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Application of new void detection algorithm for analysis of feed pressure and rotation pressure of roof bolters

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ABSTRACT

Roof and rib instability is an important issue in underground mining. To optimize ground support design, enhance ground stability, and reduce the possibility of roof or rib failure with minimal use of artificial ground support, it is essential to have an accurate understanding of ground conditions. This includes the location of voids, cracks, and discontinuities, as well as information about the different strata in the immediate roof. This paper briefly introduces ongoing research on void detection by using the roof bolter feed and rotation pressure. The goal of this project is to improve the sensitivity of detection programs to locate smaller joints and reduce the number of false alarms. This paper presents a brief review of the testing procedures, data analysis, logic, and algorithms used for void detection. In addition, this paper discusses the results of preliminary laboratory tests and statistical analysis of the data from these two drilling parameters used for void detection.

1. Introduction

Roof falls are one of the most serious and frequent accidents in underground mining. Each year, personnel are injured or killed because of roof falls. Equipment can also be damaged when this occurs. According to Mine Safety and Health Administration statistics collected from 1999 to 2008, ground falls were the largest cause of fatal accidents in underground coal mining, causing around 40% of all fatalities [1]. Out of 8 to 10 fatalities and over 800 injuries are recorded each year in underground mines, there are nearly 2000 reportable non-injury ground falls every year [2]. From literature review of published paper from other countries, although there were some differences of total numbers of injuries caused by ground falls in underground mining and tunneling, it showed similar trend in the world [3,4].

Certain features in the ground, such as voids, cracks, and discontinuities, are significant factors that cause roof support failures and roof fall accidents. The detection of those geological features are essential for design of effective ground support in underground support. Void detection in underground space can be performed by various techniques including bore scoping, visual observation and geophysical loggings, rock mass rating of the roof and ribs. However, these techniques also offer many shortcomings. For instance, although the bore scoping is widely applied in field for the identification of the rock types, voids, cracks and formation boundaries, it is a time-consuming method for stability analysis, and it requires pre-training on operators. In addition, visual observation and geophysical loggings usually failed to provide sufficient geological features information of the ground. Rock mass rating method typically cannot be performed in advance of mining activities, because some on site observation and measures are required. Thus, it seems that these methods could not provide sufficient geological information for support strategy improvement in a timely manner [5].

Many researchers have worked on this problem using instrumented drilling machines. For instance, Itakura et al. instrumented a pneumatic drill to monitor the torque, thrust, rotational speed, and stroke; both in the laboratory and the field. Fig. 1 shows typical patterns corresponding of torque to discontinuities [6,7]. From the laboratory tests, this system could identify locations of discontinuities, but it could not discriminate between cracks and layer boundaries. To achieve in-situ evaluation of roof rock, Itakura et al. developed a measurement while drilling (MWD) system to locate discontinuities by monitoring drilling parameters of torque, thrust, rotation speed, and stroke [8]. They state that torque and

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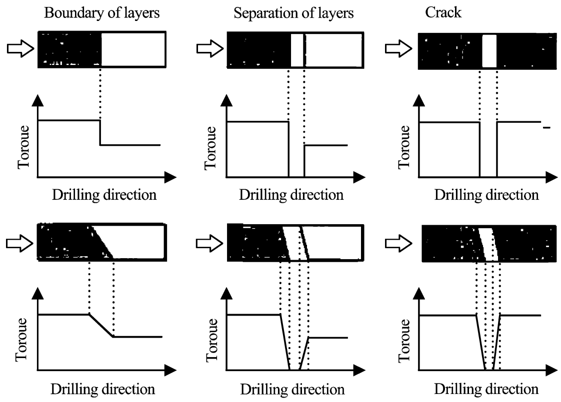

Fig. 1. Typical patterns corresponding to discontinuities [6].

thrust data had better performance in detecting geological structures in field tests. However, the MWD system still could not detect discontinuities with small size.

A research team at West Virginia University applied the J.H. Fletcher & Co.™ HDDR Model Walk-Thru Dual Head Roof Bolter to detect the location of voids, joints, bed separation, fractures, and formation interfaces by analyzing several drilling parameters. These drilling parameters included rotational speed, thrust, torque, and penetration rate values [9]. They note that the specific energy of drilling, SED in short, is a good indicator of ground features for identifying fractures. SED, which was calculated using drilling parameters, indicated a significant variation in the same material. Finfinger conducted a series of laboratory tests to use the primary drilling parameters, including thrust, torque, rotational velocity and penetration rate, to identify voids, joints and fractures, and mentioned that those features could be determined by "thrust valleys" when the penetration rate was preset (Fig. 2) [10]. A real time drilling display system for the J.H. Fletcher HDDR Dual Head Roof Bolter was developed and tested in the field to detect voids or fractures in the roof [11]. While successful in some cases, the sensitivity of this system still needed to be improved to detect joints or fractures with small aperture. After this, Anderson and Prosser developed a new software with improved algorithms to indicate void or separation locations in real time during the drilling process, but it could not detect hairline or vertical cracks [12].

More recently, Bahrampour et al. at the Pennsylvania State University research group installed vibration and acoustic sensors on the J.H. Fletcher drill unit to monitor vibration and acoustic signals for void detection [13]. Similar to previous studies, voids with openings smaller than 0.318 cm could not be successfully detected. There were also some false alarms in the detection process [14,15]. Rostami et al. also mentioned that these geological feature information collected by instrumented drills can be applied for roof characterization to offer an instant mapping of roof conditions before mining activities [16].

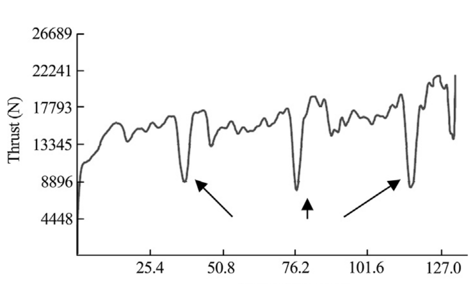

Fig. 2. "Thrust valleys" associated with fractures in concrete block [9].

Currently, several manufacturers provide smart roof bolters with limited capabilities for void detection. While successful in many instances, in laboratory experiments, the existing void detection systems have limited success in detecting void openings that are less than 0.318 cm. This limited success was observed in testing concrete blocks with gaps in between, simulating a rock medium with voids. Detection programs have missed some voids, while, in some cases, they have shown false detection. These algorithms need to be revised in sensing voids to improve the capabilities of these programs. This paper focuses on void detection by using a new algorithm to analyze the feed pressure and rotation pressure, which comes from thrust and torque correspondingly. This paper will also provide statistics on their void detection performances. The laboratory results indicate the feasibility of this new detection programs for void detection purposes.

2. Instrumented J.H. Fletcher drilling system

As shown in Fig. 3, a drill control unit, DCU in short, had been developed by J.H. Fletcher to record drilling parameters including torque, thrust, rotation rate, drill bit position, and vacuum pressure during the drilling processes. In this study, a DCU was used for laboratory tests on various samples at the Fletcher testing facility in Huntington, WV. For void detection purposes, a set of concrete blocks were made by casting grout with designed strengths. This included soft (S, approximately 20 MPa), medium (M, approximately 50 MPa), and hard (H, approximately 70 MPa) grout samples to represent various rock types and sequences of strata. The dimension of each block was approximately 0.5 m × 0.5 m × 0.75 m.

To simulate the void, each testing sample was set up by placing one block on top of another block. This left a gap of less than 2 mm between two blocks and was considered the void. Nine different combinations of rock strength sequences were tested, including soft to hard (S-H), hard to soft (H-S), and other possible scenarios (M-H, H-H, H-M, M-S, S-M, M-M, and S-S). Moreover, the drilling facilities used a sampling rate of 100 Hz to monitor drilling parameters.

3. Void detection by using the cumulative sum (CUSUM) algorithm

As discussed above, various pattern recognition systems have been studied for detecting joints using different drilling parameters. The most promising of the parameters seem to be the drilling thrust or feed pressure, and the rotation pressure, representing torque. Other parameters, including vibration and acoustic data, have also been considered and used in previous stages of this study [13]. While working on various pattern recognition systems, different mean change detection algorithms have been examined. Among the algorithms used for void detection, the CUSUM algorithm has been most promising and was used to evaluate recorded data for void detection. The CUSUM algorithm is a sequential analysis technique, introduced by Page, which is typically used for detection of abrupt changes in streaming data [17]. While drilling, the feed pressure and rotation pressure show sudden changes at the location where the drill bit encounters a void or a crack. This sudden drop is hidden in the monitored parameters and noises of the signal and is often difficult to locate. The CUSUM algorithm can be used to sense these changes and locate the features representing the open joint or void in the rock strata. Because of this, new void detection programs were developed based on the CUSUM algorithm to improve capabilities to detect the location of void.

Fig. 4 is an example of three drilling parameters that were recorded while drilling into a hard to hard (H-H) concrete block