# A comprehensive roof bolter drilling control algorithm for enhancing energy efficiency and reducing respirable dust

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**Full-text paper:**
Mining, Metallurgy & Exploration (2022) 39:241–249, https://doi.org/10.1007/s42461-022-00566-4

**Keywords:** Roof bolter, Drilling control, Respirable dust, Specific energy, Bit condition

## Special Extended Abstract

*A roof bolting drilling operation in an underground coal mine can expose the operator to a high concentration of respirable coal and crystalline silica dusts (smaller than 10 µm). Overexposure of high-level quartz dust for a roof bolter operator can lead to the development of silicosis in as little as three years [1]. This study proposes a drilling control algorithm for the bolt hole drilling process. This algorithm can be integrated into a current drilling control system on the roof bolter machinery and is expected to reduce the generation of respirable dust while enhancing the energy efficiency of the roof bolter machine. In addition, the drilling efficiency and bit condition can be evaluated while drilling based on the real-time feedback parameters. This capability enables the algorithm to ensure the drilling is performed under a relatively high energy efficiency with less respirable dust generation and to avoid drilling with an excessively worn bit that can cause bit clogging or steel buckling failure.*

### Background

Investigations on the respirable coal and quartz dust hazards that occurred during an underground roof bolting cycle were conducted by researchers [2]. The results indicate a quartz content of more than 50 percent can be found from the total roof bolting dust. For the sub-5 µm fraction, the quartz content can be as much as 20 percent. These quantified results confirmed that roof bolting dust contains a higher percentage of quartz than other dust sources from mining activities. Several dust control technologies, such as vacuum dust collection systems and canopy air curtains, have been developed and implemented to address the exposure issue for the roof bolter operator [3]. The research in this study is focused on investigating the relationship of drilling control parameters, such as penetration and rotation rates and bit condition, with the dust generation characteristics, then proposing a drilling control algorithm to minimize the respirable dust generation while increasing the drilling energy efficiency.

### Method

Fifty-two laboratory drilling tests were conducted on a Fletcher drilling test platform. Dust samples from the dust collection system were collected and analyzed in the laboratory for their size distributions.

In this study, drilling bite depth, $b$, defined as bit penetration depth per revolution, was introduced to describe the roof bolter drilling process. Drilling bite depth can be calculated from penetration, $v$, and rotational rate, $w$, with the following equation:

$$b = \frac{60v}{w} \qquad (1)$$

The specific energy is used for evaluating the energy efficiency of the roof bolter machine in this study. The specific energy for rotary drilling can be expressed mathematically in terms of drilling bite depth, penetration rate, torque and thrust, as shown in [4]:

$$\varepsilon = \frac{2\pi T}{A_b \cdot b} + \frac{W}{A_b} \qquad (2)$$

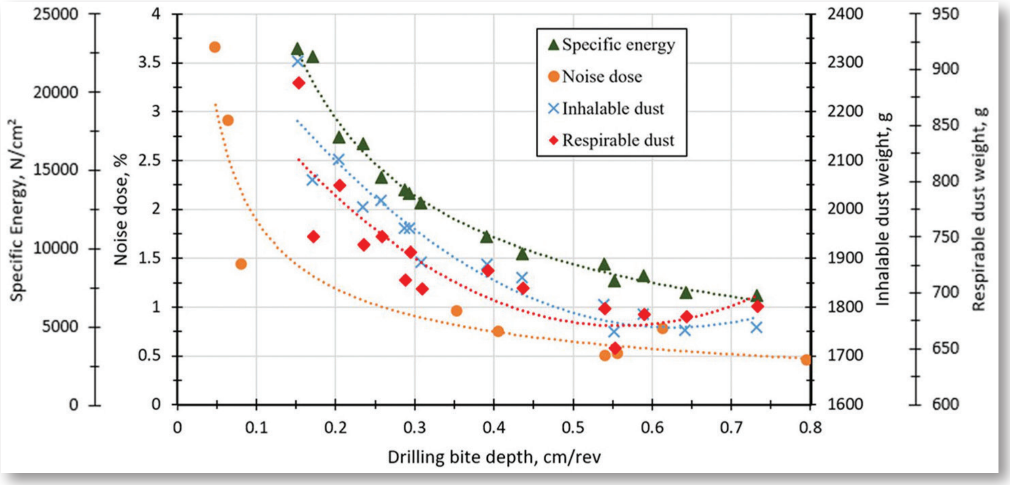


**Fig. 1** Relationships of drilling bite depth with noise dose, dust weight and specific energy.

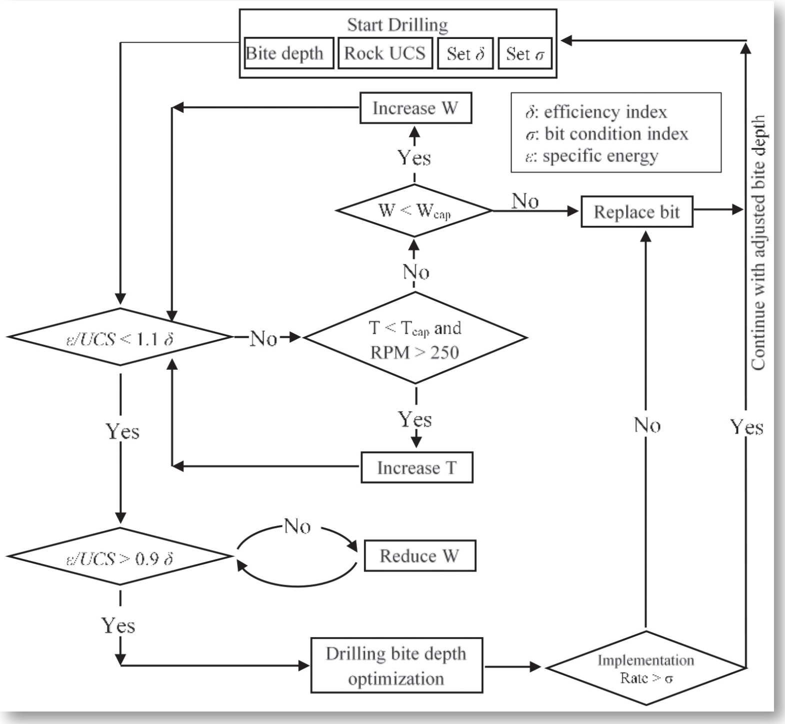


**Fig. 2** Schematic diagram of the drilling control algorithm.

where $A_b$ is the borehole area in $cm^2$, $b$ is the drilling bite depth in cm/rev, and $T$ and $W$ are the torque and thrust in Nm and N, respectively. It should be noted that all these parameters were monitored and recorded in real time by the drilling control system.

## Results

The concrete drilling inhalable and respirable dust weight, specific energy, and noise dose results are plotted against the achieved bite depth in Fig. 1. It was shown that specific energy reduced significantly while drilling with a larger bite depth, which also indicates improved energy efficiency with higher bite depth. A 70 percent reduction was achieved when increasing the bite depth from 0.152 to 0.732 cm/rev. Both inhalable and respirable dust weight results show a rapid decrease as bite depth increases, until bite depth reaches 0.541 cm/rev. However, after this point, the generation rate of inhalable dust becomes stable with further increase of bite depth. Meanwhile, the respirable dust shows an uptick after this point in the operation. Overall, the generated inhalable and respirable dust are reduced by 550 and 200 g, respectively, within the tested drilling bite depth range.

## Discussion and conclusion

As stated, the optimum bite depth is the depth when the specific energy reaches the minimum. However, it is impractical to achieve the optimum bite depth due to safety and power limitations. A rational bite depth is that for which any further increase in bite depth will only result in an insignificant reduction in drilling specific energy.

The recommended drilling control algorithm is shown in Fig. 2. In a real-time drilling process, the drilling acquired — that is, penetration and rotational rates, thrust and torque — are used with bite design and wear condition to determine rock strengths. The rock strength is then used to determine the rational bite depth. Because a higher rotation rate, RPM, would accelerate bit wear, a lower RPM combined with a correlated rate of penetration, ROP, is preferable to reach a targeted drilling bite depth. In addition, an excessively worn drill bit prevents the system from achieving the targeted bite depth and can increase the respirable and inhalable dust generation rates by as much as 61.5 percent (respirable) and 43.6 percent (inhalable). The overall drilling specific energy using a worn bit is higher than a new bit due to the increased rubbing area and friction between the drill bit and the rock. Therefore, a bit wear condition check is included in the algorithm according to the implementation rate (achieved versus targeted bite depth). When the drill penetrates a different rock layer with its determined strength significantly different from the previous layer, a rational bite depth is determined based on the rock unconfined compressive strength, UCS, bit wear condition, and implementation rate. As the drilling progresses, the specific energy is monitored, and the ratio can be calculated simultaneously. If the ratio is within 10 percent of the efficiency index, then the system will continue drilling with the initial bite depth. However, the algorithm still needs to evaluate the bit condition using the implementation rate. If the implementation rate is lower than the bit condition index, the system will stop, and a new bit needs to be installed to continue drilling.

By adapting this drilling control algorithm, the drilling efficiency and bit condition can be monitored in real time, so that at any point in the drilling the system can stay in a relatively high energy efficiency with less respirable dust production and also reduce the chance to encounter bit clogging or steel buckling, which can expose the operator to a tremendous safety and health hazard. Due to the limitation of the data sources, to improve the algorithm's prediction accuracy for respirable dust and noise production rates, more dust and noise results from drilling different types of rock need to be collected for the calibration process. ■

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