Research on monitoring and prevention technology of rock burst in junde coal mine

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Abstract: Rock burst, a dynamic phenomenon in coal mine, is a special manifestation form of the rock pressure. In brief, rock burst is a kind phenomenon of catastrophic failures of the coal and rock mass. Without any obvious macroscopic premonitory symptoms, a large amount of energy is released when the rock burst occurs, thus causing enormous casualties and equipment damages. Since 2004, rock burst accidents have occurred many times in Junde Coal Mine, resulting in damages of mining roadways, suspension of mining activities, or worse still, abandonment of mining roadways and casualties. Over these years, Junde Coal Mine has formed a set of systematic methods and measures which have achieved good result in filed practice.

1. Experimental system
Located in the south of Hegang City, China, Junde Coal Mine is the southernmost mine field of Hegang Coalfield. Its highest elevation altitude reaches 301.86 m and lowest of that is 228 m in the orefield. Most of coal seams in this area are medium-thick and thick coal seams, few are super thick seams. The total minable seam is 51.37 m thick and its percentage of coal content is 4.7%. In 23 minable seams, the roof and floor of most of them are fine sandstone and that of a very few seam are tuffaceous siltstone. During the process of mining, due to the concentration of stress and the movement of the rock strata, the coal-rock mass is destroyed, thus releasing a large amount of accumulated energy, forming mine earthquake and even causing rock burst.

2. Pre-assessment methods of rock burst
Rock burst is one of the most serious dynamic disasters faced by coal mines in China[1-3]. At present, the risks of rock burst and its dangerous degree in the working face of Coal Mine could be forecast and predicted mainly by micro-seismic monitoring method, rock noise monitoring method, electromagnetic radiation method, and cuttings method [4,5].

2.1. Micro-seismic monitoring
Micro-seismic monitoring system could realize the remote, real-time, dynamic and automatic monitoring of the signals of mine earthquake, providing the complete waveform of mine earthquake signals, including rock burst. Via analyzing and studying, the shake whose energy is large than 100 J, time, energy and spatial three-dimensional coordinates of rock burst (as shown in figure 1) could be
calculated, which could assist to determine the vibration type of each shake, judge the force source of rock burst and evaluate the dangerous degree of mine rock burst[6,7].

The energy trend method and frequency trend method are adopted to finish the statistical analysis in every five days. The main reasons need to be found and checked by KBD5 or cuttings method when the energy increases or decreases.

The results of micro-seismic monitoring show that a value of Junde Coal Mine is minimum and b value is relatively small. That proves that the seismic activity of Junde Coal Mine is low, the frequency of mine earthquake is small. The proportion of high-energy mine earthquake is big. Therefore, the risk of rock burst triggered by mine earthquake in Junde Coal Mine is higher than other mines. By linear fitting of straight line segment of logarithmic graph of magnitude number, the result shows that the number of rock burst and the earthquake magnitude in Junde Coal Mine obey the rules of distribution \( \log(N) = -2.213 + 1.231M \), as shown in figure 2.

The frequency and energy of mine earthquake are periodically distributed in term of time and there are several small periods in the large period. During the mining process, the distribution of mine earthquake in roof is relative less and the mine earthquakes mainly distribute in the floor of the working face. Additionally, the mine earthquakes are distributed like a strap, which is closely related to the distribution of fault in the floor. On the cross of the faults, the energy and the frequency of mine earthquake is relatively large.

2.2. Rock noise monitoring

Rock noise refers to the acoustic effect that is generated by the energy released from the fracture of coal-rock mass via elastic wave form during the process of outward transmission. In coal mine, the rock noise is triggered by the mining activities underground, whose vibration energy is in the range of 0~103 J. With 150 ~ 3000 Hz, the frequency of shake is large. Compared with micro-seismic phenomenon, rock noise is a kind of shake with high frequency and low energy. Rock noise monitoring system could monitor the rock noise events whose frequency is in the range of 28~1500 Hz and energy is less than 103 J. Its monitoring range and the micro-seismic monitoring system could complement each other. A large amount of researches suggest that the rock noise is the premonition that the coal-rock mass release energy, The dynamic phenomenon that might occur in the following days in local scope could be monitored by the relationship between rock noise and stress state of coal-rock mass. figure 3 is the cartogram of the frequency and energy of rock noise in one mine and figure 4 is the tendency chart of the frequency and energy of rock noise before and after strong pressure.

From figure 4, it is known that from 24th, August, 2012, there was a trend that both energy and frequency increased along with time, which demonstrates that pressure values in monitoring areas increased continuously. At 20:00 on 29th August, the energy and frequency of signal rose and the then declined and at 0:00 on 30th August, they increased again. At 3:03, the strong pressure occurred, the energy and frequency rose to the highest value and then declined, which suggested that the acoustic emission could correctly reflect the stress conditions within the monitoring areas.
The previous monitoring analysis shows that the micro-seismic events always occur within few hours after a peak in the weighted average energy or an hour-weighted average frequency of the rock noise event (especially in the first 2 hours). From the analysis, the reason for this phenomenon is that before micro-seismic events occur, energy in coal-rock mass accumulates continuously. The energy and frequency released from the rock noise events in this period increase and until the end of the micro-seismic events, the energy in coal-rock mass releases, the stress concentration decreases, and the energy as well as frequency of rock noise events continuously reduce again. Therefore, rock noise and micro-seismic complement each other in the field of rock burst monitoring[8].
2.3. KBD5 portable electromagnetic radiometer
In the process of driving or mining, the original stress state of surrounding rock is broken and the stress is redistributed and transformed into new balance state. During the transform, deformation or fracture in coal must occur, thus causing electromagnetic radiation, whose strength is relative to stress condition of coal seam. In the fracture area of coal seam, the stress is relatively low, and the signal of electromagnetic radiation is weak, whose variation is small. In the stress concentration area, the process of deformation and fracture is strong, the signal of electromagnetic radiation is strong and its frequency is high[9]. The higher the stress concentration of coal seam, the greater the risk of rock burst. Therefore, monitoring the intensity and variation of electromagnetic radiation signal of coal seam could predict the rock burst risk degree of coal seam.

There was one measuring point in every 10 m in the monitoring range of the entry. And three measuring points were set in the working face, located in two ends and the middle of the working surface, respectively. The monitoring data need to be analyzed in time and cuttings method should be used to verify as soon as possible when finding the data exceed its limitation. If there is any rock burst risk, measures should be immediately taken to relief the pressure. The trend curve of electromagnetic radiation test of the measuring points on the lower entry is shown in figure 5.

2.4. Cuttings method
In the process of drilling the holes in the compressed coal seam, when the hole enters the high stress area of coal seam, the dynamic characteristics are shown, the coal around the borehole might suddenly squeeze into the hole, accompanied by vibration, sound, impact and other effects. The amount of pulverized coal discharged per unit length is greater than that under normal condition with large granularity and sticking of tool[10]. Therefore, the risks of the rock burst are quantified. During the process of drilling, if the phenomenon that the drill pipe jams, crown drills, vibrates, or sounds occurs, there is the rock burst risk, which needs to be solved by taking measures.

Before mining, the reference data of cuttings method should be measured. There were ten boreholes in two entries and working faces respectively, whose depth was 8 m. The amount of drilling powder per meter (the first 1 m was not collected) was collected and recorded and the average data per meter was used as the reference data of cuttings method. If the measuring data exceed the critical value (1.5 times of the base number), there is the rock burst risk, and measures need to take to relief pressure.

3. Application of pre-assessment methods of rock burst
The method of water injection and soften in coal seam was employed to prevent and control rock burst in Junde Coal Mine. When the water content of seam in tail entry after injecting water reaches 5%, if the risk is still exist, pressure relief by large-aperture borehole method and pressure relief by blasting in coal seam method should be used to relief the rock burst risks. When the risk of rock burst could not be relieved by the above methods, the roof presplitting blasting method should be carried out. During the process of pressure relieving, the production of working face should be stopped[11,12].

3.1. Water injection in coal seam
The water injection and softening in lower side coal seam not only reduces the impact tendency of coal, but also increases the plasticity of coal seam, making the peak value of lateral stress move to the far area of coal seam. The work of water injection and softening in coal seam begins from the C4 measuring point (15 m). There was one injection hole in every 7.5 meter in the coal seam of low-side of tail entry, whose borehole diameter is 42 mm, depth is 15 m, angle between drill hole and tail entry is 40°, angle between drill hole and horizontal included angle is -15°.

To soften the coal seam, the high pressure water-injection pump was adopted to make the injection and there were two to three times to inject water. The first water injection was stopped for 24 hours after the seepage of coal seam occurred and the high pressure water injection was carried out again. If
the seepage of coal seam occurred again, the static pressure water injection was adopted, thus ensuring that the coal seam had enough water content.

3.2. **Pressure relief by large-aperture borehole**

By using the large-aperture borehole to relief pressure in coal seam, the high-stress area around the roadway moves into the far area of coal seam, thus reducing the risks of rock burst, lessening the damage, ensuring the safety of staff and equipment and achieving the safety excavation of the coal seam which has risk of rock burst.

The main parameters of pressure relief by large-aperture borehole are shown in table 1. The advantages of pressure relief by large-aperture borehole include simple requirement, construction and operation and fast speed of construction. Besides those, the construction of the rock burst risks area could be carried out at any time.

| Location | Direction      | Angle/° | Length/m  | Distance among hole/m |
|----------|----------------|---------|-----------|-----------------------|
| Up-side  | perpendicular  | 0       | 5 m from the upper caving zone | 1                     |
|          | to up-side     |         |           |                       |
| Low-side | perpendicular  | -28     | 15 m from the upper caving zone | 1                     |
|          | to low-side    |         |           |                       |
| Floor    | parallel to    | -25     | 15 m from the upper caving zone | 1                     |
|          | roadway        |         |           |                       |

3.3. **Pressure relief by blasting in coal seam**

Through the comprehensive analysis and cuttings detection, when the serious dynamic phenomenon such as the measured data exceeding its critical values and the occurrence of inter-hole impact, the rock burst risks exist in this area and the pressure should be relieved by blasting method.

In the construction of tail entry, the methods of heading face pressure relief and entry low-side pressure relief were used to relief the pressure.

(1) Heading face pressure relief: there was one pressure relieving hole in every 10 m and the depth of borehole was 10 m. The heading face constructing must be within the pressure relieving range. The pressure relieving hole was set in the heading face and the hole was opened at 1 m away from the entry low-side and 0.5 m–0.8 m away from the floor. The hole was parallel to the center of the entry, whose falling gradient was 0° and depth was 10 m.

(2) Entry low-side pressure relief: the pressure relieving holes were placed in the entry low-side and there was one pressure relieving hole in every 5 m in the area within 30 m from the heading face. The pressure relieving hole was set at 0.5 m away from the floor, whose depth was 10 m. The pressure relieving hole in the low-side was 15 m behind the heading face.

3.4. **Roof presplitting blasting**

When the effect of coal seam pressure relief by blasting was not meeting requirement, the roof presplitting blasting method was used to release in tail entry. Along the direction of tail entry, the ZY-750 drilling rig was applied to finish the construction of the boreholes for blasting. The drilling parameters were as follows: along the tail entry, the holes were punched once with 15 m, the final hole distance was 5 m and the aperture was 75 mm.

The explosive dose of each hole for pressure relief blasting was 30 kg, the aperture was 75 mm. The φ45 mm×400 mm special explosive was used. There was one detonator in every five tubes of explosive with positive charge. Four pieces of Water-stemming were used to seal the holes, whose outside were sealed by yellow mud.

3.5. **Strengthening support in the entry**

During the construction of tail entry, two sides and roof hang the double-layer steel mesh with inter-network interface. Row spacing between anchor cables was 2 m in the roof and that of two sides
was 2 m. The anchor cables were made of seven steel strands, its size is φ17.8 mm. The anchor cable anchorage depth was not less than 7 m and that of two sides were not less than 6 m. Anchor cable was fastened by double tee iron with the length of 1000mm and lockset. The tension pretightening force was not less than 80 kN and the maximum distance between the lastest anchor cables and heading face was 2 m.

4. Conclusions

Micro seismic monitoring realizes the goal of locating the vibration of mine, calculating vibration energy and evaluating the risks of vibration. The remote, real-time and dynamic monitoring of large-scope shake events could be realized. The rock noise monitoring could realize the real-time monitor of small-scope weak shake events, thus complementing with the micro seismic. Additionally, the electromagnetic radiation and cuttings method are the visualized and effective monitoring methods in the small scope area.

In the long-term struggle with rock burst, Junde Coal Mine has accumulated rich experience and established the integrated control technology system. The monitoring methods of this system focus on micro seismic monitoring, rock noise monitoring, electromagnetic radiation monitoring, cuttings method monitoring and regard roof dynamic monitoring, observation of roadway movement and daily monitoring of fully mechanized mining support dynamometer as assistant. Moreover, the prevention and control methods of this system are based on water injection in coal seam, pressure relieving by large-aperture holes, roof pre-blasting, coal seam loose blasting and supplemented by roadway strengthening support. Therefore, this control technology system has obtained good prevention and control performance, which could be adopted to guide the on-site mining work.

Reference

[1] Pan YS, Li ZH, Zhang MT. (2003) Distribution, Type Mechanism and Prevention of Rock Burst in China[J]. Chin. J. Rock Mech. Eng., 22(11):1844-1851.
[2] Qi QX, Dou LM. (2008) Theory and Technology of Rock Burst[M]. China University of Mining and Technology Press, Xuzhou.
[3] Dou LM, He XQ. (2001) Theory and Technology of Rock Burst Prevention[M]. China University of Mining and Technology Press, Xuzhou.
[4] Jiang FX, Wei QD, Yao SL, Wang CW, Qu XC. (2013) Key Theory and Technical Analysis on Mine Pressure Bumping Prevention and Control[J]. Coal Sci. Technol., 41(6):6-9.
[5] Jiang FX, Qu XC, Yu ZX, Wang CW. (2011) Real Time Monitoring and Measuring Early Warning Technology and Development of Mine Pressure Bumping[J]. Coal Sci. Technol., 39(2):59-64.
[6] Gao LJ, Huang N. (2017) Micro-Seismic Identification Technology for Dynamic Information of Rock Burst[J]. Shandong Coal Sci. Technol., (8):110-112.
[7] Li WJ. (2015) Application of Microseism Monitoring Technology in Rock Burst Coal Mine[J]. Chin. J. Geol. Hazards and Control, (4):116-120.
[8] Li Y, Ma ZJ, Zuo Z. (2016) Application of Rock Sound Monitoring Technology in Early Warning of Rock Burst in Changcun Coal Mine[J]. Chin. Coal, (1):22-26.
[9] Gu HL, Wang W, Lin D. (2015) Application of Electromagnetic Radiation in Rock-brust Prediction[J]. Coal Technol., (8):105-108.
[10] Qu XC, Jiang FX, Yu ZX, Ju HY. (2011) Rock burst Monitoring And Precaution Technology Based On Equivalent Drilling Research And Its Applications[J]. Chin. J. Rock Mech. Eng., 30(11):2346-2351.
[11] Wang L. (2018) Risk Assessment and Prevention Measures of Rock Burst[J]. Sci. Technol. vision, (14):87-88.
[12] Zhao DC. (2018) Prevention and Control of Rock Burst Under High Stress Concentration Area[J]. Coal Sci Technol Mag., 155(03):84-85.