

Application Research of Microseismic Monitoring Technology in Coal Mine Excavation Face

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Abstract

To address dynamic hazards such as coal and gas outbursts and rockbursts during deep mining, this study takes a certain Coal Mine as the research subject. A mine-wide microseismic monitoring network was established using the Polish SOS microseismic monitoring system. By collecting, transmitting, and processing microseismic data in real time, the spatiotemporal distribution characteristics of microseismic events were analyzed. A dynamic hazard early warning model was developed based on the microseismic data, and targeted prevention measures were formulated in combination with the warning model. The results show that: Real-time microseismic monitoring and early warning effectively detected and mitigated multiple potential dynamic hazards. The early warning model provided sufficient time for the implementation of preventive measures. And the targeted prevention measures significantly improved mine safety and production efficiency. Practical applications demonstrate that this research has high practical value and broad applicability.

Keywords

Coal Mine Dynamic Hazards; Working Face; Microseismic Monitoring; Outburst Early Warning; Safety Production.

1. Introduction

Coal, as a fundamental energy source in China's energy structure, its safe production is directly related to the stability of the national energy supply and the sustainable development of the socio-economic landscape [1]. With the continuous increase in coal mining depth, power disasters such as coal and gas outbursts and rockbursts in high-gas mines have become increasingly prominent issues [2-4]. Liyazhuang Coal Mine, an important production mine under Huozhou Coal and Electricity Group, has a designed production capacity of 1.5 million tons per year and is classified as a high-gas mine. In recent years, with the increase in mining depth, the mine has experienced frequent power disasters, particularly coal and gas outbursts and rockbursts, which seriously threaten the safe production of the mine.

Scholars both domestically and internationally have conducted extensive research on the monitoring, early warning, and prevention of power disasters such as coal and gas outbursts and rockbursts. Microseismic monitoring technology, as an emerging monitoring method, has been widely applied in the monitoring of power disasters in mines [5-9]. Countries such as Poland and South Africa have taken an early lead in microseismic monitoring technology and have developed relatively complete technological systems. In recent years, China has also intensified its research and application efforts in microseismic monitoring technology, achieving a series of significant results. However, research on the monitoring, early warning, and prevention of compound disasters such as coal and gas outbursts and rockbursts during

deep mining in high-gas mines remains insufficient, necessitating further in-depth exploration. Therefore, in response to the power disasters faced by Liyazhuang Coal Mine during deep mining, such as coal and gas outbursts and rockbursts, this paper primarily focuses on researching microseismic early warning and prevention & control measures in heading faces. By introducing advanced microseismic monitoring technology, real-time monitoring and early warning of micro-fracturing events in coal and rock masses are achieved, providing a scientific basis for the prevention and control of power disasters. Meanwhile, by combining microseismic monitoring data, the occurrence mechanisms and evolutionary patterns of power disasters are analyzed, and targeted prevention and control measures are formulated to enhance the safe production level of the mine.

2. Analysis of Research Status and Existing Shortcomings

2.1. Current Status of Monitoring and Early Warning Technologies for Mine Power Disasters

Currently, the monitoring and early warning technologies for mine power disasters mainly include the drill cuttings method, electromagnetic radiation method, geophone method, and microseismic monitoring method [10-11]. The drill cuttings method predicts rockburst hazards by detecting the amount of coal dust and its variation pattern during the drilling process, but it suffers from issues such as limited monitoring range and low accuracy. The electromagnetic radiation method predicts rockburst hazards by utilizing changes in the intensity of electromagnetic radiation during the deformation and fracture of coal and rock masses under loading. However, it is prone to external interference and has poor stability. The geophone method predicts power disasters by monitoring acoustic emission signals generated during the fracture of coal and rock masses, but its monitoring range is limited, making it difficult to achieve full-mine coverage. The microseismic monitoring method, as an emerging monitoring tool, offers advantages such as a wide monitoring range, high positioning accuracy, and strong real-time performance, and has been widely applied in the monitoring of mine power disasters.

2.2. Current Status of Prevention and Control Technologies for Mine Power Disasters

For power disasters such as coal and gas outbursts and rockbursts, the main prevention and control measures currently adopted include optimizing mining and excavation layouts, strengthening ventilation management, implementing gas drainage, pressure-relief blasting, and coal seam water infusion [12-13]. Optimizing mining and excavation layouts can avoid stress concentration and reduce the probability of power disasters. Strengthening ventilation management ensures air circulation in the mine, lowers gas concentration, and reduces the risk of gas explosions. Implementing gas drainage effectively reduces the gas content and pressure in coal seams, thereby decreasing the danger of coal and gas outbursts. Measures such as pressure-relief blasting and coal seam water infusion can alter the stress state and physical-mechanical properties of coal and rock masses, reducing the danger of rockbursts.

2.3. Existing Shortcomings

Despite the achievements made in the monitoring, early warning, and prevention and control technologies for mine power disasters both domestically and internationally, the following shortcomings still exist:

(1) **Insufficient Accuracy and Real-Time Performance of Monitoring and Early Warning Technologies:** Existing monitoring and early warning technologies struggle to achieve real-time monitoring and precise early warning of micro-fracturing events in coal and rock masses. In particular, they are inadequate in monitoring and early warning of complex power disasters such as coal and gas outbursts and rockbursts.

(2) Lack of Targeted and Effective Prevention and Control Measures: The existing prevention and control measures often lack specificity and effectiveness during implementation, making it difficult to fundamentally solve the problem of power disasters. This is especially true during deep mining in high-gas mines, where the prevention and control of compound disasters such as coal and gas outbursts and rockbursts are even more challenging.

(3) Low Level of System Integration and Intelligence: Existing monitoring, early warning, and prevention and control systems often operate independently, lacking system integration and intelligence. This makes it difficult to achieve data sharing and collaborative processing, thereby affecting the effectiveness of prevention and control measures.

3. Key Technology Research

3.1. Construction of Microseismic Monitoring System

In this paper, the Polish SOS microseismic monitoring system is selected due to its advantages of wide monitoring range, high positioning accuracy, and strong real-time performance. Eleven microseismic monitoring probes have been deployed in the second and sixth mining districts of Liyazhuang Coal Mine, achieving full-mine coverage monitoring. The probe layout adheres to the principle of "enveloping" the monitoring area to ensure more accurate seismic source localization. The installation of the microseismic monitoring system includes steps such as probe installation, data transmission line laying, and construction of a ground monitoring center. During probe installation, it is essential to ensure verticality and establish a good and tight connection with the transmission lines of the mine's microseismic network. The data transmission lines utilize an independent trunk-style data transmission system to achieve bidirectional control transmission. The ground monitoring center is equipped with professional data analysis software to enable real-time acquisition, transmission, and processing of microseismic signals.

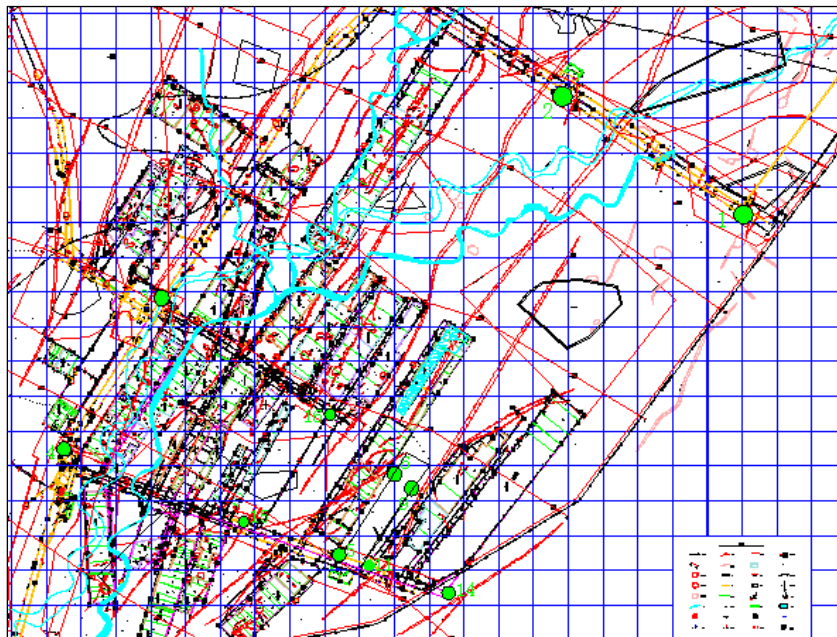


Figure 1. Layout diagram of microseismic sensors

3.2. Processing and Analysis of Microseismic Signals

The microseismic monitoring system continuously collects elastic wave signals generated by micro-fracturing events in coal and rock masses and transmits these signals to the ground monitoring center through the data transmission system. At the ground monitoring center, the

collected signals undergo preprocessing, including steps such as filtering, denoising, and gain adjustment, to improve signal quality. Characteristic extraction of the preprocessed microseismic signals is performed using methods such as time-domain analysis, frequency-domain analysis, and time-frequency analysis. The extracted features include signal amplitude, frequency, duration, energy, etc. Based on these extracted features, microseismic signals are classified to identify different types of microseismic events (e.g., roof tensile fractures, fault activation).

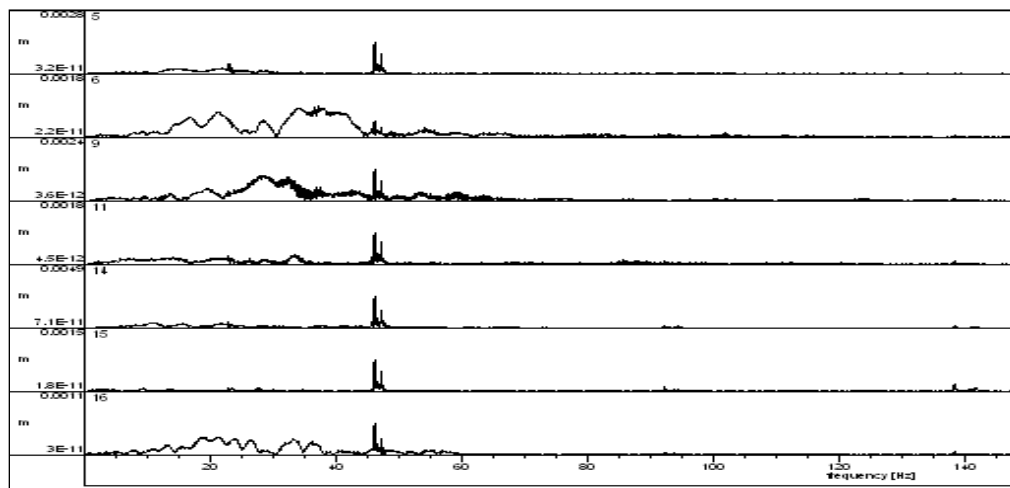


Figure 2. Spectrogram of microseismic signals

3.3. Construction of Power Disaster Early Warning Model

Based on microseismic monitoring data and analysis results, an early warning indicator system for power disasters is constructed. The early warning indicators include the frequency, energy, spatiotemporal distribution, and spectral characteristics of microseismic events. By setting early warning thresholds, early warnings for power disasters can be achieved in advance. Machine learning and deep learning algorithms are employed to learn and train the early warning indicators, thereby constructing a power disaster early warning model. The accuracy and reliability of the early warnings are improved by continuously optimizing the model parameters. In practical applications, real-time monitoring data is input into the early warning model to output early warning results.

3.4. Formulation and Optimization of Prevention and Control Measures

Targeted prevention and control measures are formulated based on microseismic monitoring results and the early warning model. For coal and gas outburst issues, measures such as strengthening gas drainage, optimizing mining and excavation layouts, and implementing pre-drainage of coal seam gas are adopted. For rockburst issues, measures such as pressure-relief blasting, coal seam water infusion, and forced caving are implemented. The prevention and control measures are continuously optimized based on actual prevention and control effects. By adjusting gas drainage parameters, optimizing blasting schemes, and improving water infusion processes, the prevention and control effects are enhanced. Meanwhile, the implementation process of prevention and control measures is closely monitored and managed to ensure their effective execution.

4. Application Effect and Analysis

4.1. Analysis of Microseismic Monitoring Effect

Since the microseismic monitoring system was put into operation, Liyazhuang Coal Mine has achieved real-time monitoring of micro-fracturing events in coal and rock masses. Analysis of the monitoring data reveals that microseismic events exhibit significant regularity in their spatiotemporal distribution. During the advancement of the working face, the frequency and energy of microseismic events gradually increase, particularly in areas of high stress concentration and geologically complex regions where microseismic events occur more frequently. Furthermore, in-depth analysis of microseismic events indicates a close correlation between these events and power disasters such as coal and gas outbursts and rockbursts. Microseismic events occurring in high stress concentration areas and geologically complex regions often signal an increased risk of power disasters. By continuously monitoring changes in microseismic events, potential hazards associated with power disasters can be promptly identified, and appropriate countermeasures can be taken.

4.2. Analysis of Early Warning Model Effect

The early warning model constructed based on microseismic monitoring data has been successfully applied in Liyazhuang Coal Mine. Practical application verification demonstrates that the early warning model possesses high accuracy. Prior to multiple power disaster events, the early warning model issued early warning signals in advance, alerting relevant personnel to take countermeasures, thereby effectively reducing the occurrence probability and severity of power disasters. The timeliness of the early warning model is also an important indicator for evaluating its performance. Practical applications reveal that the early warning model can issue early warning signals hours to days in advance of power disasters, providing sufficient time for the formulation and implementation of prevention and control measures. This facilitates the timely adoption of countermeasures to avoid or mitigate losses caused by power disasters.

4.3. Analysis of Prevention and Control Measure Effect

The prevention and control measures formulated for power disasters have been effectively implemented in Liyazhuang Coal Mine. Measures such as strengthening gas drainage and optimizing mining and excavation layouts have effectively reduced the risk of coal and gas outbursts. Additionally, implementing pressure-relief blasting and coal seam water infusion has effectively alleviated the problem of rockbursts. Meanwhile, the management of the mine ventilation system has been strengthened to ensure its stability and reliability. Comparative analysis of power disaster occurrences before and after the implementation of prevention and control measures reveals significant effects. Following the implementation of these measures, the frequency and severity of power disasters have markedly decreased, and the safe production level of the mine has significantly improved. This indicates that the prevention and control measures formulated in this study are effective and feasible.

5. Conclusion

By introducing the Polish SOS microseismic monitoring system, this paper has established a microseismic monitoring network covering the entire mine, achieving the following main results:

- (1) Successful Establishment of Microseismic Monitoring System: Real-time monitoring and early warning of micro-fracturing events in coal and rock masses have been realized, providing a scientific basis for the prevention and control of power disasters.
- (2) Revelation of Occurrence Mechanisms and Evolutionary Patterns of Power Disasters: Through analysis of microseismic monitoring data, the occurrence mechanisms and

evolutionary patterns of power disasters such as coal and gas outbursts and rockbursts have been revealed.

(3) Construction of Early Warning Model for Power Disasters: Based on microseismic monitoring data, an early warning model has been constructed to achieve early warning of power disasters.

(4) Formulation of Targeted Prevention and Control Measures: In conjunction with the early warning model, targeted prevention and control measures have been formulated, effectively reducing the occurrence probability and severity of power disasters.

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