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Research on the mechanism of coal and gas outburst and the screening of prediction indices

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Abstract

According to coal and gas outburst mechanisms, lab and field measurement, actual situations of Sihe coal mine and articles in \textit{Prevention Regulations of Coal and Gas Outburst}, the relevancy among chief static indices of outburst prediction are analyzed. The static sensitivity index system is screened out to predict coal and gas outburst by multi-source information in Sihe, such as destruction type of coal, coal’s consistent coefficient, initial rate of methane diffusion, gas pressure, gas content, depth of coal seams, occurrence change of coal seams, geological structure, cuttings desorption index $K_1$, etc. $K_1$ has the characteristics of easy measurement, strong generalization, high reliability and accuracy. So $K_1$ should be firstly chosen when a single index is adopted to predict outburst. The provision of article 34 in \textit{Prevention Regulations of Coal and Gas Outburst} about the drilling holes’ diameter, depth and test contents for the same prediction method are different from article 38. These will lead to ambiguity in practical applications. The research shows that articles should be revised as follows: prediction drilling apertures should be determined by engineer drilling tool, and $K_1$ of wet or dry cuttings each can be used as prediction index.

Keywords: coal and gas outburst mechanisms; screening of outburst prediction indices; desorption index for drill cuttings; profession standard; revision

1. Introduction

Coal and gas outburst is a very complex dynamic phenomenon affected by varied factors. Up to the present, there has been not a unitive understanding about coal and gas outburst mechanisms in different geology and mining conditions. And these result in numerous outburst prediction indices, information redundancy for multi-source information prediction and are difficult to predict outbursts accurately. So combining with actual situation of Sihe coal mine, and analyzing the relationship between outburst mechanisms and prediction indices, this paper will bring forward suggestions to revise some articles about the \textit{Prevention Regulations of Coal and Gas Outburst}, and...
select an easily-measured and high reliable prediction index system as essential input data of multi-source information prediction of coal and gas outburst.

2. Outburst mechanisms and the principles screening out the sensitivity indices of outburst prediction

Nearly all the methods of outburst prediction index or index system are based on the comprehensive assumption of coal and gas outburst mechanisms. Comprehensive supposition means that coal and gas outburst is the result of interaction among structural mechanical properties of coal, ground stress and gas pressure [1]. In the process of outburst, the ground stress and gas pressure are the motive power for the coal (rock) and gas outburst; elastic energy, potential energy, and gas pressure energy stored in stratum are the maintenance energy of outburst; pore structure and mechanical properties of coal are the essential factors to initiate outbursts. All the factors above exist in one system composed of outburst coal seam, surrounding rock and gas, and have the extremely close immanent link, which are interdependent and have some restrictions to each other.

Coal’s pore structure has two kinds, microscopic and macroscopic, which determine coal mechanical properties together. For example, pore, fracture, fault and destruction type, all have important influence on coal’s strength, hardness and elastic-plasticity, and also the ability of coal adsorption, diffusion and permeation. The fundamental reason that different coal seams under same external force condition shows different mechanical effect and the outburst that will not occur in every coal seam is due to the different pore and geological structure. So, coal’s construction and geological structure are the inherent factors to determine whether outburst occurs or not.

The interaction of ground stress and gas pressure determines the coupled motion rule of coal and gas. Coal mining or gas drainage results in stress redistribution, and forms destressing zone, stress concentration zone and original in-situ rock stress zone. In the destressing zone, the coal seam porosity and permeability increase, and ground stress and gas pressure reduce. While in the stress concentration zone, porosity and permeability increase, and ground stress and gas pressure decrease. When the gradients of stress and gas pressure between destressing zone and stress concentration zone reach certain value, and surpass the coal strength, coal body is destructed, and elastic energy is released. After the coal body is destroyed, the coal seam fracture and permeability of wider range coal seam increase, and the flow of free gas speeds up. This will highly enhance the diffusion desorption ability of adsorption, meanwhile desorption gas provides the energy continuously for ejecting coal in the process of outburst. The bigger gas diffusion desorption rate which is determined by the resistance of internal diffusion and surface mass transfer resistance are, the higher outburst risk is [2].

In addition to above factors affecting coal and gas outburst, in the gestate process of coal and gas outburst, some phenomena of the sound, electricity, magnetism and heat are also created. Therefore, we can predict coal and gas outburst by measuring the variable quantity of these phenomena.

After above analysis, we can see that, under the existing engineering factors, how to choose the right outburst prediction index and prediction method is the urgent problem which needs to be solved. According to outburst mechanisms analysis and convenience in project application, the principles of choosing gas outburst prediction indices should include the following four items. (1) The index could comprehensively and indirectly or directly evaluate or reflect the factors influencing outburst and physical phenomena in the gestate process of coal and gas outburst, and naming the index should be comprehensive. (2) The index should be sensitive. (3) The indexes have high measuring accuracy, and are convenient for measurement. (4) The prediction index should have comparability, and the prospect of popularization and application.

3. The classification of coal and gas outburst prediction methods and indices

Through protracted and unremitting efforts, many countries’ researchers bring forward various outburst prediction methods [1-6] based on the understanding of outburst mechanisms. According to prediction time and range division, these mechanisms and models are divided into two kinds——regional prediction and mining face prediction; according the number of indices used, there are single-norm prediction method and multiple indices prediction method; according to the contact type between coal and instrument, they are divided into two kinds——contact prediction and non-contact prediction; according to the persistent prediction, we get continuous prediction and discontinuous prediction, or static prediction and dynamic prediction.
The major prediction method in Prevention Regulations of Coal and Gas Outburst (called Regulations for short in the following paragraphs) prescribed by China in 1995 and Rules of Preventing Coal and Gas Outburst (edition asking for opinion, 10, 2008) belongs to contact static prediction method. Both regulations stipulate that coal’s destruction type, initial rate of methane diffusion $\dot{p}$, consistent coefficient of coal $f$ and seam gas pressure $p$ should be taken as foundation indices of coal seam outburst prediction, and the regional prediction should be based on the geological statistical method and the comprehensive indices $D$, $K$; the comprehensive indices $D$, $K$ and desorption indices for drill cuttings ($h_2$ or $K_1$) should be selected for outburst prediction at crosscutting coal face; initial velocity of gas emission from drill holes ($q_m$), value $R$ index method and desorption indices for drill cuttings (include desorption indices for drill cuttings $h_2$ or $K_1$, the volume of cuttings $S$) should be used at coal heading face and mining face.

Non-contact dynamic prediction method is the method assessing outburst risk by monitoring the physical properties of sound, electricity, magnetism, thermal, and gas emitting in the gestate process of coal and gas outburst, mainly including AE acoustic emission signal method, electric radiation detection method, the gas emitting and coal temperature change monitoring method.

Multi-source information comprehensive prediction of outburst or multi-source information artificial intelligence prediction, means the method that a series of representative indicator system is screened out from two former predicting methods, then analyzed and calculated by computer and artificial intelligence technology to predict coal and gas outburst. This method is discussed at present, and has many prediction models. But no matter what kind of models, one of the key technological problems is chosen by a comprehensive sensitive index system for multi-source information comprehensive prediction.

4. Screening of outburst risk multi-source information comprehensive prediction indices system

4.1. The indices which reflect coal structure and gas reserves

Destruction type $T$ reflects coal structure and also determines coal strength, diffusion and desorption ability and other mechanical properties. Coal consistent coefficient $f$ reflects coal strength and the energy needed to crush coal. According to outburst mechanisms analysis, the higher coal strength is, the more energy is needed to crush coal, and the bigger the resistance to outburst development is, the smaller outburst risk is; on the contrary, the outburst risk is greater. In the same gas pressure situation, gas initial rate of methane diffusion $\dot{p}$ reflects the volume of gas released at the initial moment of coal outburst. The bigger $\dot{p}$ is, it’s easier to form gas flow to throw out coal, and the higher the outburst risk is. The bigger the gas pressure $p$ and contents $C$ is, the higher the outburst risk is. Therefore, these 5 parameters: $T$, $f$, $\dot{p}$, $p$, and $C$ can be used as the important input data for multi-source information comprehensive prediction of outburst risk.

4.2. Coal seam’s diffusion ability, permeation ability and the factors influencing them

Lab and field test shows that the relationship among cuttings gas diffusion cumulative amount, initial velocity of gas emission from drill holes and time can be expressed as:

\begin{align*}
V_t &= K_1 t^{1/2} \\
q &= q_m e^{-at}
\end{align*}

where $V_t$ (ml) is the cuttings gas diffusion cumulative amount at any time $t$ (min); $K_1$ (ml/(min·0.5·g)) is the cuttings desorption index that reflects cuttings diffusion ability; $q$ (l/min) is the velocity of gas emission from drill holes at time $t$; $q_m$ (l/min) is the initial velocity of gas emission from drill holes; $a$ (l/min) is the attenuation coefficient.

According to the formula (1) and (2), Regulations prescribes $K_1$ and $q_m$ as outburst prediction indices. The physical meaning of $K_1$ is the slope of linear equation (1), which is obtained through regression analysis with $t^{0.5}$ (cuttings’ exposing time $t$ is no more than 10 min) as variable, and it means gas diffusion cumulative amount within the initial 1 min. The physical meaning of $q_m$ is cumulative amount of gas flooding from the drill hole with diameter
of 42 mm and depth of 0.5 m within the initial 2 min. Although $q_m$ is the intensity of gas flooding from drill hole, considering that the reason of test time is short and drill hole wall is broken, $q_m$ is similar to $K_1$ in essence, mainly reflecting gas diffusion in crushed coal wall. Since the different measuring instruments are used, Regulations also prescribes cuttings desorption index $h_2$ (Pa) as outburst prediction index. The physical meaning of $h_2$ is the pressure increment caused by diffusion desorption gas from 10 g cuttings in specific container within the initial 3~5 min.

From the analysis above, we can see indices $K_1$, $q_m$ and $h_2$ are similar in some aspects. They are all amount of gas emission from certain weight coal or length drill holes within initial time; all have the meaning of initial velocity; all reflect coal’s diffusion and permeation ability, gas content and gas pressure; these indices in field test also reflect the influence of ground stress; and all have strong generalization. Therefore, when choosing single index to predict outburst, any of three indices will have the similar result theoretically. But according to practice, instrument of $K_1$ test can be continuously and conveniently operated during drilling, the mutual interference with drilling is less, and also $K_1$ value is the statistical calculation result of multipoint test data, taking on higher reliability, advance cycle prediction distance is 8~10 m. Above superiority makes $K_1$ prediction method be widely accepted. And the other two parameters are single point data and possessing lower reliability. During the test $q_m$ and $h_2$, technicians have to quit the drilling rig, which interferes in drilling, and advance cycle prediction distance is no more than 3.5 m (edition ask for opinion provide 8~10 m). So this paper suggests taking value $K_1$ as outburst prediction index, when using single index or multi-source information comprehensive technology to predict the outburst risk in front of the working face.

Desorption index for cuttings $K_1$ changing with drill hole depth $L$ accords with the ground stress and gas pressure changes. This is confirmed in numerous lab and field test. Fig.1 is one of the field test results at heading face of Shaqu mine.

In Fig. 1, the distribution of $K_1$ at coordinates graph is more scattered and random, but it is still showing a certain regularity that the $K_1$ value in 5 m ahead of the face is minimum, in 5 ~ 20m is the biggest and in the range over 20 m is between the two. That $K_1$ value which changed regularly with depth is caused by ground stress and gas pressure redistribution. At 5 m in front of coal wall, the depressurization makes the fracture of coal increase, great mount of gas flooding into the roadway, and gas pressure reduces. As a result, the amount of gas diffusion and value $K_1$ is small. In the range of 5~20 m, because stress concentrates, coal body is pressured consolidation, at the same time porosity volume reduces, gas pressure increases. Therefore, the amount of gas diffusion increases, and value $K_1$ become bigger. In the range over 20 m, ground stress and gas pressure return to the original condition, so value $K_1$ reduces slightly. We can see the regularity of value $K_1$ change around coal wall is similar to the ground stress. Experiment shows that value $K_1$ has high generalization of the outburst factors, such as the coal self diffusion property, the dimension of ground stress, mining stress, gas pressure and the effect of their change.

![Fig. 1. Relations between K1 and L](image)

The provisions of article 34 in Regulations is different from article 38, when adopting the same index and method to respective prediction for outburst of rock cross-cut face uncovering coal and coal heading face. In two provisions, the depth of prediction drill holes is both 10 m (may be more than 10 m, article 34), value $K_1$ should be determined,
and has the same critical index value, but takes the different apertures 50~75 mm and 42 mm. Article 38 stipulates that the coal drilling cuttings $S$ should be measured with value $K_1$, but article 34 does not; article 34 stipulates that wet cuttings desorption index $K_1$ can be used as an outburst prediction index, but not in article 38. About the same prediction index and method, *Regulations* has the different provisions about pore diameter, depth and test contents. Therefore, it’s easy to cause the various interpretations in the practical application. Suggestion draft gives up the provision of the test pore diameter on rock cross-cut coal uncovering working face, but it is still inconsistent.

Articles 38 in *Regulations* stipulates that value $S$ and $K_1$ should be measured at the same time in the drilling process, but the reality shows that in case that drilling process and speed are not influenced, $S$ test and prediction has low accuracy, and the index is hyposensitivity. According to Sihe coal mine western region’s statistic result of outburst prediction from January 3, 2007 to May 16 (i.e. before 5·20 outburst accident), $K_1$ is 77 times more than the critical value, but $S$ only 2 times among 266 prediction results.

Based on above analysis, in order to simplify the prediction process, focus on $K_1$ measuring in drilling process, determine the value $K_1$ by cuttings from drilling hole of a range of apertures, and carry out an unified prediction method of desorption index for drill cuttings, author suggests that article 34 and 38 and other relevant provisions of prediction method based on desorption index for drill cuttings should be merged into one provision. The provision should be that, when index $K_1$ is used to predict outburst risk of the working face no matter rock cross-cut coal uncovering, coal roadway driving or mining, if drill hole aperture is less than 75mm and depth of drill hole is no more than 20m, either value $K_1$ of dry or wet cuttings can be used as prediction index and $S$ is just a reference index. Then special drilling tool for the prediction is not necessary, common drill hole such as suction and bleed-off holes can be used as prediction drill hole, and also increase the advance cycle forecast distance. As a result, it reduces the influence on the mining work, and rises the speed of the mining work.

Besides, there is also a $R$ index method in *Regulations* in article 37. Value $R$ is a combination of the initial velocity of gas emission from drill holes $q_m$ and $S$, so value $R$ is not suggested as an outburst prediction index for the same reason. In 2007 Chongqing Coal Research Institute carried out a contrast test that using $R$ value index method, the initial velocity of gas emission from drill holes $q_m$ and cuttings desorption index $K_1$ predicts outburst at Sihe coal mine. They did the test 9 times, drilled a total of 27 drill holes, and obtained the result that all the $R$ values are zeros or negative numbers, value $q_m$ exceeds critical value just 1 time, but value $K_1$ exceeds critical value 26 times. The results showed that value $q_m$ and $R$ are not sensitive to western regions in Sihe coal mine.

### 4.3. Occurrence condition and geological structure of coal seams

Lots of outburst examples show the areas where coal seam is buried deep, the occurrence changes rapidly or are around geological structure, which may be the prone location of outburst [10]. And its distribution performs a zonation pattern. So these 3 parameters can be used as input for multi-source information comprehensive prediction of outburst risk. At Sihe coal mine western region, the outburst scene of 5·20 outburst accident is just at the area where has 4 faultage; the occurrence changes rapidly and stress superposition, shown as Fig. 2. The distance each fault to outburst scene is about 30~80 m, about 33 meters in front of the transfixion of 6# crossheading and western belt roadway.

![Schematic diagram of outburst scene](image-url)

Fig. 2. Schematic diagram of outburst scene
In geological structure region, the destruction type of coal seam structure increases, and soft stratification becomes thicker; coal consistent coefficient becomes smaller, specific surface area increases, initial rate of methane diffusion rises, and tectonic stress exists; if the geological tectonic region is sealed, gas pressure and gas content also increase. So tectonic region is the region where outbursts frequently occur. Structure information is an outburst comprehensive prediction index which has strong generalization and directly inflects multiple outburst information sources. Therefore, tectonic coal body near geological structure lines is a risk region where warning should be directly shown and outburst prevention measures are taken, and this region is also called directly alarming area for short. Tectonic coal body a little far away from geological structure lines is the region where the comprehensive prediction should be taken combined with other indices. It means geological tectonic information is just one important input for multi-source information comprehensive prediction; this region is named awaiting comprehensive prediction area for short.

The concrete region of directly alarming area and awaiting comprehensive prediction area can be determined based on the practical condition of outburst. If there is no actual parameter, considering actual example of Sihe coal mine western region, the range of stress concentration caused by mining nearby the exposure coal wall, the relation between $K_1$ and stress concentration, and relevant clauses in Regulations, the author suggests that tectonic coal body which do not surpass 20 m to the lineation is directly alarming area, and tectonic coal body in the range of 20~50 m is awaiting comprehensive prediction area.

5. Conclusions

Coal and gas outburst is the result of structural mechanics properties of coal, ground stress and gas pressure. And in the gestate process of coal and gas outburst, some phenomena of the sound, electricity, magnetism and heat may be also created. So we can determine or predict the risk of coal and gas outburst by measuring these physical parameters.

The static sensitivity index system based on multi-source information comprehensive prediction of coal and gas outburst risk in Sihe coal mine includes many indices, such as coal’s destruction type, consistent coefficient, initial rate of methane diffusion, gas pressure, gas content, buried depth of coal seam, change of coal seams occurrence condition, information of geological structure, and cuttings desorption index, etc.

The standard code of article 34 in <Regulations> about specification of prediction drilling tool and prediction contents is inconsistent with article 38. These will lead to ambiguity in practical applications. This study suggests that articles should be all revised as follows: prediction drilling apertures should be determined according to engineering drilling tool and value $K_1$ of wet or dry cuttings which can be used as prediction index.

At last the screening of the dynamic continuous index system about multi-source information comprehensive prediction of coal and gas outburst risk still needs further study.

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