Study on monitoring and analysis of rock dynamic disaster based on multi-parameter coupling

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Abstract. The problems of ground pressure appeared in a deep gold mine, so a microseismic monitoring system was established. In order to break through the bottleneck of independence among microseismic monitoring, rock mechanics parameters, stress and strain monitoring, to realize information fusion of multiple parameters under time synchronization, and to improve the reliability of analysis results, especially early warning, firstly, the temporal and spatial evolution of microseismic events such as magnitude-frequency, volume potential-frequency and energy-frequency were analyzed, secondly, the relationship between microseismic events and rock mechanics parameters was constructed, thirdly, the multiple parameters such as microseism, stress and strain were mutually analyzed, finally, the mining disturbance parameters and the overall trend of mine dynamic disaster were analyzed. The results show that the combination of microseismic monitoring in a wide area and stress-strain monitoring in a key area can realize the mutual identification and verification of the parameters, and greatly improve the reliability of the overall trend analysis of rock dynamic disasters. The overall trend analysis method of rock dynamic disasters based on multi-parameter coupling is worth popularizing.

1. Introduction
At present, the dynamic disasters of mine rock occur frequently in China, which cause many production accidents and seriously threaten the lives and property safety. Therefore, the analysis of rock dynamic monitoring data and the timeliness, accuracy and effectiveness of the analysis are very important. Although there are many monitoring methods for dynamic disaster of rock, the parameters obtained by various monitoring methods are often collected independently. It is difficult to achieve synchronous collection of multiple parameters, let alone to analyse comprehensively after full integration. The reliability and accuracy of monitoring and early warning of dynamic disasters such as rock burst cannot be achieved by single parameter analysis, so it is very urgent to carry out the monitoring analysis of dynamic disasters in rock mass based on multi-parameter coupling[1].

A gold mine belongs to deep mine, the depth of development has reached more than kilometers, the problems of ground pressure have gradually appeared. Small rock dynamic disasters such as pillar spalling and roof fall occur frequently, which pose an growing potential threat to the safety of production. At present, the mine is mainly exploited in the west, with large mining disturbance, but the stress in the east is relatively concentrated, and there are risk inducing factors such as rock burst, gas outburst, rib spalling and roof fall on both sides. Therefore, based on the combination of microseismic monitoring system for wide area and stress and strain monitoring system for key areas such as stope, a demonstration project of dynamic disaster analysis and early warning which used the method of multi-parameter coupling was established, the multiple parameters obtained were deeply analyzed, the trend evaluation and early warning were carried out, in order to grasp the law of ground pressure disasters,
and provide technical support for mine safety production. The following focuses on the data analysis process.

2. Study on the temporal and spatial evolution of microseismic event set
The rock mass has the self-organized critical characteristics. Under the constant disturbance of manual excavation, the rock mass always changes from one metastable state to another. In this process, through deformation, destruction, release of energy, it reaches a kind of self-adjustment. The characteristics of this change are not only reflected in the magnitude-frequency, but also volume potential-frequency and energy-frequency. The Gutenberg Richter relation quantifies the response characteristics of rock mass to mining activities, and can be used to statistically analyse the microseismic disasters. Based on the modified Gutenberg Richter relationship and the calculation of the parameters for single microseismic event, the relationships between magnitude and frequency, energy and frequency, volume potential and frequency were analyzed[2][5].

2.1. Calculation of source parameters of single microseismic event
To describe a microseismic event quantitatively, at least two independent parameters, which are related to the source and can be determined reliably, are needed besides time and location coordinates. They are the microseismic volume potential P and radiated release energy E.

By using the method of analysing source spectrum parameters and calculating seismic parameters, the parameters of microseismic event, such as magnitude, 3D positioning coordinate, angular frequency, quality factor, seismic moment and energy, were obtained[2].

2.2. Analysis of the relationship between magnitude and frequency
Figure 1. The relation between magnitude and frequency
Figure 1 shows the distribution of magnitude and frequency. The left ordinate is the cumulative number of events, the right ordinate is the recurrence period of microseismic events, and the abscissa is the magnitude. It can be seen from the figure that the linear characteristic of the first half is not obvious, and the second half is almost a straight line, and the negative number of its slope is the power exponent. The relationship between magnitude and frequency shows that there is a power-law relationship between them, the magnitude is inversely related to its frequency of occurrence. The negative number of the slope of the straight line in the figure is generally called b value. The change of B value reflects the adjustment of the internal structure of the microseismic event set, which shows the change of the proportion between the number of large events and small events. It can be understood in such a narrow sense that a decrease in the b value indicates an increase in the number of large events, whereas a decrease in the b value indicates an increase in the number of large events, the b value
before the earthquake is lower than that of the aftershock, so the b value can be used as a sign to identify the foreshock[3][5].

Figure 2 shows the change curve of b value in three consecutive months. The curve rises first and then declines, with a larger decline than the rise. The decline of b value means that the non-uniformity of rock stress increases, the stress increases, the rigidity of surrounding rock decreases, and the safety risk of the mine increases[5].

2.3. Analysis of the relationship between volume potential and frequency

Figure 4 shows the curve of β value in a period of time. The value first declines and then rises, which is opposite to the change curve of B value in Figure 2. However, the two reflect the same dynamic state of rock mass, indicating the increase of large magnitude events, that is, the rock mass is in the softening stage, the inelastic deformation increases, and the system releases too much energy, which means the risk of disasters increases[5].
2.4. Analysis of the relationship between energy and frequency

Figure 4. The curve of $\beta$ value

Figure 5. The relationship between energy and frequency

Figure 6. The curve of $\beta$ value
The trend of curve in July, August and September in 2013 is basically the same. The increase of $\beta$ value means that the number of events releasing more energy increases, and also means that the rock mass tends to be non-uniform, the rigidity decreases, and the potential safety risk increases[5].

3. Relationship between microseismic events and rock mechanics parameters
The rheological properties of rock refer to creep, stress relaxation, time-dependent dilatancy and time effect of strength. By studying them, long-term stability of rock and many important problems in seismology can be analyzed.

The 3D coordinates, time of occurrence, energy, magnitude and other information of the source can be obtained from the seismic waveform monitored by microseisms. If the microseismic events are considered to occur in a certain volume within the $\Delta t$ time, the following parameters can also be defined: the time between the viscosity and relaxation, the diffusion and the number of Schmidt.

Figure 7 shows the response process of a microseismic activity with $m$ 2.1 caused by blasting. Within a few hours before the microseismic event, the number of schmidts decreased significantly, while the cumulative apparent volume increased sharply.

![Figure 7. The curve of Schmidt number and cumulative apparent volume](image)

4. Joint analysis of microseism, stress and strain
A stope had completed the mining of it’s room, forming a $7 \times 10^4$ m$^3$ empty area, leaving 104 thousand tons of high-grade pillars, which were in urgent need of recycling, but the ground pressure activities were relatively frequent. In this mine, a ground pressure monitoring system was set up, which used microseism, stress, strain and other monitoring means to carry out multi-parameter analysis of dynamic disasters.

4.1. The spatio-temporal analysis of microseismic events
Figure 9 shows the spatial distribution of microseismic events. There are four concentration areas of microseismic events. No.1 area is located in the northeast of the test panel, which is caused by the blasting operation in the production stope, with the largest number. The roofs of No.2 and No.3 area are relatively broken, resulting in more microseismic events. No.4 area is caused by 1 and 2 pillars cutting in the test panel, which is small in number and magnitude, indicating that the roof is relatively stable.
4.2. Stress analysis

Figure 10 is the stress distribution of microseismic events for one month. It can be seen that the stress in the south of the test panel is relatively concentrated, and the stress value is about 10 KPa. The concrete stress of 1 # pillar and the drilling stress of 5 # pillar have obviously changed, which shows that the stress of 1 # pillar and 2 # pillar is transferred to 1 # pillar and 5 # pillar after cutting the roof. After the concrete stress and drilling stress increase to 14 KPa, they tend to be stable, basically consistent with the stress value predicted by microseismic monitoring analysis, as shown in Figure 11 and Figure 12.
4.3. Strain analysis

Figure 13 is the strain distribution of microseismic events in a period of time. The overall deformation is small, and the strain value is about $10^{-6}$. The deformation in the northeast of the test panel area is relatively large, which is closely related to the blasting operation in the production stope near the area. There are significant changes in the concrete strain and roof displacement of 1# pillar. After the roof displacement decreases by 1.2mm, it tends to be stable. After the concrete strain increases to $3.2 \times 10^{-6}$, it tends to be stable, which is basically consistent with the strain value calculated by microseismic monitoring, as shown in Figure 14 and Figure 15.
The microseismic monitoring can obtain the key areas with obvious stress concentration and deformation as a whole, and the parameters of stress, strain and displacement in these areas also confirm the results of microseismic monitoring. The parameters are confirmed by each other, which is basically consistent with the actual results in the field. In general, the multi-parameter analysis gets a more reliable conclusion and has a good effect. At present, the roof of the test panel has become stable, and the next work can be continued.

5. Correlation analysis of mining disturbance and rock dynamic disaster

In order to study the relationship between mining disturbance and microseismic activity, cumulative seismic apparent volume ($\Sigma VA$) and energy index (EI) are used to compare the response characteristics of seismic activity and mining in different periods of time, and the time history curves of cumulative excavation volume and cumulative seismic apparent volume are established to study the relationship between mining rate and microseismic strain rate. From the point of view of energy storage and release, the relationship between energy storage and release of rock mass expressed by cumulative seismic apparent volume ($\Sigma VA$) and production excavation volume ($\Sigma VM$) is studied, and its variation characteristics with mining rate are studied. Thus, the microseismic activity response coefficient CSR is proposed to represent the response relationship between seismic activity and mining rate, which is used to provide theoretical basis and technical guidance for daily monitoring analysis and mine production planning[4].

5.1. Analysis of the relationship between production and seismic apparent volume

Figure 16 shows that cumulative apparent volume $\Sigma VA$ and energy index EI have obvious correlation with mining activities. The slope of cumulative apparent volume $\Sigma VA$ reflects the speed of
microseismic strain, i.e. the size of strain rate, while the slope of cumulative mining volume $\Sigma VM$ reflects the size of mining rate. Therefore, microseismic strain rate and mine production rate have correlation.

5.2. *Analysis of the relationship between mining volume and microseismic response coefficient*

![Figure 17. The relation curve between mining volume and CSR](image)

The response sensitivity of rock mass to microseismic activity can be reflected by microseismic activity response coefficient (CSR). If CSR increases, the response of rock mass is sensitive, and a small amount of mining will lead to a large microseismic activity. From the point of view of system stability, when CSR increases, the system tends to be unstable; when CSR remains unchanged or decreases, the system tends to be stable[4].

6. Conclusion

The research results of the project have been tested in a typical deep gold mine, the demonstration project of dynamic disaster analysis and early warning based on multi-parameter coupling has been established. At present, there are many difficulties in the monitoring and early warning of mine dynamic disaster, such as the isolation of microseismic events analysis and conventional rock mechanics analysis, the independence of analysis and early warning between microseismic parameters and stress-strain parameters, the quantitative analysis method of mine disturbance intensity. This research broke through the bottleneck of independent microseismic monitoring and rock mechanics monitoring, realized the multi-parameter joint analysis under time synchronization and digital analog conversion synchronization, and quantitatively analyzed the disturbance intensity of mining, integrated the multi-parameter monitoring analysis and early warning, greatly improved the accuracy and reliability of monitoring and early warning for mine dynamic disasters.

Acknowledgments

This research was financially supported by the National Key Research and Development Project of China (2017YFC0602904).

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