

## Research Article

# Multi-Index Monitoring and Evaluation on Rock Burst in Yangcheng Mine

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Based on the foreboding information monitoring of the energy released in the developing process of rock burst, prediction system for rock burst can be established. By using microseismic method, electromagnetic radiation method, and drilling bits method, rock burst in Yangcheng Mine was monitored, and a system of multi-index monitoring and evaluation on rock burst was established. Microseismic monitoring and electromagnetic radiation monitoring were early warning method, and drilling bits monitoring was burst region identification method. There were three identifying indexes: silence period in microseismic monitoring, rising period of the intensity, and rising period of pulse count in electromagnetic radiation monitoring. If there is identified burst risk in the workface, drilling bits method was used to ascertain the burst region, and then pressure releasing methods were carried out to eliminate the disaster.

## 1. Introduction

Rock burst is one kind of typical dynamic disasters in coal mining. When the rock or coal is under ultimate strength state, energy in the rock will be released abruptly and severely. This will cause instantaneous rock burst damage, which threatens workers' life and the coal production [1–3]. Rock burst is difficult to research due to its complex occurrence conditions, multiple influence factors, and various fracture modes [4, 5].

In the developing process of rock burst, the rocks' stress state changes constantly, and energy releases accompanying with some physical effects, such as microseismic, acoustic emission, electromagnetic radiation, and so forth. By analyzing the foreboding information, monitoring system can be established to predict rock burst disaster [6–9]. At this stage, many rock burst monitoring methods are used in mining widely and popularly, such as pressure observation method, drilling method [10], electromagnetic radiation method [11–13], microseismic method [14–16], and seismic CT technology [17, 18].

Different monitoring methods have various monitoring principles, objectives, accuracy, and regions. In rock burst prediction, multiple methods should be combined together to establish more effective multi-index monitoring technology. In this paper, Yangcheng Mine in China was taken as the research site. Microseismic method, electromagnetic radiation method, and drilling bits method were combined to monitor rock burst. A system of multi-index monitoring and evaluation on rock burst was established, and field applications showed that this evaluation system predicted rock burst effectively.

## 2. Site Conditions

The coal seam's ground elevation of 1304 workface in Yangcheng Mine ranges from –535 m to –660 m, and the mining area is 159824 m<sup>2</sup>. The coal seam dip angles change from 17° to 21°, and the average angle is 19°. The thickness ranges from 7.0 m to 8.2 m, and the average thickness is 7.5 m. The workface length is 184 m, and the mining distance is

870.5 m. The mining method is long-wall fully mechanized top-coal mining overall height all caving method.

The hardness coefficient of the coal is 1.5, and the coal seam is medium hard. The immediate roof is siltstone, and the main roof is grayish fine sandstone. The floor is siltstone. The upper coal seam shows strong burst trend, and the bottom seam shows light trend. The roof and floor show light burst trend.

### 3. Monitoring Approaches

**3.1. Microseismic Monitoring.** Energy of seismic wave can be generated and spread around when the underground rock mass fractures. Microseismic monitoring equipment is used to receive and record these seismic waves. According to monitoring results, various characteristics of the rock fracture can be analyzed, such as the amount, frequency, intensity, density, and dimension [19].

Microseismic monitoring system can identify and analyze the development of mine vibration according to the energy release, the center position and waveform diagram of the vibration, and so forth. And then the occurrence possibility of rock burst can be predicted. According to the seismology's basic equation of Gutenberg-Richter formula, the relation between the frequency and the number of microseismic can be expressed as [20]

$$\lg N = a - bM, \quad (1)$$

where  $N$  is the frequency of microseismic events;  $M$  is the number of microseismic events;  $a$  and  $b$  are constants.

The relation between the frequency of rock burst and its magnitude shows a linear correlation. According to this law, we can predict the maximum magnitude of rock burst based on the information of occurring rock burst. The detecting method is to take 1 for the Gutenberg-Richter formula, which means there is only one maximum rock burst, and the maximum magnitude  $M_m$  is

$$M_m = \frac{a}{b}. \quad (2)$$

According to the change rule of value  $b$  in the formula (2), the trend of rock burst's occurrence can be predicted. If  $b$  increases, the possibility of the large magnitude rock burst will decrease. If  $b$  decreases, the possibility of the large magnitude rock burst will increase.

**3.2. Electromagnetic Radiation Monitoring.** Electromagnetic radiation in coal or rock is a release expression of electromagnetic energy in the process of deformation, and it has a close relation with the deformation process [21]. The occurrence of rock burst is a process of instantaneous energy release. When the accumulated energy of coal or rock reaches the strength limit, rock burst will happen. In the fracture process of the rock under high stress, cracks and friction can produce electromagnetic radiation. High stress and intense fracture will release strong electromagnetic radiation. The strength of electromagnetic radiation signal indirectly reflects the degree of stress concentration in the coal and rock. The higher

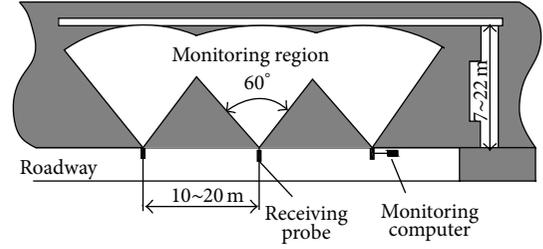


FIGURE 1: The region of electromagnetic radiation monitoring [21].

the degree of stress concentration is, the greater rock burst risk will be. We can predict the risk degree of rock burst by monitoring the intensity and changes of electromagnetic radiation signal.

The hardware of electromagnetic radiation monitoring system mainly includes the monitoring computer, receiving probes, conversion interface, and communication cable. It has characteristics of noncontact, regional, continuous monitoring. The main monitoring indicators are the intensity of amplitude and the number of pulses. In the application to monitor electromagnetic radiation in the mining area, noncontactable inductance type wideband directional receiving probe is usually used. The distance between the electromagnetic radiation instrument and the measured area is in the range of 0.6~1.0 m, and the station spacing is about 10 m. The effective monitoring depth ranges from 7 m to 22 m. The layout of the electromagnetic radiation monitoring positions is shown in Figure 1. Electromagnetic radiation signal is recorded according to the number of measuring points in sequence, and the monitoring time for the data at each point is 180 s.

**3.3. Drilling Bits Monitoring.** When drilling one hole in the high stress area of the coal seam, the drilling process can show dynamic characteristics, like the coal near the wall suddenly squeezing into the hole, accompanying with the phenomenon of vibration, noise, or microshock. Drilling bits method is a practical way to identify rock burst according to the coal dust amount and the relevant dynamic effect [22].

Indexes of drilling bits method for monitoring rock burst are coal dust amount, drilling depth, and dynamic effect. Coal dust amount is the discharged amount of the coal dust per meter. Drilling depth is the length between the coal wall and the dust amount measured location. Dynamic effect includes sticking of the drill, shock of the hole, and changes of particle size of the coal dust.

The danger of rock burst is often identified by dust amount index  $K$  [22]:

$$K = \frac{Q}{Q_0}, \quad (3)$$

where  $Q$  is the practical amount of the coal dust and  $Q_0$  is the normal amount.

Identification standard of the coal dust amount is listed in Table 1. The higher rate of the coal dust than the calibration

TABLE 1: Coal dust index for identifying rock burst [22].

Drilling depth/mining thickness	1.5	1.5~3	3
Coal dust amount index	$\geq 1.5$	2~3	$\geq 4$

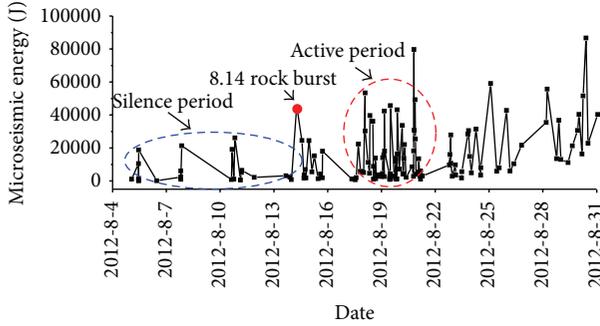


FIGURE 2: Microseismic events statistical data curve.

value shows the raised degree of stress concentration and the increased risk of rock burst.

For the convenience of calculation, the index of dust amount can be converted into an easily measured critical dust amount:

$$G_l = G \cdot K \cdot \alpha, \quad (4)$$

where  $G_l$  is the critical dust amount and  $G$  is the standard amount;  $K$  is the dust index; and  $\alpha$  is the correction coefficient.

When using drilling bits method to monitor the danger of rock burst, if the actual amount of coal dust exceeds the critical value, there will be a trend of rock burst in the monitoring area. Measures of relieving pressure should be taken to prevent the occurrence of rock burst.

When drilling in the high stress area, there will be brittle fracture in the coal without the participation of the drill, because the coal around the drill has come into the ultimate limit state of stress. So the drill grinds the coal slightly, and particle sizes of dust are large. Therefore, the proportion of large-size particles (the diameter is larger than 3 mm generally) in the dust can be used as an index for predicting the local rock burst.

## 4. Results and Discussion

**4.1. Microseismic Data.** Microseismic data per time and per day were recorded and shown in Figures 2 and 3. Before “8.14 rock burst,” the microseismic events were few, and the released energy was low, with the value smaller than  $1.0 \times 10^4$  J mostly. This period was called microseismic silence period or energy accumulation period. After “8.14 rock burst,” there was a high-incidence period of microseismic events, and it lasted four days. In this period, microseismic events occurred frequently, and the amount of released energy per day was very high. This period was called microseismic active period or energy release period.

Before rock burst, there is a silence period, in which microseismic events are few, and the total microseismic

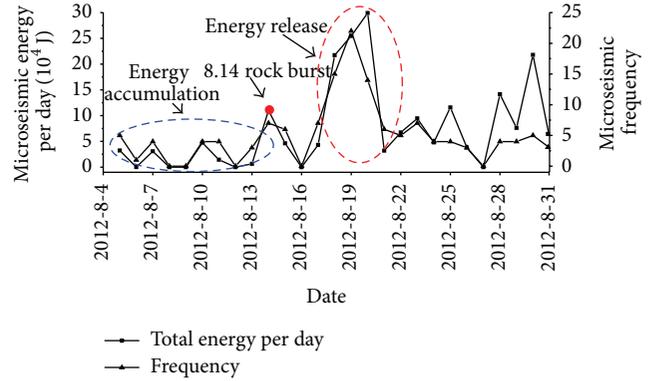


FIGURE 3: Total microseismic energy and frequency curves.

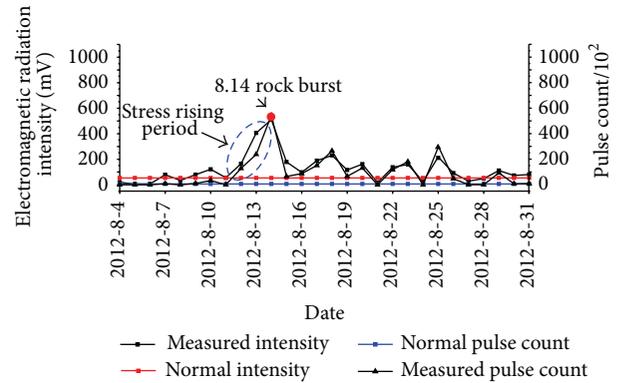


FIGURE 4: Electromagnetic radiation signal curves.

energy per day is smaller than  $5 \times 10^4$  J. If the energy exceeds  $5 \times 10^4$  J, the silence period ends, and burst risk should be warned. The lasting time of the silence period can be long or short and generally longer than five days. The longer the lasting time is, the greater the rock burst trend will be.

**4.2. Electromagnetic Radiation Data.** The electromagnetic radiation data in the workplace was shown in Figure 4. From August 1 to August 8, the intensity and pulse count of the electromagnetic radiation fluctuated around the normal value, which showed that the stress distributed in the coal was stable. From August 11 to August 14, the intensity and pulse count of the electromagnetic radiation rose steadily. The increasing value was very large, nearly ten times of the normal value. The stress in the coal increased fast. High stress caused coal fracture and severe friction, accompanying with strong electromagnetic radiation signal. And then in August 14, rock burst happened.

Before “8.14 rock burst,” there were a rising period of the intensity and a rising period of pulse count in electromagnetic radiation. The rising period reflected the increasing stress in the coal, and the steadily increasing stress caused rock burst.

**4.3. Drilling Bits Data.** At the beginning of the mining, five holes were drilled in the roadway of the workplace, and the coal dust amount data was recorded in Figure 5. The dust amount

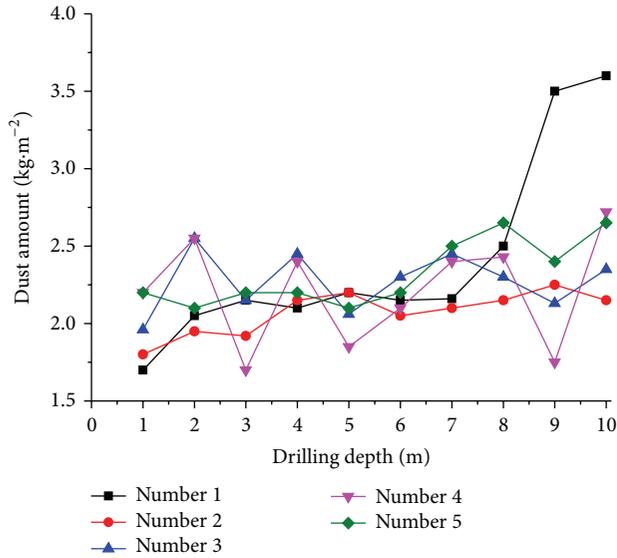


FIGURE 5: Coal dust amount changing curves.

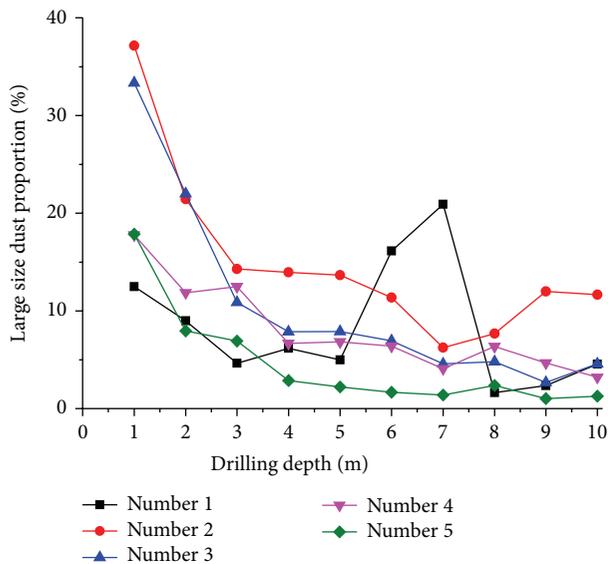


FIGURE 6: Large size dust proportion changing curves.

mainly ranged from 1.5 kg/m to 2.5 kg/m, and the max value was 3.6 kg/m. No. 1 drill was 15 m far from the workface, and the stress in the coal was high under the influence of advanced support pressure. When the dust amount reached 3.6 kg/m, there was dynamic effect like sticking of the drill.

The proportion of particles larger than 3 mm in the dust at different drilling depth in five holes was shown in Figure 6. At the coal wall, the coal was more fractured and bigger coal pieces dropped under the drill vibration, so the proportion at the drill outer end was high. The energy at the coal wall was already released, and there was no burst trend. The proportion at the wall could not be taken as monitoring index data.

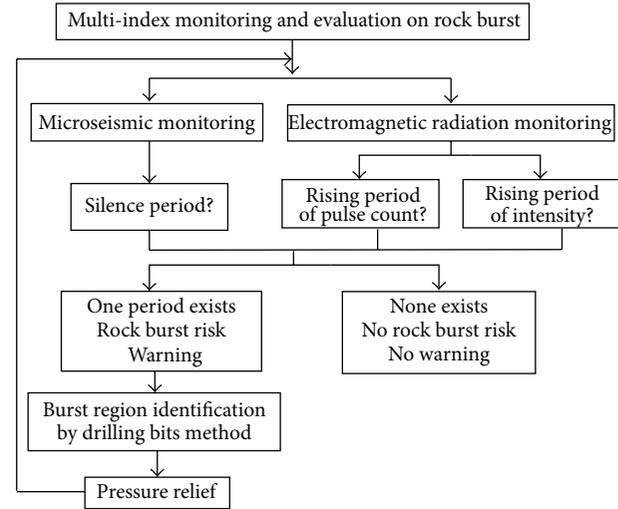


FIGURE 7: Flow chart of multi-index evaluation system on rock burst.

The average thickness of the coal seam is 7.5 m, so the critical dust amount is 3.68 kg/m, calculated from formula (4) by setting  $K$  to be 1.5 and  $\alpha$  to be 1.1. If the actual amount of coal dust exceeds the critical value, there will be a trend of rock burst in the monitoring area. If there are dynamic effects like sticking of the drill, or the proportion of large-size particles in the dust is higher than 30%, there will be burst risk though the dust amount is smaller than the critical value. When using drilling bits method to monitor the risk of rock burst, multiple indexes should be considered together.

**4.4. Multi-Index Evaluation.** By analyzing the monitoring data, we found that there was a silence period in microseismic monitoring, as well as rising periods of intensity and pulse count of electromagnetic radiation. The foreboding information is taken as prediction index for rock burst, and a system of multi-index monitoring and evaluation is established, as shown in Figure 7.

There are three identifying indexes in the evaluation system. They are the silence period in the microseismic events and rising period of the intensity and rising period of pulse count in electromagnetic radiation. If any one of the three periods exists, it is identified burst risk. Only when the three periods all do not exist, there is no burst risk in the workface. If there is identified burst risk, the drilling bits method is used to ascertain the burst region. Then pressure releasing methods will be carried out to eliminate the disaster.

## 5. Conclusions

By using microseismic method, electromagnetic radiation method, and drilling method, rock burst in Yangcheng Mine was monitored, and a multi-index monitor and evaluation system for rock burst was established. The investigations show the following.

- (1) There is one microseismic silence period before rock burst, as well as one active period after burst. The

longer the silence period lasts, the greater the rock burst trend probability will be. The silence period is one index to identify burst risk.

- (2) There are steadily rising period of intensity and rising period of pulse count in electromagnetic radiation when the stress in the coal increases, which can cause rock burst. These two periods are other two indexes to identify burst risk.
- (3) Drilling bits method can ascertain the burst region after identifying burst risk. Coal dust amount, dynamic effect, and proportion of large-size particles should be considered together.

### Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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