drill collar, which is shifted to the sides of the bit blades. However, any disadvantage due to bit wear is overshadowed by the improved performance of the drilling assembly.

Although experimentation with a larger bit diameter such as 3-3/4 inches was not attempted, results of the tests with the 3-5/8-inch bit indicate the performance of the drilling assembly can be improved further. The 3-3/4-inch bit will arc downward more rapidly than the 3-5/8-inch bit. To overcome this tendency, thrust levels must be increased to about the 2,100-pound level to maintain the bit on a horizontal trajectory. Penetration rates will be increased in general.

## DRILL AND POWER UNIT

Figures 16 and 17 show the drill and power units, respectively. The power unit consists of a 30-hp, 440-volt permissible motor and starter box, hydraulic pumps, and a 40-gal hydraulic fluid reservoir. A fire-resistant fluid (water in oil emulsion) is used in the hydraulic system. The drill unit consists of a 5-foot hydraulic cylinder mounted within its frame, a spindle mounted on a movable carriage, and valves, gages, and levers for controlling rotational speed, thrust, and movement of the carriage.

The electric motor drives two hydraulic pumps. One pump (20 gal/min) pressurizes the 5-foot hydraulic cylinder on the drill unit, which provides

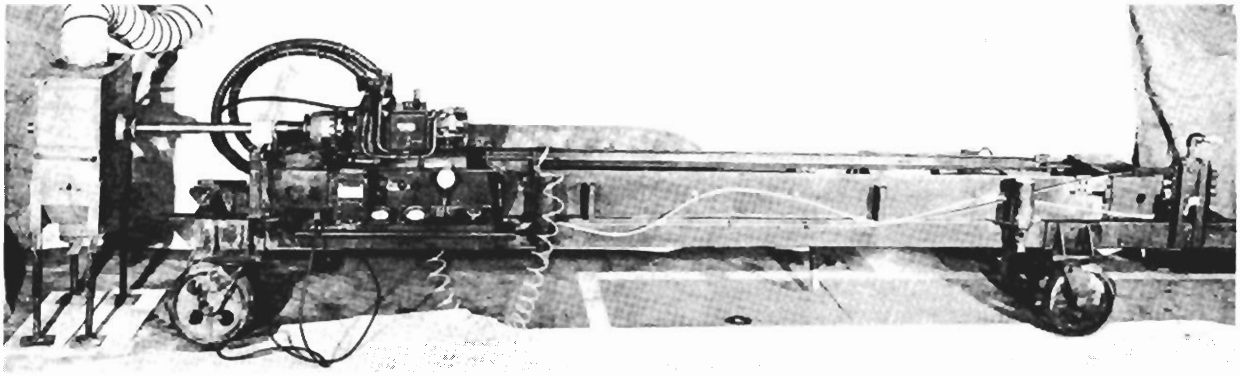


FIGURE 16. - Drill unit.

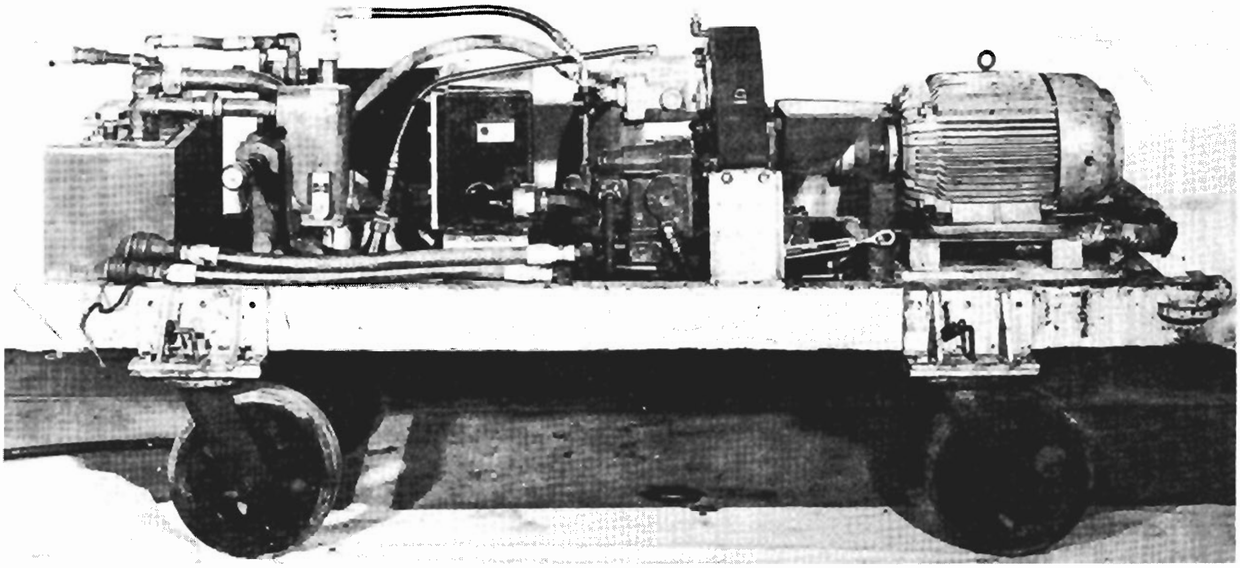


FIGURE 17. - Power unit.

thrust on the bit. The second is a reversible, variable displacement pump (29 gal/min), which powers a hydraulic motor mounted on the spindle of the drill unit.

The thrust potential of the drill unit is 13,000 pounds. The 5-foot hydraulic cylinder is connected by steel cable to the carriage through a system of pulleys. The carriage travels about 10 feet as the piston extends to 5 feet.

Figure 13 shows a view of the control panel of the drill unit. The driller is able to monitor and control drill rotational speed, thrust, drill pipe water pressure, and direction of carriage travel from one location. Drill pipe water pressure is monitored to insure water circulation at the bit at all times. Monitoring the return water does not insure that bit cuttings are being properly flushed. A blockage can occur within the drill pipe or bit and the return waterflow will not be affected for several minutes. Therefore, several feet of coal will have been drilled with no cutting removal and, consequently, the drill string may become lodged. However, monitoring drill pipe water pressure would indicate the blockage by a sudden rise in pressure. A drop in drill pipe water pressure indicates a loss of water at the drill unit. Both require that drilling be stopped until the problem is solved.

During drilling operations underground, the power unit is kept in fresh air entries. Hydraulic lines are run between power and drill units, which may be 500 feet apart. At the drilling site, the drill unit is cribbed so that the horizontal hole is started in about the center of the coalbed. In addition, the drill is anchored to the coalbed to prevent backward movement of the drill unit when high thrust levels are being applied to the bit.

## CONCLUSIONS

A proven technique for horizontal drilling in coal has been presented. Drilling parameters have been derived for the Pittsburgh coalbed, which may or may not be applicable to other coalbeds. However, these parameters are a starting point, and, with experience, the levels for dropping, holding, or lifting hole trajectory may require slight modification for drilling in other coalbeds. This can be accomplished in about the first 300 to 500 feet of drilling.

Surveying to obtain bit angle is important and necessary. The drilling example presented shows that bit angle can change radically in 30 feet. Best results are obtained when bit angle is maintained $\pm 1.0°$ of programed trajectory.

When hole direction is being changed from an upward to a downward trajectory or vice versa, the surveying interval should not exceed 20 feet. The turn should be made gently to avoid angles of the order of $\pm 2°$ from programed trajectory.

Success in long hole horizontal drilling depends to some degree upon the driller. There is no substitute for experience at this stage of development. The driller must respond immediately to changes in hardness of the coalbed, which require thrust and rotational speed levels to be altered.

The drill string configuration (fig. 8) must be used. This assembly can be turned upward or downward using either a 3-1/2- or 3-5/8-inch bit. Drag bits are recommended because of their high penetration rates and low cost.

The drill and power units used in this study have ample reserve power, and at no time was the equipment taxed. The drill unit is about 18 feet long to accommodate the 10-foot feed and could be made shorter for ease in handling; however, the 10-foot feed would be sacrificed. The drill unit was equipped with gages for monitoring thrust, spindle rotation speed, and water pressure during drilling, a necessity for controlled horizontal drilling.

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