Research on sensitive index and critical value of local prediction for coal roadway in steep seam

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Abstract: In response to the prediction of the local outburst danger of steeply inclined coal seams, it tested the initial gas emission rate of coal $\Delta P$, the firmness coefficient $f$ of coal, and the gas desorption characteristics $K_1-P$ in laboratory. Using the methods of historical data analysis, on-site inspection and on-site expansion verification, it was determined that the drill cuttings volume index $S$ and drill cuttings gas desorption index $\Delta h_2$ are the sensitive indexes and critical values for the coal roadway prediction in Qingshan Coal Mine. The application effect is good, which provides reference for mines with similar conditions.

1. Introduction
The prediction of coal roadway local outburst danger is to predict the outburst danger in the process of coal roadway excavation, it is to predict the outburst danger more finely in a smaller area, and it is to further test and confirm the effect of regional comprehensive anti-burst measures. Coal tunnel driving is important for preventing outburst. In China, the prevention of outburst of coal roadways in steep and outburst coal seams is mainly studied by gas pressure relief extraction \cite{1-5}, and there are few studies on the prediction of coal roadway local outburst danger. Although the technology of coal roadway local prediction methods is relatively mature, the accuracy of outburst prediction needs to be improved; many mines in China have experienced outburst accidents due to predictions or test results below the critical value. In this paper, the cuttings index method is applied to Qingshan Coal Mine, in order to provide reference for similar conditions.

2. Research plan

2.1. Overview of the test area
Qingshan Coal Mine is mining Qingshan Coalfield, Triassic Anyuan Coal Measures, coal seam strike NE50°~60°, SE trend, dip angle 70°~85°. The thickest coal seam has a thickness of 30-40m and an average thickness is 5.6m. It is anthracite, lean coal or lean coal, with a gas content of 7.33-18.07 m³/t and an average of 12.98 m³/t. The relative gas emission of the mine is 8.14~20.76 m³/t, with an average of 14.68 m³/t; the absolute gas emission of the mine is 8.17~20.19 m³/min, with an average of 13.40 m³/min.
The test sites are East 515 panel, West 517 panel and West 519 panel. The thickness of coal seam is 0.6-17.6m and an average thickness is about 4.6m. The inclined mining elevation is -246~-377m, the height difference is 131m, and the inclination angle is 65°.

2.2. Test plan
Predicting sensitive indicators and their critical values are studied by laboratory testing, historical data analysis, on-site inspection and on-site expansion verification.

The laboratory mainly tests are the initial gas emission velocity $\Delta P$ of the coal seam in the test area, the coal's firmness coefficient $f$, and the coal gas desorption characteristics $K_1$-$P$ relationship.

The survey indexes are mainly included the amount of drill cuttings $S$, the desorption index of drill cuttings gas $\Delta h_2$, the initial velocity of gas gushing from the borehole $q$ and its attenuation coefficient $C_q$. In each survey, 2~5 predicted drill holes are arranged, with a hole diameter of $\Phi 42mm$ and a hole depth of 8~10m. The index is tested starting from the 2nd meter. The amount of drill cuttings $S$ is measured every 1m of drilling, and the gas desorption index $\Delta h_2$ of drill cuttings and the initial velocity $q$ of the gas emission and its attenuation coefficient $C_q$ are measured every 2m.

3. Laboratory research
After testing, the initial gas emission velocity $\Delta P$ of the coal sample is 21~33, the firmness factor $f$ is 0.13~0.33.

It is that the gas desorption index $K_1$ increase as the gas pressure $P$ increases. The $K_1$ value and the $\Delta h_2$ value are basically the same in nature, and both can reflect the danger of coal seam outburst to a certain extent. However, there is a difference between the test process and the error, so the drill chip gas desorption index $\Delta h_2$ can be used as a prediction index.

4. Site inspection
4.1. Historical forecast data analysis
During the tunneling process of the cumulative 307m roadway in the eight-story down channel in the east 515 panel, the eight-story down channel in the west 517 panel, and the four-story east down channel in the west 519 panel, it tested 49 cycles of the drill cutting volume $S$ index and drill cutting gas desorption index $\Delta h_2$. The $S$ index of drill cuttings was all distributed between 3.0~4.0kg/m, $S_{max}=3.9kg/m$; the $\Delta h_2$ index of drill gas desorption was all distributed between 110~180 Pa, and $\Delta h_{2max}=178.4Pa$. Under normal circumstances, $S_{ave}$ and $\Delta h_{2ave}$ rise slowly along the borehole depth and have a certain linear proportional relationship. According to preliminary analysis, they are sensitive to the amount of drill cuttings $S$ and the gas desorption index $\Delta h_2$.

4.2. On-site inspection of forecasting indicators
It was inspected 81 cycles in the excavation of the four-layer down channel in the East 515 panel, the six-layer down channel in the West 517 panel, and the second-layer down channel in the West 519 panel. The total of roadways is 416m. The prediction index $S_{max}$ exceeded the standard 2 times, is respectively 6.2kg/m and 6.3kg/m; the prediction index $\Delta h_{2max}$ exceeded the standard 14 times, and the range exceeded is 205.8~284.2Pa. The variation of the index $S$ of drill cuttings and the gas desorption index $\Delta h_2$ of drill cuttings along the borehole depth are shown in Figure 1.
It can be seen from Figure 1(a) that, the $S_{\text{ave}}$ curve rises slowly along the borehole depth under normal circumstances, and the value is concentrated between 3.05–3.5 kg/m. The $S_{\text{ave}}$ shows an increasing trend with the increase of the borehole depth, and the maximum value appears in 8–10 m, the working face is judged that there is no protruding danger. Under abnormal conditions, the $S_{\text{ave}}$ increases rapidly after the position of 6 m, and along with the dynamic phenomena of spray holes, top drilling, and pinch drilling, the judgment of the working face has protruding danger.

It can be seen from Figure 1(b) that the $\Delta h_2^{\text{ave}}$ curve rises slowly along the borehole depth under normal conditions of coal roadway, and the value is concentrated between 90–140 Pa. The $\Delta h_2^{\text{ave}}$ shows an increasing trend with the increase of the borehole depth, the maximum value appears at 8–10 m, the working face is judged to have no protruding danger. Under abnormal conditions, it increases rapidly after the position of 6 m, and is accompanied by the phenomena of injection hole, jacking, and pinch drilling, and the judgment of the working face has protruding danger.

After on-site testing, the prediction index $q$ is generally small and no obvious change, and it often occurs the phenomenon of zero index. Therefore, the prediction index $q$ and the attenuation coefficient $C_q$ cannot reflect the prominent danger of the working face. Therefore, it should not be used as a sensitive indicator for prominent prediction of the working face under this condition.

4.3. Sensitivity analysis of forecast indicators

4.3.1. Drill cuttings volume index $S$

When the prediction index $S_{\text{max}}$ is greater than 6kg/m during the inspection, dynamic phenomena such as jetting, jacking and pinch drilling will occur during the driving process; when the prediction index $S_{\text{max}}$ is less than 6kg/m, there will be no dynamic phenomenon during the driving process. It appears that most of the data distribution is between 3.0–3.5 kg/m, and the prediction index increases linearly along the borehole depth. The comprehensive analysis believes that the amount of drill cuttings $S$ is relatively sensitive in predicting the risk of outburst in the large groove coal seam driving face of Qingshan Coal Mine.

4.3.2. Drilling cuttings gas desorption index $\Delta h_2$

When the prediction index $\Delta h_2^{\text{max}} < 200$Pa, there is no dynamic phenomenon during the driving process. The $\Delta h_2^{\text{ave}}$ curve rises gently along the borehole depth, the value is concentrated between 90–140 Pa. The $\Delta h_2^{\text{ave}}$ shows an increasing trend with the increase of the borehole depth, the maximum value appears in 8–10m.

So it is judged that there is no protruding danger at the working face. When the prediction index $\Delta h_2^{\text{max}} > 200$Pa, it increases rapidly after the position of 6 m, and it is judged that there is protruding danger at the working face along with the dynamic phenomena of spray holes, top drilling and pinch drilling. The analysis shows that the drilling chip gas desorption index $\Delta h_2$ is relatively sensitive in predicting the danger of outburst in the driving face of the large-slot coal seam test area of Qingshan Coal Mine.
4.4. Preliminary determination of critical values of sensitive indicators

Through the aforementioned laboratory measurements, historical prediction data, and on-site investigation and comprehensive research, it is preliminary determined that $S_0 = 6.0$ kg/m and $\Delta h_{20} = 200$ Pa is the critical values of the relative sensitive indicators of the coal road outburst prediction under normal geological conditions in the test area. Under abnormal conditions, the coal roadway predicts 80% of the critical value of the relative sensitive index, which is $S_0 = 4.8$ kg/m and $\Delta h_{20} = 160$ Pa, such as Shimen uncovered coal, steep incline under the conditions of coal roadway uphill driving, coal roadway first layer driving and geological anomalies etc.

5. Expand verification

5.1. Expansion of verification inspection

Using the critical value of the index determined by the first stage of preliminary research, expanded verification was carried out in the six-story flume in the east 515 area, the four-story flute in the west 517 area, and the four-story flute in the west 519 area. During the extended verification period, the prediction index $S_{\text{max}}$ exceeded 0 times; the prediction index $\Delta h_{2\text{max}}$ exceeded 8 times, and the range exceeded 205.8~254.8 Pa. The variation of the index $S$ of drill cuttings and the gas desorption index $\Delta h_2$ of drill cuttings along the borehole depth are shown in Figure 2.

![Figure 2. The distribution of along-hole depths when prediction indicators are normal and abnormal during extended verification](image)

It can be seen from Figure 2(a) that a linear increase trend shows the distribution of the forecast indicator $S_{\text{ave}}$ along the hole depth generally, with an average value of 3.0~3.6 kg/m, and the maximum average value appears at the hole depth of 8~10 m. During the driving process, there are no dynamic phenomena such as injection hole, top drilling and pinch drilling, which realizes the safe driving of coal roadway.

It can be seen from Figure 2(b) that the distribution of $\Delta h_{2\text{ave}}$ increases linearly along the depth of the hole. Under normal circumstances, there is no dynamic phenomenon during the driving process; while in abnormal conditions, it increases rapidly after 6 m, and is accompanied by the injection hole and the top Drilling, clamping drill power phenomenon.

The predictive index $\Delta h_2$ of the working face is obviously different from the normal and abnormal conditions. After the predictive index exceeds the standard and measures are taken, after checking and checking it is less than the critical value, it is safe to digging.

5.2. Reasonable analysis of critical value of sensitive index

During the extended verification period, the working face is safely excavated at 331 m, which is analysis on 48 cycles of sensitive index prediction cycle.

The predicted index can reflect the prominent danger of the working face, and the accuracy rate of the non-protruding danger is 100%, which ensures the safe and smooth excavation of the working face. This indicates that the determined critical value of the relative sensitive index is safe and effective.
6. Conclusion
The cuttings volume index $S$ and the cuttings gas desorption index $\Delta h_2$ have good sensitivity in predicting the danger of coal roadway outburst in the test area, and the initial gas velocity $q$ and its attenuation $C_q$ are relatively poorly sensitive under this geological condition.

In the normal geological conditions of coal roadway driving in the large-slot coal seam test area, the critical value of the relative sensitive indexes for coal roadway outburst prediction is $S_0=6.0$ kg/m and $\Delta h_{20}=200$ Pa. When Shimen uncovered coal, steeply inclined coal roadway uphill tunneling, coal roadway first layer tunneling, and tunneling encountered geological anomalies, coal tunnel outburst prediction critical value of relative sensitive indicators is $S_0=4.8$kg/m and $\Delta h_{20}=160$ Pa.

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