Rock burst risk prediction method based on multi-factor pattern recognition and its application in coal mine

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Abstract. Rockburst is one of the typical dynamic disasters in coal mine, and risk prediction of rockburst is the primary task of implementing comprehensive prevention and control measures. In order to predict the risk of rockburst in different areas of No. 9 coal seam in Jixian coal mine, the geo-dynamic division method is adopted to determine the characteristics of fault developments and mine field structures. Geological structure model is established and the influencing factors of rockburst such as fracture structure, roof lithology, stress and mining depth are analyzed in this paper. On these basics, the multi-factor pattern recognition method for predicting rockburst risk is put forward, and the risk of rockburst in Jixian coal mine is divided into four grades. The prediction results of the comprehensive index method for the 4th panel in second mining area are compared with the prediction outcomes of the multi-factor pattern recognition method. Results show that the multi-factor pattern recognition method have good performance in predicting the rockburst risk, thus providing theoretical and technical support for the management of rockburst.

1. Introduction
Rockburst has become a worldwide difficult problem in the prevention and control of mine dynamic disasters because of its complex occurrence mechanism and multiple influencing factors [1-4]. Risk prediction, monitoring and early warning, control technology and safety protection constitute a "four-in-one" theory and technology system of rock burst prevention and control. The risk prediction of rock burst is especially critical for the system. Pan et al. (2014) applied the charge monitoring system of coal and rock to detect the charge radiation signal of coal and rock mass in front of the working face, and studied the change rule and characteristics of the electric radiation signal of mine dynamic disasters during the incubation process [5]. Jiang et al. (2014) studied the mechanism of rock burst in Yuncheng Coal Mine based on the structural model of "three load zones" and combined with microseismic monitoring data. The results show that high in-situ stress and movement of hard and thick roof are the main causes of rock burst in Yuncheng Coal Mine. The large borehole pressure relief measures and reducing mining speed are effective ways to control rock burst in similar mines [6]. Pan et al. (2014) analyzed the correlation between concentrated static load and rock burst, and constructed a pre-evaluation model of impact risk based on Concentrated Static load detection [7]. In view of the incompatibility and uncertainty of rock burst risk evaluation index, Zhang et al. (2011) established a set pair analysis and prediction model of rock burst risk by using set pair analysis method [8]. Based on fuzzy mathematics and catastrophe theory, Jin et al. (2013) put forward the catastrophe series evaluation method of rock burst risk [9]. According to the different influencing factors of rock burst,
the corresponding evaluation model is constructed. Zhou et al. (2010) established Fisher discriminant analysis model for classification and prediction of rock burst risk based on the main influencing factors of rock burst, such as coal thickness and inclination [10]. The model was applied in Yanshitai Coal Mine. Based on Bayes discriminant analysis, Wen (2015) analyzed the prediction and risk classification of rock burst [11]. On the basis of considering the natural factors, geological factors and mining factors, the rock burst is divided into four grades according to the risk. Sample analysis shows that the accuracy of this evaluation method is over 93%. Ronghai et al. (2017) put forward the concept of "coal-rock dynamic system", constructed the model of "relationship between coal-rock dynamic system and rock burst appearance", and gave the calculation method of each regional scale of "coal-rock dynamic system". And then he established the corresponding evaluation index system, and calculated the specific impact scale of coal-rock mass with different impact risk degree [12]. The main inducing factors of rock burst in steeply inclined and extra-thick coal seams are analyzed by using the methods of geodynamic zoning and rock stress calculation, and the dangers in different areas are divided by multi-factor pattern recognition method [13-15].

The triggering mechanism of rock burst is complex. When we predict the risk of rock burst, the influence of multiple factors on rock burst should be considered. The prevention and control of rock burst need to fully consider the main factors affecting rock burst, and analyze the impact of each factor on the rock burst risk. In this paper, the multi-factor pattern recognition is used for comprehensive evaluation.

Through the analysis of the occurrence mechanism of rock burst in Jixian Coal Mine, the main influencing factors are determined. The multi-factor pattern recognition and prediction method of rock burst risk is put forward. The weight of each influencing factor of rock burst in Jixian Coal Mine is quantitatively analyzed, and the corresponding probabilistic prediction model is established. This model will be used to predict the rock burst in Jixian Coal Mine. The risk of rock burst in different regions is evaluated and predicted, and the accuracy of prediction results is verified by comprehensive index method. The research results provide theoretical and technical support for ensuring mine safety production.

2. Analysis of the influencing factors of rock burst in Jixian Coal Mine

2.1. Rock burst in Jixian Coal Mine

Jixian Coal Mine is located in Jixian County, about 19 km southwest from Shuangyashan City. It belongs to the northeast of Shuangyashan Mining Area, and is under the administrative jurisdiction of Sifangtai District. Jixian Coal Mine now mainly mines Nos. 3, 9 and 17 seams, and no. 16 seams will be mined in the next stage. Among them, No. 9 coal seam has undergone many times of rock burst during mining. The earliest rock burst occurred in April 2010. The maximum energy of rock burst measured by microseismic monitoring is 4.02×10^8 J, which seriously damages roadways and mechanical equipment and threatens the safety of workers. It has become an urgent problem to be solved. The distribution of rock burst and some statistical results in Jixian Coal Mine are shown in Fig. 1 and Table 1.

2.2. Factor analysis on fault structure of rockburst in Jixian Coal Mine

The mine rock burst is influenced by factors, including the geological conditions, the mining depth, fault structure, stress, roof lithology and coal-rock structure characteristics. Among them, the fault structure and stress distribution play a dominant role in the occurrence of rock burst.

The geodynamic division method is used to divide the block of fault structure in Jixian mine field. A geological structure model which links plate structure with mine engineering practice is established, which provides a basis for stress state analysis of rock mass and risk prediction of rock burst. The corresponding relationship between fault block structure of grade V and rock burst in Jixian Coal Mine is shown in Fig. 2.
Fig. 1. Distribution diagram of rockburst in Jixian coal mine.

Table 1. Rockburst part statistics in Jixian coal mine.

| Number | Grade | Energy of rock burst (MJ) | Place of rock burst occurrence |
|--------|-------|---------------------------|-------------------------------|
| 1      | 2.4   | 17.7                      | Panel 9107                    |
| 2      | 2~2.4 | 3.72~17.7                 | Panel 9107                    |
| 3      | 2.4~2.8 | 17.7~84.3               | Panel 9107                    |
| 4      | 2.6~3.2 | 38.6~402                | Panel 9106                    |
| 5      | 2~2.4 | 3.72~17.7                 | Panel 9106                    |
| 6      | 2.4~2.8 | 17.7~84.3               | Panel 9106                    |

Fig. 2 illustrates the rock burst in Jixian mine field is mainly controlled by the faults II-1, IV-4 and V-3. The occurrence point of rock burst is located in the 9103, 9104, 9105, and 9106 panels near the fault IV-4 and fault V-3 in the No. 9 coal seams. The fault II-1 is related to Fujin-Xiaojiahe fault, and the strike of Beigang fault is basically consistent with that of the southern boundary of mine field. The IV-4 fault segment intersects R25 of panels 9104 and 9105 West mining area. The segment of fault V-3 coincides with R24 strike of panels 9108 and 9109 in middle mining area. It can be seen that the fault structures determined by the geodynamic division method are related to the known faults and other geological structures in the mine, which have a certain influence on rock burst and provide the fault structural conditions for its occurrence.

Fig. 2. Relationship between rock burst and the position of fault structure in Jixian Coal Mine.
2.3. Factor analysis on the stress condition of rock burst in Jixian Coal Mine

Based on fault division map of grade V in Jixian mine field, the model is constructed. The rock mass stress state analysis system is adopted to calculate the stress within rock mass. According to the degree of stress concentration, the tectonic stress region of mine can be divided into high stress zone, stress gradient zone and low stress zone. The rock burst occurred in the panels of 9102, 9103, 9104, 9105, 9106 and 9107 in the No. 9 coal seam are located in the stress gradient zone.

Figure 3. Relationship between rockburst and tectonic stress zone in Jixian coal mine.

Coal and rock mass in stress gradient zone and high stress zone can accumulate and store a large amount of elastic energy. Some rock mass may be exceed the limit equilibrium state. When the external factors destroy the mechanical equilibrium state, the high stress in the rock mass drops sharply, and the stored elastic energy will be released suddenly. Most of the released energy is transformed into kinetic energy, which is beneficial to the occurrence of rock burst. Hence, the tectonic stress plays a dominant role in controlling the rock burst, and provides the tectonic stress conditions for the occurrence of rock burst.

3. Risk prediction of rock burst by multi-factor pattern recognition

3.1. Basic principles of multi-factor pattern recognition

Multi-factor pattern recognition method is used to analyze the multiple influencing factors and the mode of mine rock burst. By dividing the prediction unit in the studied areas, the probability prediction function of "modularization" and "gridding" is realized. The former model of “point risk, single-factor and qualitative prediction” is transformed into the model of “risk regional, multi-factor and quantitative prediction”. Based on the triggering mechanism of rock burst, the quantitative analysis is carried out one by one of various factors, and the probability prediction criterion of rock burst risk is determined. It assumes that the occurrence of rock burst is affected by n factors, and analyses each factor affecting the occurrence of rock burst. Influencing weight is used to establish the internal relationship between single influencing factor and rock burst risk. The n factors correspond to the n-type model of rock burst induced by vectors in the form of a set of vectors. After meshing the predicted area, the model corresponds to the element mesh one by one, and the same model is normalized. The model of each mesh in the predicted area is compared with that of the rock burst area one by one. The similar degree determines the probability value of specific risk, and finally aggregates the risk of each element grid to form a regional risk prediction result [16-17].
3.2. Construction of prediction model using multi-factor pattern recognition

Geological structure and stress are the main factors controlling the occurrence of rock burst. While mining depth, roof lithology, structure characteristics of coal and rock also have an influence on the occurrence of rock burst. Due to the different influencing factors in different prediction areas, the intensity and duration of rock burst are different. The influencing factors of rock burst in Jixian Coal Mine mainly consider the factors including fault structure, tectonic stress, roof lithology and mining depth. The rock burst events that have occurred in Jixian Coal Mine are classified into several models according to different influencing factors, and the model differences between prediction zone and occurred rock burst zone are treated. The probability prediction criterion is determined. On the basis of this, the corresponding pattern recognition prediction model is established, as shown in Fig. 4.

![Risk prediction model for rock burst by multi-factor pattern recognition.](image)

The difference of risk models of rock burst depends on the regional difference of influencing factors and the combination forms. A feature set can represent a risk model of rock burst can be defined as:

\[ O = \{f_1, f_2, ..., f_n\} \]

where \( O \) is the feature set of \( n \) factors; \( f_1, f_2, ..., f_n \) are the all features of \( n \) factors.

After the prediction model is built, the predicted zone will be meshed. Each cell contains different influence factors. The influencing degree of factors is expressed by probability and treated by fuzzification and dimensionlessness. Therefore, the dimensionless predicted value of rock burst risk probability can be obtained. Then the dimensionless predicted value of impact risk probability can be obtained. The probability critical value of rock burst risk can be divided into different dangerous grades of different prediction zones.

4. Dangerous zone division of rock burst in Jixian Coal Mine.

Based on the constructed multi-factor pattern recognition model of rock burst risk and the GIS technology, the information management system for rock burst prediction in Jixian Coal Mine is developed by utilizing VB language. The detailed information of regional prediction of rock burst risk in Jixian Coal Mine is visually displayed. The integration function of regional prediction and decision-making of anti-impact measures can be realized. Minefields are divided into non-rockburst dangerous zone, weak rockburst dangerous zone, medium rockburst dangerous zone and strong rockburst dangerous zone. Each zone is represented by the corresponding color resulting from regional prediction. The risk probability values of 0.25, 0.5 and 0.75 were taken as the critical values respectively. The results of rock burst prediction in Jixian Coal Mine are presented in the form of stress layered coloring map and stress contour map, and can be combined with the plan of mining engineering to facilitate the inquiry and analysis of the prediction results (Fig. 5).
5. Risk prediction and analysis of rock burst in panels

5.1. Comprehensive index method of rock burst risk

The Coal Mine Safety Regulations in China (2016 edition) stipulates that regional and local risk prediction must be carried out in rock burst mines. According to the geological and mining conditions, the regional and local prediction can give priority to the comprehensive index method to determine the rock burst risk. The comprehensive index of rock burst risk assessment is calculated by the following formula:

\[ W_t = \max\{W_{t1}, W_{t2}\} \]  

where \( W_t \) is the comprehensive index of rock burst risk; \( W_{t1} \) is the index of geological factors; \( W_{t2} \) is the index of mining factors.

- The risk index (\( W_{t1} \)) of geological factors in panel 9102 in west mining area is 0.62, and the danger grade is "C", which belongs to medium rockburst dangerous zone.
- The risk index (\( W_{t2} \)) of mining factors in panel 9102 in west mining area is 0.33, and the danger grade is "D", which belongs to the weak rockburst dangerous zone.

Combining the influencing degree of geological and mining factors in panel 9102 in west mining area of No. 9 coal seam and the index of rock burst dangerous grade, the evaluation result of rock burst danger of this working face is evaluated as 0.62. And the dangerous grade is "C", which belongs to medium rockburst dangerous zone.

5.2. Multi-factor pattern recognition and prediction analysis of rock burst risk

Based on the regional prediction of rock burst risk in Jixian Coal Mine, the risk probability of any mining area or working face or location in the mine field can be obtained. The predicted probability value of rock burst risk for panel 9102 in west mining area is shown in Fig. 6.
As shown in Fig. 6, the panel 9102 in west mining area is divided into 12 cells according to 100 m ×100 m per cell. There are 10 cells with risk probability of 0.66, accounting for 83.33% of the predicted region. Most areas of the panel have medium rock burst danger. Only 2 cells are with risk probability of 0.76, accounting for 16.67% of the predicted region. The area from the middle position of conveyance road in the panel 9102 to the open-off cut is in strong rock burst dangerous zone.

5.3. Contrastive analysis of rock burst risk

The risk prediction of rock burst by comprehensive index of panel 9102 in Jixian Coal Mine is 0.62, which is of medium dangerous. The probability prediction results of multi-factor pattern recognition are 0.66 and 0.76, indicating the multi-factor pattern recognition method improves the accuracy and precision. Multi-factor pattern recognition prediction can divide the predicted panel into several prediction cells, and can obtain the probability value of each cell. When roadway tunneling or mining face enters different prediction cells, the danger of the location can be predetermined, and the corresponding control measures can be taken in advance. It promotes the development of rock burst prediction in Jixian Coal Mine from “point, single-factor and qualitative prediction” to “regional, multi-factor and quantitative prediction”. It is suggested that prevention and control measures should be taken in the strong rock burst dangerous zone according to the results of the risk prediction in Jixian Coal Mine.

6. Conclusions

(1) The rock burst is influenced by multiple factors. Based on the established geological structure, the prediction model of rock burst risk is developed considering the mining depth, fault structure, stress and roof lithology.

(2) Using the probability prediction method by multi-factor pattern recognition, the rock burst risk is divided into four grades according to the probabilities of 0.25, 0.5 and 0.75. The probability prediction of rock burst risk promotes the development of rock burst prediction from point to regional prediction, from single factor to multi-factor prediction, and from qualitative to quantitative prediction.

(3) Based on the results of risk classification prediction of rock burst by multi-factor pattern recognition in Jixian Coal Mine, the danger at the engineering location can be determined in advance. When roadway driving or working face mining enters different prediction cells, and corresponding control measures can be taken to reduce the risk or avoid the occurrence of rock burst, and finally realizes mine safety production.

(4) The comprehensive index of rock burst risk of panel 9102 in Jixian Coal Mine is 0.62, which is evaluated as medium risk. The probability prediction results of multi-factor pattern recognition are 0.66 and 0.76. The multi-factor pattern recognition method improves the accuracy and precision of prediction. It is suggested that prevention and control measures should be taken in the strong rock burst dangerous zone according to the results of the risk prediction in Jixian Coal Mine.
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