ISSN: 2710-0723

Research Status and Prospects of Coal and Gas Outburst Prediction Technology

Zhendong Zhang[1,2]

[1] China Coal Technology and Engineering Group Chongqing Research Institute, Chongqing 400039, China

[2] State Key Laboratory of Coal Mine Disaster Prevention and Control, Chongqing 400039, China

Abstract

This paper delves into the current research status of coal and gas outburst prediction technologies, with a focus on analyzing static prediction methods, dynamic prediction methods, as well as prediction approaches based on mathematical models and emerging technologies. By elucidating the principles, application effects, and existing issues of various prediction methods, it reveals the challenges faced by current coal and gas outburst prediction technologies. Additionally, it prospects the future development directions of these technologies and proposes suggestions for enhancing prediction accuracy and reliability, aiming to provide robust support for safe coal mine production.

Keywords

Coal and Gas Outburst; Prediction Technology; Static Prediction Method; Dynamic Prediction Method; Mathematical Model; Emerging Technology.

1. Introduction

Coal and gas outburst is an extremely hazardous dynamic disaster during coal mining, which not only causes casualties and equipment damage but also severely impacts the normal production of coal mines [1-2]. With the increasing depth and intensity of coal mining, the risk of coal and gas outburst is also escalating [3]. Therefore, accurately and reliably predicting coal and gas outburst is of great significance for ensuring safe coal mine production.

The prediction and forecasting of coal and gas outburst, in essence, involve classifying and predicting the target outburst areas based on various outburst factors [4]. China's "Detailed Rules for the Prevention and Control of Coal and Gas Outburst" clearly stipulate that outburst mines should formulate and implement comprehensive regional and local outburst prevention measures based on mining conditions, including regional outburst risk prediction, regional outburst prevention measures, effectiveness inspection of regional outburst prevention measures, regional verification, as well as working face outburst risk prediction, working face outburst prevention measures, effectiveness inspection of working face outburst prevention measures, and safety protection measures. Among these, regional outburst risk prediction and working face outburst risk prediction are crucial prerequisites for implementing outburst prevention measures. The task of regional prediction is to classify outburst-prone areas at three levels: mine, coal seam, and partial coal seam areas, primarily through gas-geological analysis combined with gas parameters. The task of working face (local) prediction is to timely predict the outburst risk within small areas such as mining faces and crosscuts based on the former. Currently, it is mainly divided into two types: contact and non-contact prediction. Contact prediction mostly belongs to static prediction, while non-contact prediction, based on its dynamic continuity characteristics, has also been widely applied. In recent years, scholars at home and abroad have conducted extensive research on coal and gas outburst prediction

ISSN: 2710-0723

technologies, achieving remarkable progress. Therefore, based on this, this paper will provide a detailed analysis of the current research status of coal and gas outburst prediction technologies and prospect their future development directions to support coal and gas outburst prediction.

2. Static Prediction Method

2.1. Principles and Methods of Static Prediction Method

The static prediction method involves on-site testing and laboratory analysis of parameters such as coal seam gas content, physical and mechanical properties of coal bodies, and geological structures. Based on the relationships between these parameters and coal and gas outbursts, prediction indicators and critical values are established to forecast the risk of coal and gas outbursts. Commonly used static prediction indicators include the amount of drill cuttings (S), the drill cuttings gas desorption index (Δh_2 or K_1), the initial velocity of gas emission from boreholes (q), and the coal body firmness coefficient (f), among others [5].

For instance, the amount of drill cuttings (S) refers to the volume of cuttings discharged during the drilling process for every certain depth drilled. When the amount of drill cuttings exceeds a specific critical value, it indicates the presence of high stress or gas pressure in the coal seam, suggesting a potential outburst risk. The drill cuttings gas desorption index (Δh_2 or K_1) reflects the gas desorption rate and content in the coal seam by measuring the amount of gas desorbed from the drill cuttings within a certain period, thereby enabling the assessment of outburst risk.

2.2. Application Effects and Existing Problems of Static Prediction Method

The static prediction method has been widely applied in coal mine production and has achieved certain prediction results. It boasts advantages such as simple operation and low cost, enabling it to predict the risk of coal and gas outbursts to a certain extent. However, the static prediction method also has several notable limitations.

Firstly, it is a "point prediction" method, which can only reflect the outburst risk at the drilling location and cannot provide a comprehensive prediction for the entire mining face or area. Due to the complexity and heterogeneity of coal seam occurrence conditions, the outburst risk may vary significantly at different locations. Consequently, the prediction results of the static prediction method may be subject to relatively large errors. Secondly, the static prediction method has a long prediction cycle, requiring substantial time and labor for drilling construction and parameter determination. During the mining process, the geological conditions and stress state of the coal seam are constantly changing, and the static prediction method cannot reflect these changes in real-time, easily leading to delayed prediction results and an inability to take timely and effective outburst prevention measures. Finally, the prediction indicators and critical values of the static prediction method are often determined based on experience or statistical data, lacking scientificity and accuracy. The outburst mechanisms and influencing factors may differ among different mines and coal seams, so uniform prediction indicators and critical values may not be applicable to all situations.

3. Dynamic Prediction Method

3.1. Principles and Methods of Dynamic Prediction Method

The dynamic prediction method involves real-time monitoring of various physical quantity changes during the process of coal and gas outbursts, such as gas emission volume, coal body stress, and acoustic emission. Based on the variation patterns of these physical quantities, the outburst risk is judged. Compared with the static prediction method, the dynamic prediction method has advantages such as real-time performance, continuity, and comprehensiveness,

ISSN: 2710-0723

enabling it to more accurately reflect the dynamic change process of coal and gas outbursts. Commonly used dynamic prediction methods include environmental monitoring technology, acoustic emission (AE) monitoring technology, electromagnetic emission (EME) monitoring technology, and microseismic (MS) monitoring technology, among others [6-8].

(1) Environmental Monitoring Technology: By continuously monitoring the change characteristics of gas emission at the working face and analyzing the relationship between gas emission and outbursts, the risk of coal and gas outbursts can be predicted. For example, based on the abnormal change characteristics of gas emission volume within 30 minutes after blasting at the mining working face, the outburst risk of the working face can be predicted.

(2) Acoustic Emission Monitoring Technology: Coal and rock masses generate acoustic emissions during the process of stress-induced failure. By installing acoustic emission sensors to monitor the acoustic emission signals of coal and rock masses in real-time and analyzing the frequency, amplitude, energy, and other characteristics of the signals, the degree of damage and outburst risk of the coal and rock masses can be judged.

(3) Electromagnetic Emission Monitoring Technology: Gas-bearing coal and rock masses generate electromagnetic emissions during the process of rheological failure. By monitoring indicators such as electromagnetic emission intensity and pulse count, the failure state and outburst risk of coal and rock masses can be reflected. This technology has the characteristics of short testing time, low labor intensity, and no impact on the efficient production of the mining working face, enabling dynamic and continuous monitoring as well as remote monitoring of the outburst risk of coal and rock masses ahead of the mining working face.

(4) Microseismic Monitoring Technology: Fractures and vibrations occur during the stress-induced failure process of coal and surrounding rock, generating microseismic waves. By arranging multiple sets of geophones in the roof and floor of the mining-affected area to collect microseismic data in real-time, and after data processing, the location of fractures can be determined using the principle of vibration localization and displayed in three-dimensional space. Microseismic monitoring technology has the characteristics of long-distance, dynamic, three-dimensional, and real-time monitoring. It can further analyze the scale and nature of fractures based on the seismic source situation, providing important evidence for coal and gas outburst prediction.

3.2. Application Effects and Existing Problems of Dynamic Prediction Method

The dynamic prediction method can reflect the dynamic change process of coal and gas outbursts in real-time, improving the timeliness and accuracy of prediction. In practical applications, dynamic prediction technologies have achieved some successful cases. For example, a certain coal mine installed an advanced gas monitoring system and successfully predicted and avoided multiple gas outburst accidents by analyzing gas concentrations in real-time. However, the dynamic prediction method also has some problems. Firstly, the cost of dynamic monitoring equipment is high, and the installation and maintenance are difficult, limiting its promotion and application in some small coal mines. Secondly, dynamic monitoring data is affected by various factors, such as noise interference and sensor accuracy, which may lead to inaccurate monitoring results. In addition, the current analysis and processing methods for dynamic monitoring data are not yet perfect, making it difficult to accurately extract feature information related to outburst risk from a large amount of monitoring data.

ISSN: 2710-0723

4. Prediction Methods based on Mathematical Models and Emerging Technologies

4.1. Prediction Methods based on Mathematical Models

Prediction methods based on mathematical models utilize mathematical theories and methods to establish prediction models for coal and gas outbursts. By analyzing and processing historical data, these models predict future outburst risks. Commonly used mathematical models include neural network models, support vector machine (SVM) models, and grey system models, among others [8-12].

(1) Neural Network Models: Neural networks possess powerful nonlinear mapping capabilities and self-learning abilities, enabling them to handle complex nonlinear problems. In coal and gas outburst prediction, neural network models can establish nonlinear relationships between input parameters (such as gas content, coal body firmness coefficient, and in-situ stress) and output parameters (outburst risk) by learning from a large amount of historical data, thereby achieving outburst risk prediction.

(2) Support Vector Machine Models: SVM is a machine learning method based on statistical learning theory. It separates data of different classes by finding an optimal hyperplane. In coal and gas outburst prediction, SVM models can classify samples with and without outburst risks, thus predicting outburst risks.

(3) Grey System Models: Grey system theory is a new approach for studying problems with small data samples and poor information uncertainty. In coal and gas outburst prediction, grey system models can process and analyze a small amount of historical data to establish grey differential equations and predict future outburst risks.

4.2. Prediction Methods based on Emerging Technologies

With the continuous development of technology, some emerging technologies are gradually being applied to coal and gas outburst prediction, such as big data, artificial intelligence (AI), and the Internet of Things (IoT), among others [13-16].

(1) Big Data Technology: Big data technology can store, manage, and analyze massive amounts of data related to coal and gas outbursts, such as gas monitoring data, geological data, and production data. By mining potential patterns and correlations in the data, key factors affecting coal and gas outbursts can be identified, improving the accuracy of prediction.

(2) Artificial Intelligence Technology: AI technology can achieve automatic optimization and adjustment of coal and gas outburst prediction models. For example, using deep learning algorithms to train neural network models can improve the prediction accuracy and generalization ability of the models.

(3) Internet of Things Technology: IoT technology can realize the interconnection and data sharing of coal and gas outburst monitoring devices. By deploying a large number of sensors underground in coal mines, various monitoring data can be collected in real-time and transmitted to the ground monitoring center, enabling real-time monitoring and early warning of coal and gas outbursts.

4.3. Application Effects and Existing Problems of Prediction Methods based on Mathematical Models and Emerging Technologies

Prediction methods based on mathematical models and emerging technologies have high prediction accuracy and intelligence levels, enabling them to better adapt to the complexity and uncertainty of coal and gas outburst prediction. However, these methods also have some problems. On the one hand, the establishment of mathematical models requires a large amount of historical data and professional knowledge. The accuracy and reliability of the models are affected by data quality and the selection of model parameters. In addition, the application of

ISSN: 2710-0723

emerging technologies faces problems such as high technical costs and a shortage of talents, limiting their widespread application in coal mines.

5. Existing Problems and Prospects

5.1. Existing Problems

(1) Limitations of Prediction Methods

Currently, various prediction methods for coal and gas outbursts have certain limitations. Static prediction methods can only perform "point predictions" and cannot comprehensively reflect the outburst risks in mining areas. Although dynamic prediction methods can achieve real-time monitoring, they have high equipment costs and their data is susceptible to interference. Although prediction methods based on mathematical models and emerging technologies have high accuracy, they have high requirements for data quality and model parameters, as well as high technical costs and talent demands.

(2) Complexity of Geological Conditions

The generation and occurrence conditions of coal seams in China are complex, with significant differences in geological conditions in different regions. The complexity of geological structures, such as faults and folds, as well as differences in the physical properties of coal seams, such as porosity and permeability, all affect the occurrence and development of coal and gas outbursts. This makes it difficult for existing prediction methods to adapt to all geological conditions, affecting the accuracy of prediction.

(3) Accuracy and Reliability of Monitoring Data

The accuracy and reliability of monitoring data are the basis for coal and gas outburst prediction. However, in the actual monitoring process, due to factors such as sensor accuracy, installation location, and environmental interference, monitoring data may contain errors. In addition, data loss or damage may occur during data transmission and storage, affecting the accuracy of prediction results.

5.2. Prospects for Coal and Gas Outburst Prediction Technology

(1) Multi-Method Fusion Prediction

Future coal and gas outburst prediction technologies will develop in the direction of multi-method fusion. By organically combining static prediction methods, dynamic prediction methods, and prediction methods based on mathematical models and emerging technologies, the advantages of various methods can be fully utilized, their respective shortcomings can be compensated for, and the accuracy and reliability of prediction can be improved. For example, static prediction methods can be used to initially divide mining areas and identify key monitoring areas. Then, dynamic prediction methods can be used to monitor these key areas in real-time. Finally, mathematical models and emerging technologies can be combined to analyze and process the monitoring data, achieving accurate prediction of coal and gas outbursts.

(2) Intelligent Prediction Systems

With the continuous development of technologies such as AI and big data, future coal and gas outburst prediction systems will be more intelligent. Intelligent prediction systems can automatically collect, analyze, and process monitoring data, identify outburst precursors in real-time, and automatically issue early warning signals. At the same time, these systems can also automatically adjust production plans and take corresponding prevention and control measures based on early warning results, achieving the integration of prediction, early warning, and prevention and control.

(3) Strengthening Basic Theoretical Research

ISSN: 2710-0723

In-depth research on the occurrence mechanisms and influencing factors of coal and gas outbursts is fundamental to improving the level of prediction technology. In the future, it is necessary to further reveal the essential laws of coal and gas outbursts, clarify the interactions between various influencing factors, and provide a more solid theoretical basis for the establishment of prediction models.

6. Conclusion

Coal and gas outburst prediction technology is an important means to ensure the safe production of coal mines. Currently, static prediction methods, dynamic prediction methods, and prediction methods based on mathematical models and emerging technologies have all achieved certain research results, but they also have their own limitations. In the future, coal and gas outburst prediction technology will develop in the direction of multi-method fusion, intelligence, standardization, and normalization. By strengthening basic theoretical research, improving the prediction technology system, and enhancing the accuracy and reliability of prediction, more powerful guarantees can be provided for the safe production of coal mines. At the same time, coal mine enterprises should increase their investment in and application of prediction technologies, actively promote advanced prediction technologies and equipment, and improve the safe production level of coal mines.

References

[1] Lei Yang, Cheng Yuanping. Cascading fracture development mechanism of coal and gas outburst [J/OL]. Journal of China Coal Society, 1-21 [2025-05-23].

[2] Li Feng, Wang Chenchen, Wang Bo, et al. Dynamic mechanism of coal and gas outburst based on multi-zone combined coal body [J]. Coal Geology & Exploration, 2024, 52(05): 12-24.

[3] Zhang Zhigang, Zhang Qinghua, Liu Jun. Research progress and prospects of early warning systems for coal and gas outburst and compound dynamic disasters in China [J]. Journal of China Coal Society, 2024, 49(S2): 911-923.

[4] Liang Yunpei, Zheng Menghao, Li Quangui, et al. Current research status of prediction and early warning of coal and gas outburst in China [J]. Journal of China Coal Society, 2023, 48(08): 2976-2994.

[5] Wei Enguang, Deng Chenghai, Pan Fudong, et al. Determination of sensitive indicators for predicting coal and gas outburst in a certain coal mine in Guizhou [J]. China Science Adventure, 2021, (01): 97-99.

[6] Hu Jie. Research and application of outburst prediction indicators during excavation based on acoustic emission characteristic parameters [J]. Coal Mine Machinery, 2025, 46(04): 158-161.

[7] Zhang Tong, Hu Yanting, Li Yinpeng. Prediction method of coal and gas outburst based on PSO-BP neural network [J]. Coal Technology, 2023, 42(11): 128-131.

[8] Song Dazhao, He Xueqiu, Dou Linming, et al. Research on microseismic regional detection technology for coal seam outburst risk [J]. China Safety Science Journal, 2021, 31(01): 89-94.

[9] Li Yang, Liu Xiaoyue. Prediction of coal and gas outburst using electromagnetic radiation method based on FOA-BP [J]. Journal of North China University of Science and Technology (Natural Science Edition), 2018, 40(01): 56-63.

[10] Duan Mengnan, Liu Zegong. Research on scale prediction of coal and gas outburst based on neural network [J]. Journal of Huaiyin Institute of Technology, 2021, 30(01): 33-39.

[11] Wang Xiaosheng, Yin Yahong, Tu Jun, et al. Research on prediction of coal and gas outburst based on PSO-KELM [J]. Energy and Environmental Protection, 2025, 47(03): 60-64.

[12] Zheng Xiaoliang, Wang Qi, Lai Wenhao, et al. Prediction of coal and gas outburst based on DBSCAN-IHHO-SVM model [J]. Journal of Hubei Minzu University (Natural Science Edition), 2025, 43(01): 53-59.

ISSN: 2710-0723

[13] Liu Chun. Research on prediction methods and technologies of coal and gas outburst disasters based on big data [J]. Jiangsu Science & Technology Information, 2020, 37(08): 50-52.

[14] Chen Benliang, Bi Bo, Yang Wei. Preliminary exploration of big data early warning indicators and architecture for coal and gas outburst [J]. Shaanxi Coal, 2023, 42(06): 78-82.

[15] Luo Weidong, Yang Cheng, Zhao Xiyu, et al. Research and application of intelligent early warning system for coal and gas outburst based on artificial intelligence [J]. Inner Mongolia Coal Economy, 2023, (05): 20-22.

[16] Qi Yu. Design of gas outburst early warning monitoring system based on the Internet of Things [J]. Coal Technology, 2022, 41(05): 226-228.