

Ground penetrating radar for highwall guidance

OBJECTIVE

To provide a safe, practical, cost-effective method for measuring coal rib thickness during highwall mining.

Background

U.S. highwall operators have been seeking a method to maintain an optimum coal rib thickness throughout the entire depth of the entry, particularly in mines where the depth of penetration can be up to 400 m. In Appalachian coal mines, the typical coal rib thickness is 1 to 2 m, depending on the mechanical properties of the particular coal seam being mined. If the rib becomes too thin, the hazard of ground fall increases and with it the resulting risk of burying the mining equipment. Freeing a buried machine is an expensive process, places workers at risk, and produces no coal. Conversely, if the rib becomes too thick, the excess coal left behind is permanently unrecoverable and makes the rib thin for the next hole. Although the current typical alignment procedures utilize precision surveys, geological and mechanical forces during mining produce uncertainties in position nearly as large as the rib thickness itself at depths of 300 to 400 m despite the accuracy of the initial alignment.

Approach

The National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Center, is evaluating a new method wherein a ground penetrating radar (GPR) is mounted on the mining machine to measure the rib thickness to the adjacent hole as cutting progresses. The advantage of GPR is that it uses electromagnetic pulses to measure the coal rib thickness directly. The GPR works best in clean coal seams; coal seams with significant partings or dirt bands tend to disrupt the radar signal so that the radar echo from the coal-air boundary is too weak or indistinct to be usable.

The success of a GPR system at a given location primarily depends on the electrical conductivity and dielectric constant of the geological formations. The electrical conductivity of coal is generally quite low (e.g., 10^{-5} S/m), which allows the radar signals to readily propagate through the coal. The dielectric constant of coal is typically 4-5; in contrast, air has a dielectric constant of 1. Consequently, there is a very distinct interface at coal/air (or air/coal) boundaries. The side of a highwall rib is fairly planar, is perpendicular to the direction of the radar, and thereby becomes a relatively easy target for the GPR. It should be noted that coal is an anisotropic (nonuniform) material, which requires that the GPR antenna be optimally oriented in such a way for maximum transmit and receive signals. This is best done by slowly rotating the antenna through a 90° arc about the transmitting direction and noting the angle that maximizes the radar signal.

How it works

The basic system consists of a radar control unit and an antenna, a PC to process the data, a Mine Safety and Health Administration-approved barrier box for intrinsic safety, and a remotecontrolled hydraulic- or electrical-powered arm attached to a highwall miner (figure 1). The antenna needs to be housed in a metal box for protection during mining operations. The remote controlled arm will keep the antenna retracted until coal rib thickness measurements are needed, at which time the operator would activate the arm to press the antenna "gently" against the coal rib to reduce the air gap between the antenna and the coal. The ability of the GPR to penetrate coal depends on the frequency of the radar, which must be selected accordingly.

For highwall applications requiring a rib thickness on the order of 1 to 3 m, a 400- or 500MHz antenna would probably be the most suitable. A 900-MHz antenna would be recommended for thinner coal ribs between 0.5 and 1.5 m. Figure 2 is a schematic of a typical highwall mining scenario using this radar system to measure coal rib thickness.

Project personnel have developed in-house software that runs on a laptop PC, which simplifies the normally cumbersome interpretation of the radar data. The PC reads and analyzes the received signals in real time, then provides the machine operator with a number corresponding to the rib thickness, as well as a tri-color display (green = "OK", amber = "caution", red = "danger") of the computed rib thickness.

Results

This GPR system was taken to a highwall mining site in Kentucky to evaluate the feasibility of using GPR to measure coal rib thickness and to obtain information regarding the depth of penetration and the effect of airgap on the GPR response. A 500-MHz antenna was used and found to be capable of measuring coal rib thickness from 0.9 m to more than 3 m. The best results were obtained with the antenna being no more than 5 cm from the coal surface. The antenna was positioned near the top of the coal seam because the cleanest coal was located there.

The operator prepared two highwall entries, each approximately 15 m long, 3.5 m wide, and 1 m high. The first entry was driven straight into the highwall. The second entry was driven in about 3 m from the first and was deliberately angled in such a way to come to within 0.9 m of the end of the first entry. Several tests were then run by moving

the antenna continuously from the entrance to the end of the entry and then back to the entrance, with each test having a different airgap (0 cm, 2 cm, and 4 cm). In all cases, the radar was capable of "seeing through" the coal rib at thicknesses ranging from 0.9 m to more than 3 m; however, the best response was when the antenna was physically touching the rib (0 cm - no airgap).

Patent status

A patent of this total system has been granted (U.S. patent No. 5,500,649, "Method and Apparatus for Monitoring the Thickness of a Coal Rib During Rib Formation"); it is available for field testing and/or licensing.

For more information

To obtain a free copy of a technical paper on this topic or for additional information, contact Gary L. Mowrey, Ph.D., National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Center, Cochrans Mill Rd., P.O. Box 18070, Pittsburgh, PA 15236-0070, phone (412) 892-6594, fax (412) 892-6764, e-mail: gdm6@cdc.gov

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To receive additional information about mining issues or other occupational safety and health problems, call 1-80035-NIOSH (1-800-356-4674), or visit the NIOSH Home Page on the World Wide Web at <http://www.cdc.gov/niosh/homepage.html>

As of October 1996, the safety and health research functions of the former U.S. Bureau of Mines are located in the National Institute for Occupational Safety and Health (NIOSH).

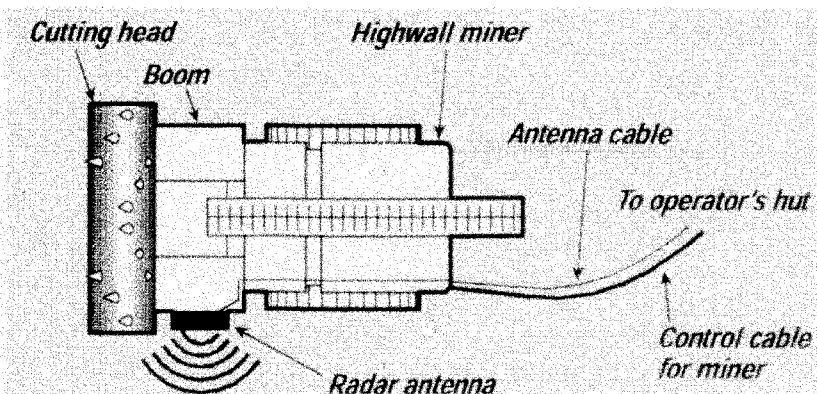


Figure 1.—Radar antenna mounted on highwall miner.

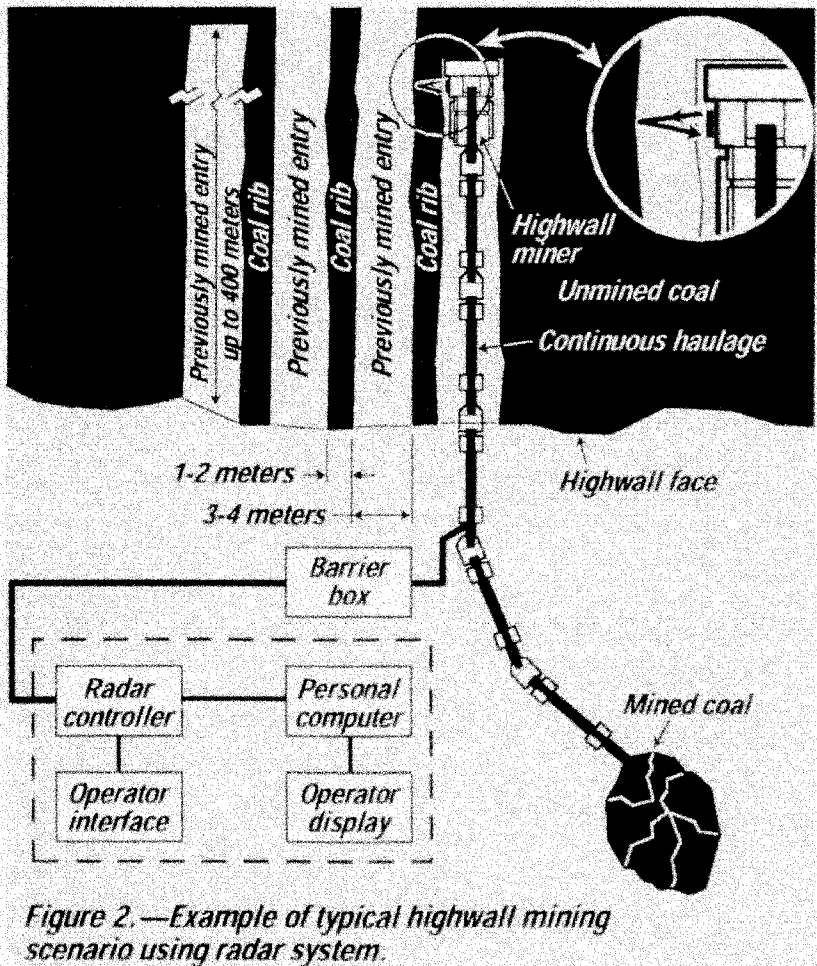


Figure 2.—Example of typical highwall mining scenario using radar system.