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Research on Microseismic Early Warning for Outburst Prevention in the Heading Face of Liyazhuang Coal Mine

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Abstract

With the increase in mining depth, the threat of coal-rock dynamic disasters in the heading faces of high-gas coal mines is becoming increasingly severe, and their manifestation mechanisms are tending to become more complex, making it difficult for traditional single prediction methods to provide effective early warnings. Taking the 2-228 high-gas isolated island heading face of Liyazhuang Coal Mine under Huozhou Coal Electricity Group as the engineering background, this study conducted research on dynamic disaster early warning and control based on microseismic monitoring technology. By systematically analyzing the mine's geological structure environment, in-situ stress field distribution patterns, and coal seam gas parameters, an optimized layout scheme for the microseismic monitoring network was established. The evolution patterns of microseismic signals induced by mining activities in terms of time, space, and energy were thoroughly studied, and the spectral characteristics of microseismic events with different energy levels and fracture types (such as fault activation and roof fracture) were identified. Combining multi-source information from the drilling cuttings method and rock pressure observation, a composite early warning indicator system centered on microseismic activity frequency, energy release rate, and the correlation between "dynamic-static" loads was constructed. Field practice has demonstrated that this early warning system can effectively identify high-risk areas, significantly reducing the risk and intensity of dynamic disasters in heading faces, providing theoretical basis and technical reference for safe mining in mines under similar conditions.

Keywords

Liyazhuang Coal Mine, Dynamic Disasters, Microseismic Monitoring, Heading Face, Early Warning Indicators.

1. Introduction

Coal occupies a dominant position in China's energy structure, and its safe deep mining is crucial for ensuring energy security[1]. As mining depths continue to increase, coal mines are facing increasingly severe and complex coal-rock dynamic disasters such as coal and gas outbursts and rock bursts[2-4]. For high-gas coal mines like Liyazhuang Coal Mine that have entered deep mining, the coupling of high in-situ stress, high gas pressure, and mining-induced stress makes it prone to dynamic phenomena such as coal guns, roof drilling, drill bit jamming, and blowout when the heading face passes through geological structures or the edges of mined-out areas[5]. Conventional point- or line-based contact prediction methods (such as the drilling cuttings method and the initial velocity method of gas emission) struggle to achieve spatiotemporal dynamic and regional continuous monitoring and early warning of disaster-prone areas.

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As a geophysical method, microseismic monitoring technology can continuously and three-dimensionally monitor elastic wave signals generated by stress adjustments and fractures in coal and rock masses in real time[6-7]. Through inversion analysis, it can determine parameters such as the location, energy, and time of fractures, thereby revealing the evolution process of the surrounding rock stress field and fracture field under mining conditions. This provides a powerful technical means for regional dynamic disaster early warning. The Polish SOS microseismic monitoring system is widely used internationally due to its high precision and strong anti-interference capability. Therefore, based on the engineering practice of the 2-228 heading face in Liyazhuang Coal Mine, this paper aims to address the following key issues: (1) How to optimize the layout of the microseismic monitoring network for precise positioning under high-gas and complex geological conditions. (2) How to extract effective precursor information related to dynamic hazards in the heading face from massive microseismic data and establish a reliable early warning indicator system. The research findings hold significant practical importance for enhancing the safety assurance level of heading faces in deep high-gas coal mines.

2. Engineering Geological Overview and Risk Analysis of Dynamic Disasters

Liyazhuang Coal Mine is located in the Huozhou mining area in Shanxi Province, primarily mining the No. 2 coal seam of the Shanxi Formation. The designed length of the 2-228 heading face is 630 m, with a burial depth ranging from 590 m to 650 m, making it a typical deep isolated island heading face. The 2-220 and 2-224 heading faces, which have already been mined, are located above and below it, respectively. The area is characterized by complex geological structures, with well-developed faults and dense collapse columns. The average thickness of the No. 2 coal seam is 3.16 m, with a dip angle ranging from 4° to 10°. The coal seam's firmness coefficient (f value) ranges from 0.7 to 1.2. The measured maximum gas pressure in the coal seam is 0.61 MPa, and the maximum gas content is 7.02 m^3/t. According to assessments, the mine is classified as a high-gas mine, and the No. 2 coal seam above the +220 m elevation is identified as a non-outburst coal seam but exhibits weak rock burst tendency.

The risk of dynamic disasters in the deep area of Liyazhuang Coal Mine primarily stems from the coupling effects of three factors:

(1) High-stress environment: Results from in-situ stress measurements and numerical simulations indicate that the in-situ stress field in this area is dominated by horizontal tectonic stress, with vertical stress increasing with depth, reaching over 15 MPa at a depth of 600 m. The layout of the isolated island heading face results in significant stress concentration in the coal pillar areas ahead of and on both sides of the heading face, with peak stresses reaching 2-3 times the original rock stress.

(2) Gas occurrence conditions: The relatively high gas pressure and content not only constitute a potential energy source for outbursts but also adsorb onto the surfaces of coal fractures, producing a "wedging" effect that reduces coal strength and alters its mechanical properties, increasing the risk of instability and failure of the coal mass under stress.

(3) Mining disturbance and geological structures: Heading activities strongly disturb the original rock stress balance, inducing stress redistribution. Geological structures such as faults and folds are not only natural stress anomaly zones but also gas-rich zones, which are prone to activation and sliding under mining influence, triggering high-energy microseismic events and even rock bursts.

A comprehensive analysis concludes that although the 2-228 heading face does not generally pose a strong outburst risk, there is a risk of composite dynamic phenomena dominated by rock

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bursts, possibly accompanied by abnormal gas emissions, in specific areas such as high-stress concentration zones and near faults.

3. Construction of Microseismic Monitoring System and Analysis of Signal Characteristics

3.1. Optimization and Construction of the Microseismic Monitoring Network

To effectively monitor the entire heading process of the 2-228 heading face, based on the optimal design theory of the D value and considering the mine's roadway layout and geological conditions, 11 microseismic sensors were optimally arranged in the second mining district. The sensors were primarily installed in areas with intact surrounding rock and away from mechanical interference, such as the return air roadway and transport roadway, forming a three-dimensional network that spatially surrounds the key monitoring area. The system employs the Polish SOS microseismic monitoring system, with sensors having a frequency range of 1-600 Hz, capable of capturing microseismic events with energies greater than 100 J and achieving spatial location accuracy requirements with horizontal errors less than 20 m and vertical errors less than 50 m for the hypocenter. The successful construction of the system lays a solid foundation for subsequent data analysis.

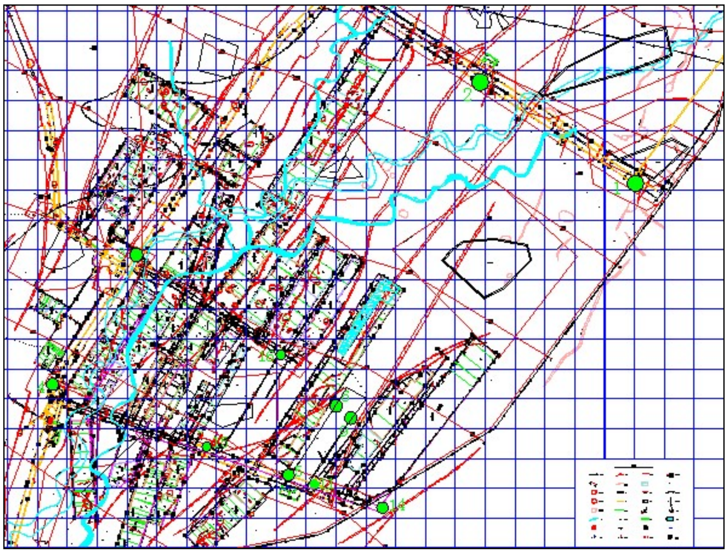

Figure 1. Layout diagram of microseismic sensors

3.2. Research on Characteristics and Patterns of Microseismic Signals

Through processing and analyzing a large amount of microseismic data obtained during the monitoring period, several important characteristics of microseismic activity in Liyazhuang Mine were revealed:

(1) Correlation between microseismic activity and production activities: Microseismic events are highly correlated with underground production activities in terms of temporal distribution. During periods of reduced production activities, such as maintenance, the frequency of microseismic events significantly decreases. Conversely, during normal production periods, especially when mining activities are intense, microseismic events occur frequently. This indicates that mining disturbances are the primary factor inducing microseismic activity.

(2) Grading and causes of microseismic energy: Microseismic events can be classified into different levels based on their energy magnitude. Low-energy events (e.g., 10^2-10^3 J) are mostly associated with local coal fractures or small roof falls, characterized by short signal durations and rapid attenuation. In contrast, high-energy events (e.g., above 10^4 J) are often linked to

macroscopic fracture processes such as extensive roof fractures, fault activation, or coal pillar instability, featuring long signal durations and large amplitudes. For example, an event with an energy of 2.78×10^5 J was monitored and confirmed through location analysis to have occurred on a known fault zone near the 228 open-off cut, exhibiting typical shear fracture characteristics in its waveform.

(3) Spatial evolution patterns of microseismic activity: The hypocenter locations of microseismic events are not uniformly distributed in space but exhibit distinct clustering characteristics. During the advancement of the 226 mining face, microseismic events were concentrated within the abutment pressure zone approximately 70-100 m ahead of the face and within the fracture development zone of the "vertical three zones" in the overlying strata of the mined-out area behind the face. Particularly in the section coal pillar area between the 224 and 226 mining faces, microseismic events were dense, indicating complex stress conditions and poor stability of the coal pillar under the influence of mining on both sides, making it a critical hazardous area requiring special attention. For the 228 heading face, as the roadway advanced, the active microseismic zone also shifted forward, clearly outlining the dynamic process of surrounding rock stress adjustment under the influence of heading.

(4) Indicative significance of spectral characteristics: Spectral analysis of different types of microseismic signals revealed that artificial vibration signals, such as those from blasting in high-level drilling sites, have a wide frequency spectrum with rich high-frequency components. In contrast, natural microseismic signals generated by rock fractures have relatively lower dominant frequencies. Large-scale fracture events (e.g., main roof fractures) with high energy typically have lower dominant frequencies than small-scale fractures (e.g., immediate roof falls). During signal propagation, high-frequency components attenuate rapidly, resulting in a decrease in the dominant frequency of signals received by sensors far from the hypocenter.

4. Establishment of a Microseismic Early Warning Indicator System for Outburst Prevention

Based on the analysis of the aforementioned microseismic activity patterns, combined with rock pressure observation (e.g., support resistance monitoring) and conventional dynamic phenomenon prediction methods (e.g., drilling cuttings method), a comprehensive multi-parameter early warning indicator system for microseismic activity at heading faces in Liyazhuang Mine was established. This system mainly includes the following three categories of indicators:

(1) Spatiotemporal-intensity comprehensive indicators: ① Frequency and energy release rate of microseismic events: Thresholds for the number of microseismic events and cumulative energy released per unit time (e.g., daily) are set. When the microseismic frequency or energy in the monitored area increases sharply over a short period or remains consistently high, an early warning is issued. For example, monitoring data shows that before the periodic weighting of the 226 mining face, the daily frequency and total energy of microseismic events above the face typically exhibit a significant upward trend. ② Abnormal "b-value": The b-value describes the relationship between the number of small and large earthquakes in seismology. In coal mine applications, a decrease in the b-value usually indicates a disproportional increase in large-energy events, reflecting an elevation in medium stress levels and an increase in fracture scale, serving as a precursor to increased hazard. ③ Spatial concentration of hypocenters: A shift in microseismic events from dispersion to concentration in space, particularly forming distinct clusters at key structural locations such as faults, coal pillars, and edges of mined-out areas, indicates high stress concentration and intensified fracture processes in the region.

(2) Spectral evolution indicators: ① Dominant frequency shift: A shift in the dominant frequency of predominant microseismic signals in the monitored area towards lower frequency

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bands may indicate the gestation of larger-scale, higher-energy fracture events. ② Spectral amplitude ratio: Analyzing changes in the energy distribution of signals across different frequency bands to identify characteristic spectral patterns associated with precursors to rock mass instability.

(3) Dynamic-static load correlation indicators: Correlating "dynamic" load information (vibration energy, frequency) obtained from microseismic monitoring with "static" load information (abutment pressure distribution, support working resistance) obtained through rock pressure observation. When regions with enhanced dynamic activity highly overlap with static high-stress zones, the risk of dynamic disasters in the region significantly increases.

During early warning implementation, a "yellow-orange-red" three-level early warning mechanism is adopted. When a single indicator shows abnormalities, a yellow early warning is issued, prompting enhanced monitoring. When multiple indicators show abnormalities simultaneously or key indicators reach critical values, orange or red early warnings are issued, and corresponding hazard mitigation measures are immediately taken.

5. Analysis of Application Effects

Since the implementation of the microseismic monitoring and early warning system at working faces such as 2-228 in Liyazhuang Mine, significant results have been achieved. The system has successfully captured abnormal increases in microseismic activity during critical stages such as when the heading face crosses faults or approaches mined-out areas on multiple occasions and issued timely early warnings. For example, after an early warning was issued, the mine immediately implemented deep-hole pressure relief blasting measures ahead of the 228 heading face. After blasting, the level of microseismic activity in the region significantly decreased, with a marked reduction in high-energy events, effectively preventing potential intense dynamic phenomena and ensuring the safe and smooth advancement of heading operations. Simultaneously, based on assessments of surrounding rock stability through microseismic monitoring, support parameters were optimized, reducing unnecessary roadway repairs. Practice has demonstrated that this technological system has achieved a transformation in managing dynamic disasters at heading faces from "passive response" to "active early warning and proactive prevention," enhancing the mine's safety management level.

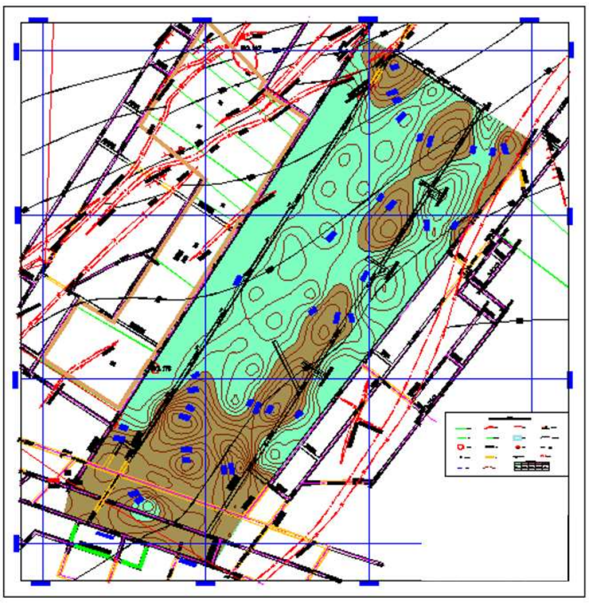

Figure 2. Zoning map of hazard levels for area 2-228

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6. Conclusion

(1) In response to the complex conditions of deep, high-gas isolated island heading faces in Liyazhuang Mine, a microseismic monitoring network based on D-value optimization theory has been established. This network effectively captures information on surrounding rock fractures, achieves precise hypocenter location, and provides a reliable data foundation for early warning of dynamic disasters.

(2) A thorough analysis of the evolutionary patterns of microseismic activity in terms of time, space, and energy has been conducted. It has been found that microseismic activity is closely related to mining disturbances. The spatial clustering characteristics of microseismic events can clearly reveal high-stress hazardous areas, such as isolated island coal pillars and fault zones. Additionally, spectral characteristics offer indicative significance for identifying fracture types and scales.

(3) A comprehensive multi-parameter early warning indicator system for microseismic activity has been constructed, integrating "spatiotemporal-intensity" parameters, spectral evolution, and "dynamic-static load" correlations. A three-level early warning mechanism has also been established, enabling quantitative and dynamic assessment of dynamic hazards at heading faces. This study provides crucial technical support for safe deep mining in Liyazhuang Mine and holds significant promotional value and reference significance for other high-gas mines with similar geological conditions.

Acknowledgments

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References

[1] Yuan Liang, Zhang Tong, Wang Yuehan, et al. Scientific Issues and Key Technologies for Safe and Efficient Mining of Deep Coal Resources[J]. Journal of China Coal Society, 2025, 50(01): 1-12.

[2] Wang Kai, Li Kangnan, Du Feng, et al. Risk Level Early Warning Method for Coal-Rock-Gas Compound Dynamic Disasters Based on Multi-Source Information Fusion and Deep Learning[J/OL]. Journal of China Coal Society, 1-19[2026-01-13].

[3] Jing Xinjun, Chen Mingming, Lei Dongji. Acoustic-Electric Response Characteristics of Coal-Rock Dynamic Disasters in Excavation Face[J]. China Energy and Environmental Protection, 2024, 46(06): 40-44.

[4] Yang Ke, Li Caiqing, Liu Wenjie, et al. Research Progress on Monitoring, Early Warning, Prevention and Control Technologies for Coal-Rock-Gas Compound Dynamic Disasters[J]. Journal of Mine Automation, 2024, 50(04): 18-32.

[5] Peng Minghui. Categories of Microseismic Signals and Spatiotemporal Analysis of Microseismic Events in Liyazhuang Coal Mine[J]. Mining Safety & Environmental Protection, 2019, 46(04): 87-91.

[6] Chen Fabing, Sun Xiaodong, Wang Yuanjie, et al. Research Status and Prospects of Coal Mine Microseismic Monitoring Technology[J]. Coal Engineering, 2025, 57(06): 133-141.

[7] Yu Jiangming, Pan Ze, Lu Yanzhong, et al. Application Status and Prospects of Microseismic Monitoring Technology in Underground Mines[J]. Mining Technology, 2025, 25(02): 253-258.