Research on integrated regional prediction method of dynamic disaster of coal and gas in deep coal roadway

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Abstract. Aiming at the existing regional prediction methods of outburst danger and shock hazard can not meet the needs of precise control of coal and gas dynamic disasters in deep coal roadway excavation working face, using weight comprehensive index method, 13 factors reflecting the outburst and rock burst are considered, such as gas pressure, content and impact energy index, the buried depth of coal seam and gas pressure are taken as the key indexes, and the integrated regional prediction of dynamic risk in deep coal roadway strip is realized; The dividing index of the dynamic risk state grade in the roadway strip is determined, which is divided into four grades: no dynamic risk, weak dynamic risk, general dynamic risk and serious dynamic risk, and the corresponding countermeasures are worked out. The application results show that the integrated regional prediction method realizes the safe and rapid excavation of in Ding Ji mine 1222(1) coal roadway and Xie Yi mine 5131(5) coal roadway which the grade are general dynamic risk, it has important reference significance for similar conditions of mine.

1. Introduction

Coal and gas outburst, impact ground pressure are the most typical two types of coal and gas dynamic disasters. Energy equation[1], Professor Hu Q T believes that the impact of ground pressure occurs in coal seams with an impact tendency, caused by ground stress, without considering the role of gas and other gas; coal and gas outburst occur in coal seams with outstanding dangers, stress and gas occur under the combined effect, gas is the main energy source. With the increase of the depth and intensity of coal mining, the dynamic disasters of deep Wells in high gas seams in some mining areas in China show new characteristics of coal and gas outburst and rock burst, For example, the emission of tons of coal and gas is less than 30m³, after the accident, the gas concentration in the return air roadway is generally less than 10%, and the stress in the ground is prominent in the process of disaster. Based on this, Wang Z[2] classified coal and rock gas dynamic disasters into 7 types, such as gas outburst, rock burst, roof caving, splay, floor heave, coal and rock extrusion, mine earthquake ; Meng X Z , Cao J J[3-4] classified coal and gas dynamic disasters into five types: outburst, ground burst, coal-rock gas pressure, coal-rock gas impact and composite. The classification of coal and gas power disasters provides a basis for coal mines to adopt targeted prevention and control measures.
According to 《Prevention of coal and gas outburst》 [5], prediction of dynamic danger area of coal and gas outburst is usually based on the method of coal seam gas parameters combined with gas geological analysis, parameters are mainly based on underground measured gas pressure and content, after regional prediction, divided into prominent and non-prominent risk areas; comprehensive index method is generally used for dynamic hazard prediction (evaluation) of rock burst[6], mainly considers the geological factors and mining technology factors that affect the dangerous state of rock burst, determines the dangerous grade.

In shallow mining, the gas parameter method and comprehensive index method are used to predict the outburst and rock burst zones respectively, and good application results have been obtained. in deep mining, the interaction between the two disasters is prominent, the existing prediction methods can no longer meet the needs of accurate management of coal and gas power disasters in deep mining and face. At the same time, through the analysis of the law of coal and gas dynamic disaster in huainan mining area, the dynamic disaster of coal roadway driving face accounts for 64.3%. Based on this, this paper studies the integrated regional prediction method of coal and gas dynamic disaster in deep coal roadway by considering coupling factors such as gas, geology, stress, physical and mechanical properties of coal and rock, so as to provide basis for the selection of precise prevention and control technical measures for coal roadway strip.

2. Existing regional prediction methods

2.1. Regional prediction of outburst risk
According to 《Prevention of coal and gas outburst》 [5], outburst risk prediction of outburst coal seam mainly depends on the measured coal seam gas pressure (P) or content (W), Less than 0.74MPa or 8m$^3$/t, it is determined as no outburst danger area; otherwise, it is outburst danger area., mainly used to guide the design of working surface and mining production.

2.2. Impact hazard zone prediction
The comprehensive index method is mainly used to predict the impact risk area, through analyzing the geological and mining technical factors that affect the occurrence of impact rock pressure, the degree and index of its impact risk are determined, and the risk state of impact rock pressure is evaluated comprehensively. according to the index size, the impact hazard degree is divided into four grades: no, weak, medium and strong, it is mainly used to guide the design of mining area, layout of working face and selection of coal mining method.

The two prediction methods have good application to the typical dynamic disaster prediction of outburst and impact respectively, but the effect to the deep composite dynamic disaster prediction is poor. For example, when the coal roadway driving in Dingji coal mine in huainan is predicted to be no outburst risk area ($W<6m^3/t$), the phenomenon of stress-dominated abnormal gas emission occurs, and there is a small amount of coal gas emission per ton, no obvious sorting of overburden coal and rock, and obvious mining pressure at the occurrence point of dynamic disaster. The existing prediction methods have certain limitations.

In addition, abrupt changes in the index size in the comprehensive index method, For example, when the dynamic failure time $D_T$ of coal is used to calculate, when $D_T=50ms$, the index is 3, and when $D_T=51ms$, the value is 2. It is obvious that the 1ms gap has a sudden change in the impact risk degree, which is inconsistent with the reality.

3. Integrated prediction method of coal and gas dynamic disaster in deep coal roadway

3.1. Identified risk factors and indices
Area of coal and gas dynamic disaster prediction need from gas, stress and physical, mechanical properties were analyzed; the analysis of influencing factors, comprehensive index method to consider mining depth, thickness of the hard strata of roof, gas pressure, content, rigidity coefficient, coal...
thickness, geological structure. That is, outburst, impact pressure unified, comprehensive determination of dynamic dangerous state level.

For coal roadway strips, the following 13 influencing factors are mainly considered:

1) $W_1$: The frequency of dynamic disasters in the same coal seam is an important empirical index to judge the risk degree of dynamic disasters. If there is no dynamic disaster in the coal seam, the coal seam itself and external conditions are not conducive to the occurrence of the disaster, and the index is 0. If the coal seam has multiple dynamic disasters ($\geq 3$) and mining activities are carried out in the same working mode, the probability of disaster is high, and the index is 3.

2) $W_2$: Roadway burial depth $h$ (key index). When $h < 400m$, $W_2=0$; When the buried depth reaches 1000m, the coal roadway working face is prone to large deformation or integral slat due to the lower strength of the coal seam than the rock mass. Therefore, when $h \geq 1000m$, no matter how other influencing factors change, the dynamic disaster level in this area is weak risk level. At the same time, in order to make the buried depth index more reasonable, when 400 $< h < 1000$, it is represented by a linear function, so that the index of dynamic disaster can change continuously, that is, $W_2 = 0.005h - 2$.

3) $W_3$, $W_6$: Uniaxial compressive strength $R_c$, sturdiness coefficient $f$ of coal. Both are the characteristics of the coal itself, the larger $R_c$ and $f$, the more elastic energy is accumulated in the coal, prone to coal burst disaster. When $R_c$ and $f$ are small ($R_c \leq 7MPa$ or $f \leq 0.3$), if the coal seam has outburst risk, outburst is likely to occur. Therefore, the influence of $R_c$ and $f$ on the dynamic disaster presents a law of high, medium and low on both sides, namely $R_c \leq 7MPa$, $W_3=3$, $7MPa < R_c < 14MPa$, $W_3=1$, $14MPa < R_c < 20MPa$, $W_3=2$, $R_c \geq 20MPa$, $W_3=3$. Similarly, when $f < 0.3$, $W_6=3$, $0.3 \leq f < 0.5$, $W_6=1$, $0.5 \leq f < 1$, $W_6=2$, $f \geq 1$, $W_6=3$.

4) $W_4$, $W_6$: Elastic energy index of coal $W_{ET}$, dynamic failure time of coal $D_T$. Both are the most direct indicators to express the bursting liability of coal. According to the Classification and index determination method of coal bursting liability, when $W_{ET} \leq 2$ and $D_T \geq 500ms$, there is generally no impact tendency, and the value is 0. When $W_{ET} \geq 5$ and $D_T < 500ms$, they generally have strong impact tendency, and the value is 3. When $2 < W_{ET} < 5$ and $500ms < D_T < 50ms$, it generally has weak shock tendency, which is expressed by linear function, $W_4 = W_{ET} - 2$, $W_6 = 0.0067D_T + 3.33$.

5) $W_7$: Coal seam gas pressure (Key indicators). It plays an important role in the strength and crack development of coal body, and is the key index affecting the dynamic disaster of coal and gas. Therefore, introducing gas pressure into the index system is one of the key factors. When $P \leq 0.5MPa$, the elastic energy condition of solid stress required for disaster is higher, so $W_7=0$. As gas pressure is the key index, when $P \geq 1.5MPa$, regardless of other conditions, the dynamic hazard level in this region is above weak risk. When $0.5MPa < P < 1.5MPa$, it is expressed as a linear function, $W_7 = 3P - 1.5$.

6) $W_8$: Coal seam gas content $W$. According to statistical data analysis, the average coal seam $W = 8m^3/t$ was calculated according to the minimum outburst gas pressure of 0.74MPa. Therefore, when $W \geq 8m^3/t$, $W_8=3$; When $W < 6m^3/t$, the energy condition required for power disaster is higher, $W_8=0$. When $6m^3/t < W < 8m^3/t$, it is expressed as a linear function, $W_8 = 1.5W - 9$.

7) $W_{10}$: The roof of coal seam has a thickness of hard rock within 30m $M_1$. Rock burst is easy to occur when there is a hard rock layer with thickness over 10m at 100m above the coal seam, especially within 30m, So when $M_1$ is greater than 10m, $W_{10}=3$; when $M_1 \leq 5m$, the existing supporting method of coal roadway can ensure the overall stability and integrity of roadway surrounding rock, $W_{10}=3$. When $5m < M_1 < 10m$, $W_{10}=0.6M_1 - 3$.

8) $W_{11}$: Coal seam thickness $M_2$. The thicker of coal seam, the better of gas generation and storage conditions and the higher of gas content, which provides material conditions for the occurrence of dynamic disasters, and the greater the risk of dynamic disasters in the coal seam. Generally speaking, it is difficult for $M_2 < 0.3m$ to form catastrophic prominent accidents, $W_{11}=0$; When $M_2 \geq 3m$, the phenomenon of retaining roof or bottom coal is easy to form in the roadway. It is difficult for these areas to meet requirements of support strength and become breakthrough point for occurrence of dynamic disasters. At this time, $M_2=3$; when $0.3 < M_2 < 3m$, $W_{11}=1.11M_2 - 0.33$. 
Table 1. Influence coal roadway dynamic risk factors and index

| serial number | factors | instructions | classification | dynamic hazard hazard index |
|---------------|---------|--------------|----------------|-----------------------------|
| 1             | $W_1$  | Frequency of dynamic disasters in the same coal seam $n$/time | $n=0$ | 0 |
|               |         |              | $n=1$ | 1 |
|               |         |              | $2 \leq n < 3$ | 2 |
|               |         |              | $n \geq 3$ | 3 |
| 2             | $W_2$  | Buried depth of roadway $h$ /m | $h < 400$ | 0 |
|               |         |              | $400 \leq h < 1000$ | $W_2=0.005h-2$ |
|               |         |              | $h \geq 1000$ | $W_2=\sum w_{w_{max}}$ |
| 3             | $W_3$  | Uniaxial compressive strength of coal $R_c$ /MPa | $R_c \leq 7$MPa | 3 |
|               |         |              | $7 < R_c < 14$ | 1 |
|               |         |              | $14 \leq R_c < 20$ | 2 |
|               |         |              | $R_c \geq 20$ | 3 |
| 4             | $W_4$  | The elastic energy index of coal $W_{ET}$ | $W_{ET} \leq 2$ | 0 |
|               |         |              | $2 \leq W_{ET} < 5$ | $W_4=W_{ET}-2$ |
|               |         |              | $W_{ET} \geq 5$ | 3 |
| 5             | $W_5$  | The complexity of geological structure | simple | 0 |
|               |         |              | medium | 1 |
|               |         |              | complex | 2 |
|               |         |              | very | 3 |
| 6             | $W_6$  | Dynamic failure time of coal $D_T$ /ms | $50 < D_T < 500$ | $W_6=-0.0067D_T + 3.33$ |
|               |         |              | $D_T \geq 500$ | 0 |
|               |         |              | $P \leq 0.5$ | 0 |
|               |         |              | $P \geq 1.5$ | $W_7=\sum w_{w_{max}}$ |
| 7             | $W_7$  | Coal seam gas pressure $P$ /MPa | $P \leq 0.3$ | 3 |
|               |         |              | $0.3 < P < 0.5$ | 1 |
|               |         |              | $P \geq 1$ | 2 |
| 8             | $W_8$  | Coefficient of firmness of coal $f$ | $W < 6$ | 0 |
|               |         |              | $6 < W < 8$ | $W_8=1.5W-9$ |
|               |         |              | $W \geq 8$ | 3 |
| 9             | $W_9$  | Coal seam gas content $W$ /m$^3$/t | $M_1 \leq 5$ | 0 |
|               |         |              | $5 < M_1 \leq 10$ | $W_{10}=0.6M_1-3$ |
|               |         |              | $M_1 \geq 10$ | 3 |
| 10            | $W_{10}$ | The roof of coal seam has a thickness of hard rock within 30m $M_1$/m | $M_1 \leq 0.3$ | 0 |
|               |         |              | $M_1 > 0.3$ | $W_9=1.11M_1-0.33$ |
| 11            | $W_{11}$ | Coal seam thickness $M_2$ /m | $H \leq 6$ | 0 |
|               |         |              | $6 < H < 15$ | 3 |
|               |         |              | $15 < H < 30$ | 2 |
|               |         |              | $H \geq 30$ | 0 |
| 12            | $W_{12}$ | Distance from goaf of upper working face $H$ /m | $L \leq 5$ | 0 |
|               |         |              | $5 < L < 15$ | 3 |
|               |         |              | $15 < H < 20$ | 2 |
|               |         |              | $L \geq 20$ | 0 |
| 13            | $W_{13}$ | Space distance between floor roadway and coal roadway to be excavated $L$ /m | $L \leq 0$ | 0 |
(9) $W_{12}, W_{13}$: The distance from goaf of upper stage working face $H$, the space distance between floor roadway and coal roadway to be excavated $L$. Generally, the horizontal distance between the lateral support pressure concentration area formed by working face mining and the goaf is 6~30m, and the horizontal distance between the stress concentration area formed by floor roadway excavation and the roadway space is 5~20m. Therefore, when $H \leq 6m$ and $L \leq 5m$, the coal roadway is in the unloading pressure zone, and the value is 0. When $6 < H \leq 15m$, when $5 < L \leq 15m$, the stress concentration is the largest, and the peak value is generally located in this region, and the value is 3. When $15 < H < 30m$ and $15 < L < 20m$ are generally post-peak stress concentration zones, and the value is 2. When $30 \leq H$, $20 \leq L$, it is the original rock stress zone, and the value is 0.

3.2. Determination of composite index

The weighted comprehensive index method is used to determine the comprehensive index ($W_t$) for assessing the dynamic hazard status of coal roadway working face.

$$W_t = \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} W_{i\text{max}}}, \quad h < 1000m \text{ and } P < 1.5MPa$$  (1)

$$W_t = 0.25 + \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} W_{i\text{max}}}, \quad h \geq 1000m \text{ or } P \geq 1.5MPa$$  (2)

$$W_t = 0.5 + \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} W_{i\text{max}}}, \quad h \geq 1000m \text{ and } P \geq 1.5MPa$$  (3)

In the formula: $W_t$—Comprehensive index of dynamic disaster risk; $W_i$—The $i$ factor is the actual index; $W_{i\text{max}}$—The exponential max of the $i$ influencing factor; $n$—Number of influencing factors.

4. Classification of danger level in coal roadway and its prevention and control measures

According to the calculated weighted composite index $W_t$ size, Table 2 determines the dynamic hazard status of the coal roadway strip area. To different danger grade, adopt corresponding prevention and control countermeasure.

Table 2. Classification of dynamic dangerous state in target area of coal roadway strip

| Risk rating | A | B | C | D |
|-------------|---|---|---|---|
| Composite $W_t$ | $W_t < 0.25$ | $0.25 \leq W_t < 0.5$ | $0.5 \leq W_t < 0.75$ | $W_t \geq 0.75$ |
| Dangerous state | No danger | Weak risk | General risk | Serious risk |

(1) No danger. Coal roadway strip $W_t < 0.25$. Regional measures are not implemented in the prediction region, only regional validation. When it is verified that there is no danger, tunneling can be carried out in accordance with the safety protection measures specified in the operating procedures; As long as the risk is verified once, the local comprehensive prevention and control measures shall be implemented in the subsequent tunneling operations in the area.
(2) Weak risk. Coal roadway strip 0.25 ≤ W_t < 0.5. The floor roadway measure project can be cancelled, but the comprehensive prevention measures and local comprehensive measures in this coal seam roadway area should be implemented.

(3) General risk. Coal roadway strip 0.5 ≤ W_t < 0.75. For outburst and compound coal roadway tunneling, the prevention and control measures of coal seam gas pre-extraction by drilling through layer of roof and floor roadway construction are generally adopted, and the local "four-in-one" comprehensive prevention and control measures are adopted in the process of tunneling; For the types of rock burst, the control measures of rock burst are generally adopted, and the operation can be carried out at least when the risk degree is reduced to weak risk through prediction and prediction.

(4) Serious risk. Coal roadway strip W_t ≥ 0.75. It is necessary to adopt the prevention and control measures of floor roadway combined with anti-reflection of unloading pressure and improvement of drainage effect for both outstanding and compound projects, such as hydraulic slotting, mechanical reaming, controlled blasting, hydraulic fracturing, etc. For the belt of coal roadway dominated by rock burst and stress, it can adopt pre-excavation roof and floor roadway pressure relief or adopt comprehensive prevention measures of strengthening pressure relief, gas drainage, strengthening support and dynamic risk monitoring and prediction in this coal seam.

5. Application effect

5.1. Dynamic hazard zone prediction

Ding Ji mine 1222(1) transport gateway 11-2 coal seam thickness of 2.7m on average, the average angle 3°, P_max=0.95MPa, f=0.85, ΔP=4mmHg, the destruction of the coal type III class, the rest of the indicators are shown in table 3.

Xie Yi mine 5131(5) machine lane, P_max=1.7 MPa, f=0.60, ΔP=10, the destruction of coal type III, W_t=6.49 ~ 9.27m^3/t, generally greater than 8m^3/t, the rest of the indicators are shown in table 3.

| Factors affecting | Practical factor analysis | Actual index |
|-------------------|--------------------------|--------------|
| Ding Ji Coal Mine | Xie Yi Coal Mine         |              |
| W_1               | 3                        | 0            |
| W_2               | 850~900                  | 865          |
| W_3               | 13.47                    | <7           |
| W_4               | 3.21                     | <2           |
| W_5               | Complex                  | Complex      |
| W_6               | 348                      | 590          |
| W_7               | 0.95                     | 1.7          |
| W_8               | 0.85                     | 0.6          |
| W_9               | 5.9                      | 9.27         |
| W_10              | >10                      | 8.2          |
| W_11              | 2.7                      | 1            |
| W_12              | >30                      | >30          |
| W_13              | >20                      | >20          |

Since the mining depth and gas pressure of key indexes have not reached the upper limit index, Formula (1) was used to calculate 1222(1) dynamic hazard hazard assessment index of coal roadway, W_t ≥ 0.53. According to table 2, the danger state of the whole area of 1221(1) coal roadway heading face is the general danger level.

The coal seam gas pressure in the key index is 1.7MPa, W_t ≥ 0.70 was calculated by formula (2). Therefore, the dangerous state of 5131(5) working face roadway area is the general dangerous level.
5.2. Regional control measures

1222(1) transportation gateway of Ding Ji mine adopts the prevention and control measures of drilling through strata of floor roadway to extract and relieve pressure. The vertical distance between floor roadway and 11-2 coal seam is 25m, the horizontal distance between floor roadway and coal roadway to be excavated is 30m. Each drilling yard of 40m along the strike in the bottom floor alley and each drilling yard of 30~40 drilling holes shall be constructed to control the 15m range on both sides of the coal roadway. The spacing between the bottom of the drilling holes shall be 5m×5m.

The penetration prevention measures are adopted to cover the drilling and extraction area of roof rock roadway in 5131(5) working face. The horizontal and normal distance between the roof roadway and 5131(5) roadway are 40.8m and 37m respectively. A group of perforating boreholes is arranged for each 10m of roof roadway, and each group of 7 boreholes. The boreholes are controlled to be 15m outside the contour lines of the two sides of roadway, and the spacing of the bottom of boreholes is 5m.

5.3. Application effect

In the process of 1222(1) transportation gateway tunneling, the outburst risk prediction of working face is carried out by means of circular prediction, $S_{\text{max}} = 4.8$kg/m, $q_{\text{max}} = 3.3$L/min, $\Delta h_{2\text{max}} = 140$mmHg, are less than the critical value, tunneling velocity is greater than 8m/d. 5131(5) working face tunneling velocity is greater than 10m/d, the safety and fast tunneling of coal roadway with general dangerous grade is realized, shows that the integrated regional prediction method of dynamic hazard in deep coal roadway is practical.

6. Conclusion

(1) The prediction method of coal and gas dynamic disaster area in coal roadway is improved and optimized, composite index of 13 factors reflecting outburst and impact, including gas pressure, content, impact energy index was adopted, coal seam burial depth and gas pressure are the key indicators, the integrated zone prediction of deep coal roadway is carried out by using weighted comprehensive index method.

(2) The classification index of dynamic dangerous state of coal roadway strip is determined, divided into four grades: no, weak, general and serious risk, and has formulated the corresponding prevention and control countermeasure.

(3) The safety and fast tunneling of deep coal roadway in Ding Ji and Xie Yi mine is realized by using the integrated regional prediction method of coal roadway strip.

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