Research on the Application of Acoustic Emission Intelligent Monitoring and Early Warning Technology for the Coal-rock Dynamic Disasters in Underground Mining Faces

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Abstract. Under the conditions of deep mining, it is difficult to predict the occurrence of coal-rock dynamic disasters accurately. The acoustic emission monitoring technology and equipment can realize the advanced monitoring and early warning for coal-rock dynamic disasters in deep mines, effectively make up for the problems such as single index of the dynamic disasters risk determination, low accuracy of early warning. And it can provide a basis for the prevention and control of coal-rock dynamic disasters such as coal and gas outburst, effectively assist the safe and efficient mining of the mines, and is the non-contact continuous prediction technology and equipment urgently needed for the safe and efficient production of the coal mines.

1. Introduction

With the coal mines gradual extension to the deep in China, under the deep mining conditions, the dynamic disasters such as coal and gas outburst, rock burst are becoming more and more serious, especially the occurrence frequency and disasters degree of coal-rock dynamic disasters dominated by ground stress will increase dramatically[1-3]. At present, the sensitivity of contact prediction indexes in mine depth mining conditions has changed greatly, the prediction accuracy is relatively reduced, and real-time continuous monitoring can not be achieved[4-5]. Therefore, there is an urgent need to find a non-contact continuous prediction technology that can make real-time, intelligent and accurate prediction for coal-rock dynamic disasters under the conditions of deep mining. The acoustic emission prediction technology for coal-rock dynamic disasters[1-13] is a non-contact continuous prediction technology with wide application prospect, which can realize the real-time continuous monitoring and early warning for the dynamic disasters, without the need for manual field testing, especially suitable for the monitoring and early warning for coal-rock dynamic disasters dominated by ground stress.

Through years of research and development by China Coal Technology Engineering Group Chongqing Research Institute, a set of acoustic emission intelligent monitoring and early warning technology and system for mine coal-rock dynamic disasters has been formed, which can achieve
advance monitoring and early warning for the coal-rock dynamic disasters in the deep mining work surfaces, and improve the accuracy of early warning for dynamic disasters and the safety of mines.

2. Acoustic emission intelligent real-time monitoring system

The acoustic emission intelligent real-time monitoring system named YSFS (A) for mine dynamic disasters (as shown in figure 1), independently developed by China Coal Technology Engineering Group Chongqing Research Institute, is a multi-channel parallel intelligent real-time monitoring and early warning system that the surface and the underground intersect each other, which is mainly composed of underground acoustic emission monitoring host, power supply, serial sensors, special signal shielded cables and ground real-time processing analysis software.

The system processes the massive acoustic emission signals collected by the acoustic emission sensors in situ by the underground acoustic emission monitoring host, and then the processing results are transmitted to the upper computer on the ground through the safety monitoring industrial network, so as to realize the real-time and advanced monitoring and early warning for the coal-rock dynamic disasters in the working face, effectively overcoming the shortcomings of the traditional prediction methods, such as point prediction, large quantities of work, and many human factors. It has the advantages of high accuracy of disaster prediction, wide field application experience, strong underground applicability, high degree of automation, low cost of use and maintenance.

The technology and system are mainly used for monitoring and warning for coal and gas outburst, rock burst and other mine dynamic disasters, and also for monitoring the stability of roadways, tunnels and geotechnical slopes.

![Figure 1. Schematic diagram of acoustic emission monitoring system named YSFS(A)](image)

The main technical parameters of the acoustic emission monitoring system are as follows.

(1) Underground monitoring host

The underground monitoring host realizes multi-channel parallel signal acquisition, data pre-processing, communication, working status display and alarm, etc.

a) Working voltage: 660 V,
b) Monitoring host capacity: 8-channel acoustic emission signals and 4-channel analog signals (such as gas, stress, etc.) are collected synchronously in parallel,
c) Sampling rate: up to 51.2 kS/s per channel, optional,
d) Sampling accuracy: 24 bit,
e) Real time data analysis speed: FPGA hardware level high-speed data processing,
f) Explosion proof type: mine intrinsic safety type.

(2) A series of acoustic emission sensors

a) Installation mode: according to different monitoring environment, there are various installation modes such as waveguide installation and hole bottom installation,
b) Working voltage: 12~18 V,
c) Working current: ≤ 70 mA,
d) Measurement range: 0~1 g,
e) Output range: 1~5 mA,
f) Band width: 0~3000 Hz,
g) Effective transmission distance from signal to monitoring host: no less than 2 km.

(3) Ground real-time processing analysis software

a) The system realizes the all-weather real-time monitoring and early warning of coal-rock dynamic disasters with multi-channel parallel intersection between the ground and the underground.
b) The full waveform, characteristic parameters and alarm results of the signals collected by all channels are dynamically displayed and stored on the ground upper computer in real time.
c) The instruction configuration for monitoring host is remotely carried out, including attribute setting, data export and different signal acquisition mode settings.
d) The independent database is owned, which can be used for data query and report printing.

3. Acoustic emission monitoring method and technology

3.1. Monitoring method
Through the installation of acoustic emission sensors in advance, the acoustic emission monitoring system is used to continuously monitor the work face, real-time collect and analyse the acoustic emission signals inside the coal and rock mass, to obtain the change rule, trend and disaster precursor characteristics of the acoustic emission indexes, and continuous monitoring and real-time early warning for the coal-rock dynamic disasters in the work face.

3.2. Installation technology of acoustic emission sensors
The installation effect of acoustic emission sensors directly affects the ability of receiving acoustic emission signals and the effect of noise barrier. According to different monitoring objects and monitoring environment, the sensors can be installed in the way of waveguide installation and hole bottom installation. The waveguide installation method is to use the guided wave function of waveguide, fix the inner end with the coal and rock mass at the bottom of the hole through the elastic materials after solidification, install the acoustic emission sensors at the outer end, and transmit the signals to the sensors through waveguide. The waveguide installation method is convenient and recyclable, which is suitable for use in the space environment with less noise interference from external operation, as shown in figure 2. For the hole bottom installation method, the acoustic emission sensors are coupling installed in the coal and rock mass at the hole bottom through constructing a certain depth of drilling by cement mortar, and the noise isolation treatment of the hole opening can largely isolate the external interference noise. The hole bottom installation method has the advantages of strong signal receiving ability and strong anti-interference ability, as shown in figure 3.

(1) For the longwall working face: one acoustic emission sensor should be respectively installed in advance at the place 50 m away from the front of the working face in the machine roadway and wind.
roadway of the working face, and the acoustic emission sensors should be installed in advance with the mining of the working face in a monitoring cycle of 30 m.

(2) For the excavation working face: one acoustic emission sensor should be installed in advance in front of the working face. With the excavation of the working face, the acoustic emission sensors should be installed in advance in a monitoring cycle of 20~30 m.

3.3. The acoustic emission monitoring and early warning indexes
The acoustic emission signal is a kind of pulse waveform signal with many characteristic parameters, such as ring count, energy, amplitude, signal duration, etc. Through a large number of field application research, it is found that the combination of acoustic emission ring count and energy two characteristic parameters can effectively predict the coal-rock dynamic disasters in the working face. The activity of coal and rock in working face can be analysed by the change of ring count, and the energy release in the process of coal and rock mass activity can be analysed by the change of energy index.

4. Application effect
4.1. Application of coal and gas outburst monitoring and early warning in longwall mining face

Figure 4. Evolution curve of acoustic emission characteristic parameters before and after a disaster in F15-24080 working face

The application of acoustic emission monitoring and early warning for coal and gas outburst was carried out in F15-24080 working face. The buried depth of the working face was 631~900 m. And the main mining coal seam F15 belonged to outburst coal seam. The working face had the characteristics of large mining depth, high gas, high ground stress, complex geological structure, etc., and the conventional outburst risk prediction indexes $q$ value of initial velocity of gas emission from borehole and $S$ value of cuttings amount adopted were not sensitive to the dynamic phenomena, which could no reflect the outburst risk in front of the working face timely, accurately and reliably.

The acoustic emission sensors were installed in front of the working face to monitor the mining operation. Since the acoustic emission monitoring system had been built and operated in the F15-24080 working face, it had successfully monitored and forewarned the multiple coal-rock extrusion dominated by stress accompanied by gas emission greatly exceeding the limit in the working face. After the disasters occurred, the different degrees of coal-rock extrusion outward displacement, splitting, rib spalling and bottom bulge happened accompanied by gas emission exceeding the limit.

The change curve of acoustic emission characteristic parameters before and after a disaster is shown in figure 4. It can be seen that before the dynamic disaster occurred, the two acoustic emission characteristic parameter indexes fluctuated significantly, the values of the two indexes were significantly higher than the level under normal conditions, and the overall trend was gradually increasing, and the dynamic disaster occurred in the decline stage of the overall evolution curve of the acoustic emission indexes. In the real-time monitoring process, the acoustic emission monitoring system had successfully captured the precursor information of the disaster in advance, and reflected
and warned the possible coal-rock dynamic disaster dominated by ground stress in the working face about one shift in advance, while the conventional prediction indexes \( q \) (max. 1.7 L/min) and \( S \) (max. 3.5 kg/m) of the working face in this work cycle did not exceed the standard values, and the gas emission was relatively stable without obvious abnormality. Therefore, it can be seen that in the process of real-time monitoring, acoustic emission monitoring system can well catch the abnormal precursory information in front of the working face, reflect and warn the possible abnormal situation in the working face in advance, and the sensitivity of indexes is obviously better than the traditional prediction indexes, which greatly improves the accuracy of disaster prediction.

Therefore, the early warning signal sent by the acoustic emission monitoring system provides a strong basis for the prevention and control measures of the coal-rock dynamic disasters dominated by stress in the working face, and effectively makes up for the shortage of the disaster prediction methods. When the acoustic emission monitoring system send out the disaster warning information, the hidden danger of outburst in the F15-24080 working face were eliminated in time by taking the measures of deep hole blasting, advanced gas discharge, water injection and so on, and no more coal-rock dynamic disasters such as coal and gas outburst occurred in the working face, the safe and efficient production of the working face was achieved.

4.2. Application of coal and gas outburst monitoring and early warning in excavation mining face

Acoustic emission continuous monitoring and early warning of coal and gas outburst risk was carried out during excavation by blasting technology in X10903 the machine roadway. It is estimated that the 9# coal seam will be exposed after 211 m excavation. The 9# coal seam belongs to coal and gas outburst coal seam. There was a great danger of outburst in the process of exposing 9# coal seam in the x10903 excavation working face. Therefore, the acoustic emission technology and system were used to monitor and warn the risk of coal and gas outburst during the excavation of X10903 machine roadway, in order to ensure the operation safety during the coal uncovering.

Through the acoustic emission sensors were installed in front of the excavation face of x10903 machine roadway from X105 gas drainage floor roadway with a vertical depth of 30~40 m under X10903 machine roadway, the whole process of excavation operation was continuously monitored and the change rule by the acoustic emission monitoring system. The change curve of acoustic emission characteristic parameters before and after the coal uncovering operation is shown in figure 5. It can be seen that during the coal uncovering operation, the size and trend of acoustic emission parameters had obvious changes, generally showing a trend of "up-peak-down". Before the coal uncovering, the acoustic emission parameters gradually reached the peak value. As the coal seam was exposed, the stress was gradually released, and the acoustic emission characteristic parameters gradually declined, gradually tended to be stable. During the coal uncovering period, the conventional prediction indexes such as \( K_1 \) value of gas desorption index and \( S \) value of cuttings amount did not exceed the standard and not changed greatly, and the working face did not have any abnormal situation.

![Figure 5. The change curve of acoustic emission characteristic parameters during coal uncovering in X10903 machine roadway](image)
Therefore, the acoustic emission indexes can not only reflect the whole process of stress evolution before and after coal uncovering, but also reflect the disaster risk better than the conventional prediction indexes. The acoustic emission technology and equipment can be applied to monitor and early warn for coal and gas outburst risk in the process of coal uncovering in the excavation working face, which can provide an effective technical guarantee for the safe excavation of the working face.

5. Conclusion
(1) Acoustic emission intelligent monitoring and early warning technology and system for coal-rock dynamic disasters can realize the advanced monitoring and early warning for coal-rock dynamic disasters in deep mine, and provide effective advanced technology and equipment for monitoring and early warning for coal-rock dynamic disasters under the deep mining conditions.

(2) Acoustic emission technology can catch the precursory information of coal-rock dynamic disasters in the working face in advance, and can effectively make up for the defects of the traditional prediction indexes which are relatively insensitive under the deep mining conditions, reduce the quantities and costs of drilling construction by the traditional prediction method, reduce the human measurement error, and improve the accuracy and reliability of disasters early warning.

(3) Acoustic emission technology and system can provide a very clear and intuitive early warning signal for the prevention and control of dynamic disasters in the field mining faces, provide a basis for the prevention and control of coal-rock dynamic disasters such as coal and gas outburst, greatly conducive to take measures to eliminate hidden dangers in advance, effectively assist the safe and efficient mining of the mines, which is the non-contact continuous prediction technology and equipment urgently needed for the safe and efficient production of the coal mines.

Acknowledgments
This work was financially supported by the National Science and Technology Major Project of China (2016ZX05045-004), National Key Research and Development Project of China (2018YFC0808001).

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