

Application Study on Microseismic Monitoring System in Underground Mine

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Abstract: Mine disasters can cause injuries and economic losses during coal mining operations and are a primary focus of mine disaster monitoring. In recent years, an underground microseismic monitoring system capable of real-time 3D positioning has been developed internationally. This system enables long-term, continuous, and dynamic monitoring of rock layer fractures and movements, allowing for the prediction and early warning of major mine hazards such as roof collapse, mine water inrush, coal and gas outbursts, and rockburst. One of the key challenges in implementing underground microseismic monitoring is the deployment and installation of borehole sensors. To accurately position and secure sensors in the borehole wall, the "anchor claw" installation technique is employed. As long as the claw structure is rationally designed and provides sufficient support, the construction results are highly effective. Analysis of typical microseismic events demonstrates that microseismic monitoring can determine the epicenter location, reflect rock layer fractures and movements, and reveal the characteristics and patterns of collapsed zones and fracture zones. The application of underground microseismic monitoring systems reduces costs, enhances monitoring accuracy, and provides valuable guidance for roadway design, support systems, and coal mine safety production..

Keywords: microseism; monitoring; sensor; coal mine safety

1 Introduction

In china ,The mining has the most important status in the development of national economy, and the coal industry is the most important status in countrywide mining. It is the most important factor which affects national economy and society stabilization because the 70% of energy sources is the coal in China. Now, the detected coal reserve is 9000 a hundred million ton in china which can be explored 600 years[1-3].Hence, the coal is a long-term energy sources in China, the coal industry is always the mainstay industry whether now or future, so the safe and effective well mining coal is a great thing for the national economy and the people's livelihood.

However, the mortality rate in China's coal mining process is several tens of times higher than the average abroad. According to relevant data, there are nearly 10000 casualties in mines nationwide every year. With the increase of mining depth, the threats to coal mine safety production such as gas outburst, mine water inrush, coal mine fire, roadway instability, and rockburst are becoming increasingly serious. They not only cause huge pain to the people, but also cause huge losses to national property. This is the main direction of mine disaster monitoring and control. However, in the past, there were relatively few monitoring methods for coal mine disasters, especially high-tech modern monitoring methods, which actually posed a major task for coal mine safety monitoring[4-6]. In order to solve these difficulties, there are increasingly more methods for studying and predicting changes in the spatial stress field around coal mine tunnels, predicting and forecasting impact ground pressure, measuring overburden movement and two zone height, especially using geophysical methods for research. These methods mainly include microseismic method, acoustic emission method, electromagnetic radiation method, vibration method, gravity method, etc. Among

them, microseismic positioning and monitoring technology is a new technology that can reflect a series of dynamic evolution processes such as stress, strain, cracking, instability and failure of coal mine tunnel surrounding rock. Based on this technology, a comprehensive description of rock movement and failure laws in 4D space has been achieved[9-10].

2 Current Research and Application Status of Microseismic Monitoring Technology at Home and Abroad

The US Bureau of Mines began proposing the application of microseismic methods to detect rockburst that causes serious harm to underground mines in the 1940s[11-12]. However, due to the high cost and low accuracy of the required instruments, as well as unclear monitoring results, it did not receive sufficient attention and promotion. Until the past decade, the progress of geophysics, especially the application of digital earthquake monitoring technology, has provided the necessary technical foundation for the study of microseismicity in small areas with weak signals[13-14]. Recently, research institutions and universities of some foreign companies have collaborated to conduct major engineering application experiments in order to verify and develop the enormous potential of microseismic monitoring technology in underground rock engineering, such as geothermal hydraulic fracturing, reservoir dams, petroleum, nuclear waste treatment, etc.

In 1997, a comprehensive and in-depth hydraulic fracturing microseismic imaging field experiment was conducted in Cotton Valley, eastern Texas, USA to verify the practical value of microseismic imaging technology. The experiment achieved great success, proving that microseismic imaging technology has high resolution, wide coverage, economic practicality, and strong operability compared to other technologies, and has great potential for development.

In the UK, Professor P. Young has been leading the Applied Seismology Laboratory (ASL) at KEELE University for the past decade, mainly engaged in fundamental research on microseismic applications in rock mechanics, divided into three directions: source mechanics, microseismic imaging, and rock mechanics. The main research objective is to reveal the mechanism of initial crystallization, coalescence, and propagation of cracks in rocks under changes in external conditions such as bearing capacity, temperature, and seepage pressure, and to study monitoring techniques for macroscopic damage and fracture of rocks.

To monitor the high stress concentration caused by deep excavation and prevent its harm, Atomic Energy Canada has adopted microseismic monitoring technology to quantitatively assess the degree of damage and monitor the possible pathways of radioactive nuclear fuel stored underground diffusing into surrounding groundwater to prevent pollution[15-17]. In order to ensure the stability of the underground structure for storing nuclear fuel, the research institution excavated an experimental tunnel with a diameter of 3.5m and a length of 46m at the -420m level for specialized research. The excavation surrounding rock is mainly low-permeability hard rock, and the main research topic is the columnar tunnel damage caused by the excavation of underground hard surrounding rock. In addition to traditional stress and strain monitoring, detailed microseismic monitoring was conducted, using 16 triaxial accelerometers distributed around the excavation to record and locate 10000 microseismic events over a period of one year. This is a huge research project that has resulted in many valuable research achievements. The key content is the distribution, energy levels, mechanisms, and relationship with rock deformation of microseismic events, and the establishment and analysis of mathematical models based on on-site measurement results.

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia has been studying microseismic phenomena induced by mining since 1992. After studying the microseismic activity of the Goldstone mine and several other mining areas in Queensland, it was found that during the continuous advancement of the coal mining face, the microseismic activity of the surrounding rock layers showed a regular pattern, indicating that the geological defects and faults of the surrounding rock layers would be activated by mining during the mining process, resulting in corresponding movements. This structural movement would affect the overall response, and microseismic activity would occur even hundreds of meters away from the working face. From August 1999 to June 2000, network monitoring was conducted on microseismicity caused by mining in the APPIN area. With the accumulation of experience and the improvement of technological means, it has been preliminarily proven that microseismicity can be observed near the site and can be quantitatively studied with relative accuracy. The good results achieved in microseismic research have provided a wealth of useful information for mining work, greatly stimulating the enthusiasm of mining companies to invest in such monitoring and research. So far, the Australian Institute of Scientific

and Industrial Research (CISRO) has completed microseismic monitoring experiments for 15 mines, accumulating a lot of on-site experience and laying a good foundation for the widespread development and further research of microseismic monitoring work.

In addition, significant achievements have been made in the research and application of microseismic monitoring technology in many countries such as Poland, South Africa, and India, each with its own advantages and characteristics.

The research on microseismic monitoring technology in China should be said to have started earlier. Around the 1960s, people began to study the principles and methods of microseismic monitoring technology, especially its positioning methods, which had calculation formulas. However, the specific implementation of microseismic monitoring requires precise and advanced instruments and equipment, which is only possible now when computer technology and electronic technology are highly developed[18-20].

Since the 1980s, some domestic units have hoped to use natural earthquake monitoring methods for microseismic monitoring, but in reality, they have not achieved good results. The use of natural earthquake monitoring methods for microseismic monitoring has the following limitations: firstly, there are few observation points, making it difficult to meet spatial positioning requirements; Secondly, the observation range is large and it is difficult or impossible to receive microseismic waves; Thirdly, the instruments, equipment, and interpretation methods cannot meet the requirements of microseismic monitoring.

Since 1996, the Shandong Coalfield Geological Bureau, Shandong Yanzhou Mining Group, and the Australian Federal Industrial Science Organization have collaborated on the Xinglongzhuang Coal Mine microseismic monitoring project, obtaining a large amount of data and effective results. At that time, instruments developed by the Australian Federal Industrial Science Organization were used[21-23]. The limitations of this project are: firstly, the instrument performance is relatively low, using a PC486 desktop computer and DOS operating system; Secondly, the monitoring device can only operate on the ground. Subsequently, in 2000, the Shandong Coalfield Geological Bureau independently developed and completed the "WDZ2000 microseismic monitoring instrument", which improved the instrument's performance and upgraded the computer and operating system[24-25]. This should be one of the earlier microseismic monitoring instruments developed in China, but the instrument can only work on the ground.

In the past two decades, with the application of microseismic monitoring technology, domestic enterprise groups and colleges have continuously carried out research and application work in coal mines, enriching the theoretical research and application achievements of microseismic monitoring technology. It can provide a new practical technology for coal mine safety monitoring by long-term, continuous, and dynamic monitoring of rock fractures and movements.

3 The basic principle and structure of the microseismic monitoring instrument

The microseismic monitoring instrument is special equipment, it is different from artificial seismic prospecting instrument because the microseismic monitoring instrument can not only determine and identify automatically signals but also accept and register continuously signals. In addition, it works long and continuously.

The basic principle of microseismic monitoring technology is that when underground rocks rupture or move due to human or natural factors, a weak seismic wave will be generated and propagate to the surrounding area. By using microseismic sensors set up in different directions in space, the arrival time, propagation direction and other information of these microseismic waves can be recorded. Then, various calculation methods can be used to determine the rock rupture point, that is, the location of the earthquake source.

Microseismic monitoring instruments can be applied to underground mine according to the features of underground mine in China[9-10]. The industrial control computers can be selected as the host computer because it is a small computer and it has the low power consumption and the advanced performance. The industrial control computer is equipped with Liquid Crystal Display(LCD), touching keyboard, CD-ROM and so on. Moreover, it is a enough space to fix other parts. The computer has all functions of the desk computer. The circuit boards of the multichannel preamplifier are devised and manufactured. In order to fix it easily, the size of the multichannel preamplifier is reduced largely for ensuring the performance. In addition, the data acquisition with the advanced performance is selected. The industrial control computer concludes consists of host computer, display, preamplifier board, and so on. It is fixed inside the explosion-proof case. The schematic sketch of the structure is Fig.1.

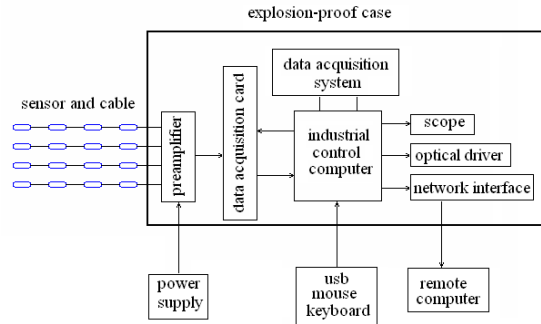


Fig.1 Schematic sketch of the structure for microseism mic monitoring instruments in underground mine

Explosion-proof case has the interface of cables, with which signal cables and computers are connected. The data communication between of microseismic monitoring instruments in underground mine and computers above ground is realized after computers are furnished with the special communication software.

Microseismic monitoring technology is the most effective means of monitoring rock mass fractures. When the underground rock mass fractures, microseismic monitoring instruments can receive and record the microseismic waves generated, and further determine the location of the earthquake source. Based on the monitoring results of underground microseismic events, various characteristics of rock mass fractures can be analyzed, such as quantity, frequency, strength, density, scale, and properties. Timely reports on underground rock mass fractures can be made, and precursors of mine disasters and accidents can be analyzed and predicted. Effective measures can be taken to avoid causing casualties or disasters. Therefore, microseismic monitoring instruments have important application value for coal mine safety. In the past, microseismic monitoring methods were outdated, with low accuracy and expensive instruments and equipment, which hindered the development of microseismic monitoring technology in terms of economy and technology. However, with the rapid development of modern technology, it has become a reality to develop new instruments, equipment, and software systems using today's high-tech technology.

4 The laying and fixing of sensors for microseismic monitoring in underground mine

Microseismic monitoring instruments in underground mine have been done microseismic monitoring tests for many coal mines. The layout map of monitoring systems for the coal mine is shown in Fig. 2. Monitoring systems are designed for the 107 working face. Two vertical bores for A and B are laid and drilled up in the laneway. The diameter of bores is 98mm, and the height of bores is 40mm, and the distance of A bore and B bore is 200mm. The two bores are laid in a side of the working face according to local conditions. In fact, 3 or 4 vertical bores are laid in two sides of the working face if there are allowable conditions in order to enhance monitoring effects. Each bore is fixed three three-component sensors, the vertical distance of them is 20m, and one of them is fixed in the mouth of a well. Two bunch of laneway sensors are laid in the laneway wall in order to enhance monitoring effects and reliability, each every bunch is fixed five sensors, the distance of sensors is 50m, and laneway sensors are fixed in the laneway wall. The plane positions of bores and laneway sensors are figure 2. The schematic sketch of bored and fixed sensors is figure 3.

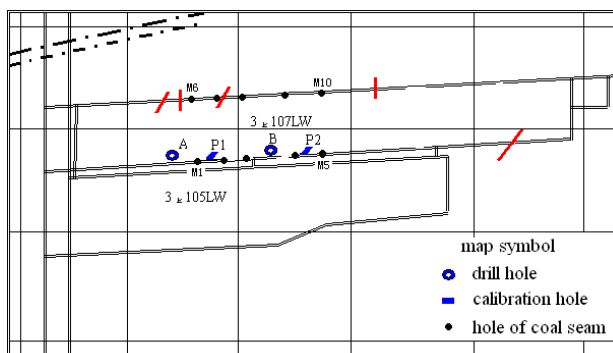


Fig.2 The plane layout sketch of bores and laneway sensors

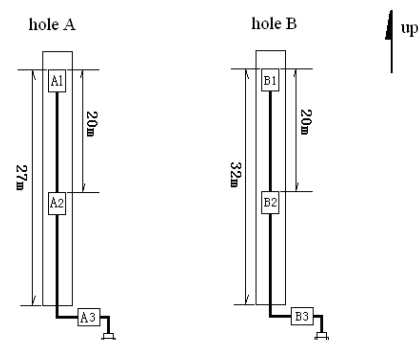


Fig.3 The schematic sketch of bored and fixed sensors

To determine the orientation of the sensor, a certain number of calibrated boreholes need to be constructed during

the monitoring process, in which explosives are placed and artificially excited to simulate the generation of seismic waves. Then, relative to the known source position, calculate the propagation direction of the wave, and further calibrate and calculate the sensor orientation based on the component values received by each sensor.

The calibration hole should be an inclined hole, and the final hole position should be near the longitudinal centerline of the working face, with the vertical position preferably reaching at least 20m above the coal seam. For the convenience of construction, the calibration drilling is carried out in the track groove construction. According to the monitoring of the dip angle of the coal seam in the working face, the calibrated borehole can be aligned with the vertical track groove. Considering the potential difficulties in calibrating hole construction and blasting, the specific implementation plan can be adjusted appropriately.

The difficulty for the construction of microseismic monitoring instruments in underground mine is the fixing of bore sensors. There are two difficulties for the fixing of sensors, one is that sensors are fixed up in accurate places, and the other is that sensors must be fixed and linked up in the wall of wells. The fixation of sensors have had studied and tried many methods, for example, elasticity support device, oil pressure support device, injecting cement device and so on. These methods can be used, but these are some problems, the most is the difficulty of setting, hence there must be search the fixation of sensors continuously.

The “flukes” fixing technique is used in order to set sensors to accurate places. First, “flukes” are set and fixed on top of bores by boring rob, and then cables and sensors are drawn in boring by draglines. Cables and draglines have signs of sizes in order to ascertain accurate places. There are tow conditions for “flukes”, one is that “flukes” must have enough supporting power in order to stop cables and sensors from sliding down, and the other is the configuration of “flukes” must be reasonable in order to fix “flukes” easily. These problems are solved preferably by trial and error.

5 The analyses of representative events for microseismic monitoring in underground mine

The matter of microseism events is a stress, strain, distortion, crazing, no stability, the breakage mode of stress and the breakage scope of stress for wall rock, hence, it has unique advantage than traditional method. The most basis of the microseismic monitoring is signal waveforms of microseism events which are noted by sensors, and these waveforms have hypocenters of new microseism events and status messages of near rocks. The most matter of the microseismic monitoring abstract useful information from signal waveforms, and these information are expressed by some quantificational parameters in order to apply to projects[5].

Figure 4 is the records of representative microseism events by a sensor. It represents a breaking and moving case of rock in underground. The time is also different When waveforms of microseismic monitoring get because the distance between places of rock breaking and sensors is different, moreover the difference of the time can be reflected by event records and identified by computers and men, so the places of hypocenter can be ascertained.

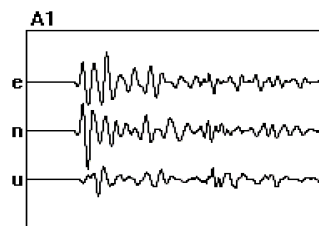


Fig. 4 The records of representative microseism events by a sensor

After the coal seam is mined out, the underground stress field loses balance and undergoes changes. According to current theoretical views, the stress distribution caused by coal mining is mainly concentrated in front of the mining line of the mining face, near the roof and floor of the coal seam. Figure 5 shows some analysis results based on the relative positions of microseismic events, which have certain significance for guiding mining design and safety production.

After the underground stress field changes, two types of fractures will occur in the coal seam roof. One is tensile fracture, which is characterized by the absence of compressive force between the strata on both sides of the fracture; Another type is shear fracture, where the strata on both sides of the fracture are compressed by each other, resulting in fragmentation and displacement. The strata in front of the mining face are mainly subjected to shear forces, resulting

in shear fractures; Behind the coal mining face, due to the temporary suspended state of the coal seam roof, it will naturally fall under the action of gravity, resulting in mainly tensile fractures. The seismic wave energy generated by tensile faults is much smaller than that of shear faults, so microseismic events mainly reflect the shear faults of coal seam roof or floor.

Based on the analysis of coal mining progress and the number and time of microseismic events, the working face compaction period can be determined, which has important guiding significance for roadway design and support. In general, this analysis requires a large number of microseismic events as the basis, and conclusions drawn when there are few events may not be accurate.

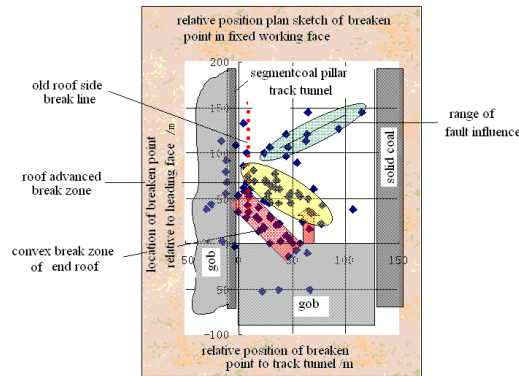


Fig.5 The analytical sketch of relative places for events

Figure 6 is a projection of the location profile of microseismic events along the direction of the coal seam. According to the figure, the height of the rupture zone is about 40-45m, which reflects the maximum height of rock rupture above the coal seam. Based on microseismic monitoring records and their positioning information, some important features can be summarized, which can provide important references for the application of microseismic monitoring results.

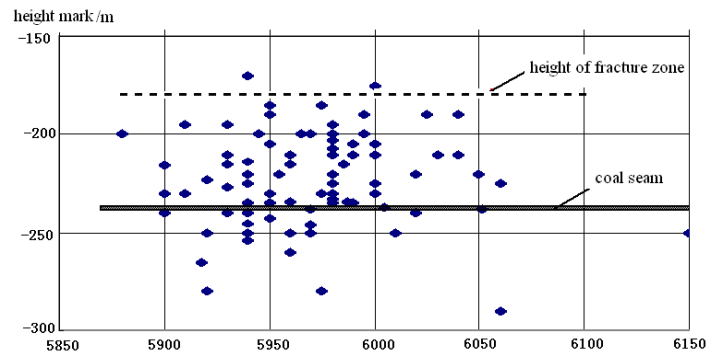


Fig.6 The section sketch for places of microseismic events

Microseismic monitoring technology can also reveal the characteristics and laws of the development of caving and fracture zones, and further study the impact of the two zones on mining. Of course, this requires more issues, such as studying the problem of surface water discharge, which needs to involve the thickness of surface plastic strata, the thickness of aquifers, the height of caving and fracture zones, and other issues. In addition, the height of microseismic events generally corresponds to the height of the fracture zone, but it may not necessarily be the height of the water conducting fracture zone. Based on the characteristics of microseismic events, the event intensive zone is generally defined as the water conducting fracture zone.

Due to the differences in geological conditions in different regions, the development characteristics and patterns of microseismic events are not the same. Therefore, the heights and characteristics of the two zones in different regions are also not the same. This indicates the importance and necessity of conducting microseismic monitoring in different mining areas to study the development patterns of the two zones.

Another important application of microseismic monitoring is the ability to predict and forecast the likelihood of catastrophic accidents such as coal mine rockburst. Although this is a challenging topic, the development pattern of microseismic events should be an important precursor to the occurrence of rockburst. The use of microseismic

monitoring to predict and forecast coal mine rockburst still requires extensive research and experience accumulation.

6 Conclusion

Microseismic events are generated by the shear fracture of coal seam roof. Although Zhang type faults can also generate microseismic events, their energy is weak and difficult to locate. So, it can be considered that the vast majority of identified microseismic events correspond to shear fractures.

Due to the different degrees of crack development, especially the fact that the cracks generated by shear action are generally not all water conducting cracks, the crack zone can be divided into micro crack zones and water conducting crack zones. Water conducting cracks generally occur in areas with dense event distribution, and individual micro fractures above the dense zone will not have a serious impact on mining. From this, it can be concluded that the height of the water conducting fracture zone generally corresponds to the height of the dense area of microseismic events, and the determination of this height sometimes requires reference to certain experience.

The application of microseismic monitoring system in underground mine, which economizes expenses, reduces costs and enhances the veracity and reliability of monitoring, hence, it plays an important role in coal mine safety monitoring. The place of hypocenter can be ascertained by analyzing representative microseism events with sensors ,with reflecting fracturing and moving of overlying strata. This has the instructional meaning for safety and production of mine. Of course, the application of microseismic monitoring in underground mine has many new problems. it make the technology perfect and mature much more by ceaseless exploration and study.

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