Integrated monitoring and control technology for stability of room and pillar goaf

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Abstract: In order to solve the technical problems of prevention and control of dynamic mining pressure in coal seam mining at the lower part of the room and pillar goaf with short distance coal seam, based on the surface movement deformation monitoring, the internal multipoint displacement monitoring of rock mass, the working face support resistance monitoring, the working face micro-seismic monitoring joint undermine and surface, integrated monitoring of stability of room and pillar goaf was realized, and the technical measures for preventing and controlling the dynamic pressure of longwall fully mechanized mining in the lower coal seam under the room and pillar goaf are proposed. The results show that integrative monitoring technology is a comprehensive, real-time and reliable method for monitoring the stability of room and pillar goaf, integrative monitoring technology has a good application effect on guiding the safe production of long wall fully mechanized mining under room and pillar goaf in western mining area and controlling the dynamic mining pressure.

1. Introduction

In the Ordos and Yulin areas of China, large-scale mining in shallow coal seams was carried out in the early stage by using room and pillar coal mining method, forming a widely distributed room and pillar goafs. According to incomplete statistics, only the room and pillar goafs formed by local coal mining in the Ordos area is about 307.61 km², and the room and pillar goaf formed by local coal mining in Yulin City reaches 220.38 km², where the coal mining room is generally 6~8m, and a coal pillar of 6~8m is left [1-2]. When the coal seams near the lower part of the room and pillar goaf are mined, it is easy to cause large-scale instability and collapse of the coal pillars in the upper room and pillar goaf, which brings the dynamic mining pressure to the working face of the lower coal seam.

At present, the research on the characteristics and laws of overburden destruction in longwall mining of the close seam under shallow buried room goaf has made some progress [3-5], but further research on real-time monitoring and prediction technology of overburden destruction needs to be developed. The research suggests that combined with a variety of monitoring techniques such as micro-seismic monitoring, multi-point displacement monitoring inside rock mass, surface rock movement monitoring, and mine pressure observation on working faces, an integrated monitoring techniques and methods are formed, and good results have been achieved in real-time monitoring,
prediction and forecast of overburden destruction on site.

2. Integrated monitoring technology for overburden destruction

The integrated monitoring technology for overburden destruction is mainly achieved by the following methods: (1) Monitoring the pick-up device by drilling micro-seismic waves on the surface of the surface and downhole, and analyzing the time and location of overburden destruction according to the frequency and energy of the micro-seismic events. (2) Multi-point displacement meter is arranged in each layer of bedrock through surface drilling to monitor the subsidence time and displacement of overlying strata in the working face, as well as the position relationship with the working face, so as to determine the fracture and destruction extent of the front and rear of the working face. (3) Determine the extent and extent of subsidence of the overlying rock behind the working face through surface rock movement observation and determine whether the mining goaf above the working face is damaged or not. Through these three monitoring, comprehensively determine the damage of bedrock on the overburden on the working face, the coal pillar in the upper axillary mining area and the aquifer in the abutment, so as to determine whether there is a large area collapse of the mining area in the lower fully mechanized mining face. (4) The mine pressure observation is carried out on the working face, and according to the periodic pressure step of the working face and the real-time monitoring results of the overburden destruction, the mining speed of the working face is reasonably arranged, avoiding the periodic pressure of the working face and the superimposed pressure from the instability and collapse of the upper room mining goaf, and ensuring the safe production in the working surface.

2.1 Micro-seismic monitoring

When the medium of the coal rock mass under the shift is deformed and damaged by force, it will be accompanied by the release process of energy. The micro-seismic is one of the physical effects of this release process, that is, the vibration effect of the coal rock mass releasing deformation energy in the form of shock wave at a lower frequency (f<100Hz) during the process of force damage [6, 7].

The micro-seismic monitoring system can monitor the micro-seismic phenomenon of coal rock mass, which is a regional and real-time monitoring method. Compared with other traditional monitoring methods, the system has the characteristics of long-distance, dynamic, three-dimension and real-time monitoring. It can also determine the rupture scale and properties according to the seismic source conditions. By arranging a certain number of seismic pick-ups within the mine, it can monitor the overburden destruction caused by mining activities for 24 hours in real time, and realize the prediction and forecast of rock damage and its development trend in the area affected by mining. The main features of its implementation include: (1) Seismic source location monitoring of the micro-seismic events during mining. (2) Analysis of the distribution law of energy and frequency of micro-seismic events during mining. (3) Prediction of development trends of energy and frequency of micro-seismic events during mining. (4) Analysis of the dynamic development law of the micro-seismic event source in space and time. (5) Comprehensive analysis based on micro-seismic waveform information and source distribution of micro-seismic events.

Combined with geological conditions and mining conditions, the information on the destruction extent of the roof, the destruction extent of the coal pillar area, and the development height of the “two belts” in the mining process are further revealed, which provides support for the prediction and forecast of overburden deformation and destruction

2.2 Multi-point displacement monitoring inside rock mass

The multi-point displacement monitoring system inside the rock mass is composed of three main parts: the displacement sensing device module, the data acquisition transmitting module and the data receiving and processing module [8, 9].

A displacement monitoring point is arranged in the rock stratum of different layers of the bedrock, and the displacement value of each monitoring point is collected by the data acquisition module. The
subsidence, deformation degree and time of the overlying strata in each layer are analyzed by the data processing module.

According to the monitoring results, the parameters such as the damage, lag time of subsidence, and lead range of the overlying strata after mining in the working face are determined, which provides a basis for prediction and forecast of overburden deformation and damage. Figure 1 shows the overlying strata displacement monitoring station.

![Figure 1. Overlying strata displacement observation station](image)

2.3 Surface rock movement observation

Under the condition of close room and pillar goaf in the upper part of fully mechanized mining work, the law of surface subsidence caused by mining is inevitably different from the general conditions. The relationship between overburden destruction, surface subsidence extent and relative position of the working face is affected by the stability of the room mining goaf. When the mining of the lower coal seam causes large-scale instability and collapse of the upper room mining area, the surface will appear to large-scale collapse and subsidence in the advanced working face [10].

Therefore, through the surface rock movement observation, it can determine the collapse extent of the room mining goaf in the upper longwall working face and realize the monitoring of the overlying strata destruction in the room mining goaf. In addition, through the real-time monitoring of surface rock movement, the statistics of the periodic instability and collapse extent of the room mining goaf and the investigation on the general instability and destruction extent of room mining goaf under the influence of mining in the lower coal seam, provide a guidance for the dynamic mining pressure prevention and treatment of the working face.

2.4 Working face mine pressure observation

The working state of the stent was analyzed by analyzing the variation characteristics of the pressure curve of the stent per cycle.

The working state of the bracket is a direct reflection of the movement change of the overburden on the stope. Therefore, the change of the support pressure can accurately determine the movement of the overburden on the stope.

Since the resistance curve of the bracket has a periodic variation with the periodic motion of the overlying rock beam, the motion step of the roof is determined by observing the periodic variation of the bracket resistance.

According to the influence of the working step cycle on the size of the step and the speed of the propulsion, the scientific and reasonable propulsion speed is determined, and the old roof cycle of the fully mechanized mining face is prevented from being superimposed with the collapsed roof of the coal pillar in the upper chamber-type goaf.

3. Monitoring examples

3.1 Overview of the monitoring area

A mine adopts a long-wall retreating type of one-time full-height comprehensively mechanized coal
mining method to exploit NO.31 coal seam with a thickness of 4m, a working face with an slant length of 311m, a length of 1860m, an average buried depth of 120m, an average loose layer thickness of 6m, and a near horizontal level.

There is No. 22 room and pillar goaf formed by the early mining in the upper part of No. 31 coal seam. The average spacing between the layers is 38m, and the mining thickness of coal No.22 is 4m. 8m is reserved for mining 8m, and the working faces are separated by about 300m. A coal pillar for concentrated isolation is set up with a width of about 14 m.

When the fully mechanized mining face of coal seam No.31 enters and exits the concentrated coal pillar area of the upper room and pillar goaf, many times due to the large-scale collapse of the room-column goaf caused by the destruction of the concentrated coal pillar, dynamic pressure is generated, threatening to fully mechanized mining face support. In order to monitor the destruction of coal pillars and roofs, and to prevent the threat of dynamic pressure, the integrated monitoring technology of overburden destruction is utilized for prediction and forecast.

3.2 Monitoring arrangement scheme

The arrangement of the micro-seismic pick-ups is divided into two main parts, and one part is arranged on the working surface, movable in the two sides of the gate entry and fixed in the roof and floor; the other part is of drilling arrangement, with four holes drilled on the surface, one pick-up arranged for one hole. Figure 2 is the layout of working face under the shift.

Figure 2. Layout of working face

Multi-point displacement meter inside rock mass: The real-time monitoring and forecasting of the dynamic mining pressure is focused on the threat of large-scale roof collapse caused by the instability of the isolated coal pillars in the upper room and pillar goaf. Consequently, the multi-point displacement meter inside the rock mass is centered on the isolated coal pillars. Drilling holes are arranged at intervals of 30m, with a total of 4 observation holes arranged, and 8 displacement monitoring points are arranged for each hole to monitor the subsidence time and subsidence rate of different strata. Figure 3 is the layout of observation hole and the displacement meter inside the hole.
Surface rock movement observation arrangement: Four measuring lines are arranged along the working face moving direction on both sides of the concentrated coal pillar, and trending lines paralleling to the coal pillar are arranged at 20m directly above and behind the coal pillar, as shown in Figure 4.

3.3 Monitoring effect analysis

According to the frequency and energy size of the microseisms, it can comprehensively judge whether the roof of the No.22 coal room mining goaf has large-scale collapses and whether a threat of dynamic mining pressure on the working face exists, to timely predict and forecast. Figure 5 displays the relationship graph between the dynamic mining pressure and the micro-seismic event.
The multi-point displacement meter inside the rock layer monitors the movement time of the bedrock at the location of the drilling hole. According to the relative relationship between the moving position of the bedrock and the position of the working face, the fracture wave of the unable roof and the front range of the working face in this room and pillar goaf are determined. Figure 6 shows the subsidence situation of the roof rock strata in each layer monitored by the multi-point displacement meter. The eight measuring points of the observation holes all subsided on March 6th from 00:49 to 02:19.

![Figure 6. Monitoring curve roof subsidence by multiple multi-point borehole extensometer](image)

The surface rock movement monitoring determines the roof overhang of the coal No. 22 behind the working face, depending on which, whether the working surface is threatened by the large-scale roof collapse in the room and pillar goaf of the upper coal seam No. 22 is determined. Figure 7 presents the monitoring curve of the surface rock movement.

![Figure 7.Surface subsidence curve by rock movement monitoring](image)

According to the real-time monitoring data by the bracket resistance monitor in the working surface, the periodic fracture law of the working face roof is analyzed, and the periodic rock pressure step on the working face is determined. Figure 8 shows the analysis chart of the periodic working surface rock pressure, and the step of the rock pressure is 10~13m.

![Figure 8. Relationship of microseismic events distribution characteristics and working face rock pressure](image)
When the coal pillars and roofs of the room and pillar goaf of the coal No. 22 above the working face are to fracture and break in the micro-seismic monitoring and prediction, the overhang distance of coal No.22 roof in the fully mechanized mining face is determined according to the results of surface rock movement monitoring. According to the multi-point displacement monitoring results of the boreholes, it is determined whether there is fracture and destruction in the No.22 coal roof in front of the working face, so as to comprehensively analyze the dynamic mining pressure to the lower fully-mechanized mining face caused by the collapse of the No. 22 coal roof. Combined with the periodic pressure monitoring results of the roof of No. 31 coal working face, isobaric pressure or blasting roof measures are adopted after the pressure on the working surface is coming. After the fractured and broken No.22 coal roof is restored to production, it needs to avoid the superposition of the periodic pressure on the No. 31 coal roof and the pressure caused by the instability and roof collapse of the No.22 coal goaf, which would result in an accident.

4. Control technology for overburden destruction of longwall fully-mechanized mining in room mining goaf

According to the above-mentioned integrated monitoring technology and effect analysis of overburden destruction in the goaf, combined with the monitoring effect and field practice, the following three control technologies are proposed:

Roof pre-splitting blasting technology in room mining goaf: During the period of passing the concentrated coal pillars in coal No. 22, through the surface rock movement and the monitoring by the multi-point displacement meter inside the rock mass, it is found that the large-scale goaf in front of the concentrated coal pillars does not collapse. Then it can be determined that coal No.22 is supported by the concentrated coal pillars, and a large suspended roof is produced in the surrounding goaf. The destruction of the concentrated coal pillar will lead to a sudden collapse of a large-scale goaf and dynamic pressures. The study proposes that under this condition, stopping production at 38m of coal No. 31 away from the concentrated coal pillars, a set of slant boreholes are arranged at 5m above the roof from the working face to the concentrated coal pillars of coal No. 22, and the explosives are placed on the roof, coal pillars and the floor of coal No.22 to conduct presplitting blasting, so that the concentrated coal pillars are destructed in advance.

Change in moving speed: Through the mine pressure observation on the working face of coal No. 31, the periodic pressure step of the working surface is grasped. Once the pressure step of the working surface is found to increase or not to come for a long distance, the production on the working surface shall be stopped to waiting the pressure, and after the pressure of the roof has come, the production is continued.

Working face adjusted to slant: During the period of passing through the concentrated coal pillars of coal No. 22, for the purpose to avoid the large pressure to the working face in the lower coal No. 31 caused by the overall destruction of the concentrated coal pillars, the working face is adjusted to slant during the period of passing through the coal pillars, and the nose is 15m ahead of the tail, making the coal pillars are partially destroyed in sections.

5. Conclusions

Micro-seismic monitoring, surface rock movement observation, multi-point displacement monitoring inside the rock strata and the mining pressure monitoring of working faces can predict the instability and collapse time and extent of the room and pillar goaf and the roof above the working face.

Combined with the conventional observation results of the periodic pressure on the working face, reasonably arranging the moving speed of the working face can effectively avoid the superposition of the periodic pressure of the fully-mechanized mining face and the pressure caused by the instability and collapse of the upper room and pillar goaf.

Combined with a variety of monitoring technologies such as micro-seismic monitoring, multi-point displacement monitoring inside the rock mass, surface movement and deformation monitoring and mining pressure observation on working faces, an integrated monitoring techniques and methods are
formed, and good results can be obtained in real-time monitoring of on-site overburden destruction, the prediction and forecast of dynamic mining pressures.

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