Application of high pressure hydraulic slotting in pressure relief and permeability enhancement of coal roadway

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Abstract. In view of the coal seam without protective layer and the first coal seam with outburst risk, the method of high-pressure hydraulic slotting through layer drilling can be adopted to reduce the gas content in the strip of the coal roadway and realize the rapid driving of the coal roadway. Based on the practice of Xin-ji coal mine, the high pressure hydraulic slotting test is carried out. The results show that after adopting the high pressure hydraulic slotting measures, the radius of the slotting is 2.10 m, and the cumulative coal output is 3.25 ‰ of the raw coal in the coal lane. The permeability of coal seam is 25 times that in the uncut area, and the average single hole extraction volume is 3.21 times that in the uncut area. The effective radius of 30 days and 60 days after cutting is 2.3 times and 2.1 times of the original drilling. 49% of the drilling work quantity and 38% of the standard time of extraction are reduced. The driving speed of coal tunnel is 1.65 times that before adopting hydraulic cutting measures. Therefore, the high-pressure hydraulic slotting through the layer drilling can provide reference for the gas prevention and control work in the similar conditions of coal seam and the first coal seam with outburst risk.

1. Introduction

With the continuous increase of mining depth and intensity, the hazards of high ground stress and high gas are also increasing, and the mining environment is further deteriorated [1]. Under the condition of high-intensity development and mining in deep mines, some mining areas have common dynamic disasters with geo-stress as the leading role in the mining process of deep mines. The dynamic phenomena are more complex, the characteristics are fuzzy, and the disaster causes are common. It can not be explained by traditional coal and gas outburst mechanism or rock burst theory [2-5]. Coal and gas outburst and rock burst are two typical coal (rock) dynamic phenomena in coal mines, and their coupling phenomenon is prominent [6-7]. Because dynamic disasters such as coal and gas outburst in deep mines, and rock bursts may exist in different areas of the same mine or coal seam at the same time, the mechanism of dynamic disasters is both common and different. The existing prevention and control technology and equipment can not fully meet the needs of coal and rock dynamic disaster management in deep mines, such as Ping-ding-shan [8-9], Bei-piao, Fushun, Feng-cheng, Feng-feng and other outburst mines, in the mining process of deep mines, there are common dynamic disasters with ground stress as the leading role. Only depending on the standard of coal seam gas drainage can not completely solve the complex dynamic disaster of coal seam. We must carry out the dynamic disaster prevention and control from the angle of coal seam gas drainage.
standard and effective pressure relief. In addition to the pressure relief measures in the protective layer area of Coal Seam Group Mining, but at present, there is no effective regional pressure relief or fracture increasing permeability measures developed. How to effectively reduce pressure and increase permeability is one of the problems to be solved in coal industry.

Mining the protective layer is an effective way to prevent coal and gas outburst. For the coal seam with the protective layer mining conditions, through the regional control measures of mining the protective layer, the ideal gas control effect has been achieved. For the coal seam without the condition of mining protective layer and the first coal seam with outburst danger, it is possible to drill through the coal seam in the floor roadway to reduce the gas content in the coal seam strip. This method has many problems, such as the number of drill holes, long construction time and slow driving speed of the coal seam. However, the hydraulic cutting method of through the coal seam can reduce the stress of the coal seam in a large area, increase the permeability of the coal seam and improve the gas content extraction efficiency.

2. Design of drilling and slotting scheme for coal lane strip through layer
The test area is 220112 working face of 2201 mining area (elevation - 563m ~ - 595m). Coal seam 1 in 2201 mining area consists of 1 upper coal and 1 coal. The average thickness of 1 upper coal is 3.4m, and the average thickness of 1 coal is 3.9m. The average distance between 1 coal and 1 coal is 0.9m, and the average inclination of coal seam is 5°. The measured maximum gas pressure of 220112 working face is 1.65MPa, the measured gas content is 6.8m³/t, the soundness coefficient of coal seam group 1 in the test area is $f = 0.54$, and the initial gas release speed is 8.

According to the mining replacement situation in the test area, taking 220112 machine lane as the test object, through the construction of 7# under ~ 13# under the 220112 baseplate lane, through the slotted drilling to pre extract the strip gas of the coal lane and shield the coal lane, the length of this coal lane strip driving test is 400m, the slotted drilling controls the range of 20 m on both sides of the central line of the 220112 transport chute, and the hydraulic slotted drilling is arranged in 5 rows with a row spacing of 10 m × 10 m, 205 boreholes in total. The drilling design plan is shown in Figure 1.

| 220112 Floor roadway |
|-----------------------|
| 6#lower 7#lower 8#lower 9#lower 10#lower 11#lower 12#lower 13#lower 14#lower |
| 220112 Machine Lane |

Fig. 1 Layout plan of drill holes for seam cutting test in Coal Roadway

During the slotting, the backward slotting is adopted, with nozzle diameter of 2.0mm, slotting interval of 2.0m, slotting pressure of 95MPa - 100MPa, maximum pressure slotting time of 5min, slotting rotation speed of 40R / min and cross slotting.

3. Investigation and analysis of gas drainage effect

3.1. Investigation of coal output from borehole
A total of 205 cross cutting and slotting boreholes are constructed in the 7# lower ~ 13# lower drilling field. During the drilling and slotting period, the pressure is 95MPa ~ 100MPa, the number of single hole slotting cutters is 8 ~ 20, the time of single hole slotting is 1h ~ 3h, the average time of each knife slotting is 6min ~ 8min, the coal output from single hole is 2.2t ~ 7.6t, the average amount of chip removal from each knife slotting is 0.31t, the radius of slotting groove formed after the slotting is 2.10m, and the cumulative coal output is 3.25 % of the raw coal inventory of the coal lane. As shown
in Table 1 for the statistics of the amount of coal scraps in the seam cutting and drilling through the layer.

| Drill field No. | Number of holes drilled | Borehole length (m) | Length of coal hole section (m) | Number of single hole slotting knives | Single hole slag discharge (t) | Average slag discharge per knife (t) |
|-----------------|-------------------------|---------------------|---------------------------------|-------------------------------------|------------------------------|-------------------------------------|
| 7# lower        | 30                      | 68~136              | 21~41                           | 9~20                                | 2.4~6.3                      | 0.3                                 |
| 8# lower        | 30                      | 65~132              | 19~39                           | 9~19                                | 2.2~4.8                      | 0.28                               |
| 9# lower        | 30                      | 67~135              | 20~40                           | 10~19                               | 2.9~6.2                      | 0.32                               |
| 10# lower       | 25                      | 64~128              | 17~36                           | 8~18                                | 2.6~5.9                      | 0.33                               |
| 11# lower       | 30                      | 66~138              | 20~41                           | 10~20                               | 3.1~7.6                      | 0.36                               |
| 12# lower       | 30                      | 70~140              | 18~42                           | 9~21                                | 2.2~5.2                      | 0.27                               |
| 13# lower       | 30                      | 67~135              | 22~40                           | 12~20                               | 3.2~6.8                      | 0.33                               |

3.2. Study on coal seam permeability

Before high pressure hydraulic cutting, the original permeability coefficient of coal seam 1 in machine lane of 220108 working face is 0.03962m²/MPa²·d by simple drainage method. The permeability coefficient of coal seam 1 is 0.9905 m²/MPa²·d, which is 25 times higher than the original coal seam.

3.3. Investigation on the net volume of extraction

After the completion of the hydraulic cutting of the drill holes through the seam in the strip of the 220112 machine lane, 205 drill holes were inspected for drainage. The 60 day gas drainage pure volume curve is shown in Figure 2. After hydraulic slotting, the maximum value of gas extraction purity in the drilling field is 9.97m³/min, the average value of gas extraction purity in the drilling field is 7.27m³/min, and the average single hole extraction purity is 0.035m³/min. The relationship between the gas extraction purity and time is stable, and the gas extraction purity decreases slowly.

Compared with the data during the pre pumping period of the coal roadway strip through the layer in the 220116 air Roadway Floor Roadway of coal seam group 1, 406 through layer boreholes are constructed within 400m, the maximum value of the net extraction volume of the drilling field is 6.31m³/min, the average value is 4.42m³/min, and the average single hole extraction volume is 0.0109m³/min.

![Fig. 2 Curve of net extraction volume of coal roadway with slit drilling](image)

After using hydraulic slotting to relieve pressure and increase permeability, the average single hole extraction purity is 0.035m³/min, which is 3.21 times of the average single hole extraction purity of 0.0109m³/min for non slotted holes. After hydraulic slotting, the net gas extraction quantity of the
through hole increases significantly. The comparison of the extraction purity before and after slitting is shown in Figure 3.

Fig. 3 Comparison of pure gas drainage volume of single hole with slotted hole

3.4. Study on residual gas content in coal seam and effective extraction radius

The residual gas content test shall be carried out respectively 30 days and 60 days after the completion of 7#lower ~ 13#lower cutting and extraction in the bottom roadway of 220112, as shown in Table 2.

| Extraction time (d) | Borehole No. | Residual gas content (m$^3$/t) | Extraction time (d) | Borehole No. | Residual gas content (m$^3$/t) |
|---------------------|--------------|-------------------------------|---------------------|--------------|-------------------------------|
| 30                  | 3-1          | 4.79                          | 6-1                 | 3.25         |
|                     | 3-2          | 4.98                          |                     | 6-2          | 3.44                          |
|                     | 3-3          | 5.27                          | 6-3                 | 3.32         |
|                     | 3-4          | 4.88                          | 6-4                 | 3.75         |

According to Table 2, the residual gas content in 30 days of extraction is 4.79 m$^3$/t ~ 5.27 m$^3$/t, with a decrease of 26.76%; the residual gas content in 60 days of extraction is 3.25 m$^3$/t ~ 3.75 m$^3$/t, with a decrease of 49.41%.

Calculate the residual gas content according to the collected extraction data, and investigate the effective extraction radius of slotted and uncut holes, as shown in Table 3 and Figure 4.

| Extraction time (d) | Effective extraction radius after slotting (m) | Effective extraction radius without slotting (m) |
|---------------------|-----------------------------------------------|-----------------------------------------------|
| 30                  | 5.5                                           | 2.38                                          |
| 60                  | 7.1                                           | 3.36                                          |

According to Table 3, the extraction effective radius of 30 days and 60 days after cutting is 4.43m and 6.01m respectively, which are 2.3 times and 2.1 times of the original drilling effective radius.

Fig. 4 Comparison of effective radius of extraction

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According to Fig. 4, under the same extraction time, the effective radius of coal seam group 1 in Xin-ji coal mine is significantly higher than that of the original extraction after high-pressure hydraulic cutting.

4. Effect comparison before and after cutting

4.1. Comparison of drilling quantities and standard extraction time before and after slotting

A total of 205 hydraulic slotted boreholes were constructed in 220112 machine lane, which reached the standard in 37 days. Based on the comparison of drilling and extraction data of 220116 air roadway strip through layer, in order to achieve the same extraction effect, 406 through layer drilling and extraction up to standard time of 60 days need to be constructed, as shown in Figure 5. By using high-pressure water jet to cut the seam, the drilling work quantity and the standard time of extraction are reduced by 49% and 38%.

![Fig. 5 Comparison between the quantities before and after cutting and the standard time of extraction](image)

4.2. Comparison of K1 value and drilling cuttings before and after cutting

As shown in Table 4 and Figure 6 for the drilling cuttings and K1 value data during the driving of 220112 machine lane and 220116 air lane. The average value of gas analysis index K1 is 0.31 mL/g·min\(^{0.5}\) and the average value of drilling cuttings is 3.27kg during the driving of 220116 air tunnel. The average value of K1 is 0.23 mL/g·min\(^{0.5}\) and the average value of drilling cuttings is 2.98kg during the driving period of 220112 machine tunnel. The data shows that the coal seam gas is fully released after the hydraulic slotting pressure relief and outburst elimination is adopted in the working face.

| The uncut working face of 220116 air lane | Amount of cuttings (kg) | 3.3 | 3.2 | 3.4 | 3.3 | 3.2 | 3.1 | 3.3 | 3.4 |
| K1 value (mL/g·min\(^{0.5}\)) | 0.29 | 0.26 | 0.29 | 0.26 | 0.33 | 0.32 | 0.33 | 0.32 |

| Amount of cuttings (kg) | 3.1 | 3.2 | 3.2 | 3.3 | 3.3 | 3.2 | 3.4 | 3.5 |
| K1 value (mL/g·min\(^{0.5}\)) | 0.33 | 0.31 | 0.32 | 0.34 | 0.32 | 0.33 | 0.34 | 0.29 |

| Amount of cuttings (kg) | 3.1 | 3.3 | 3.2 | 3.4 | 3.4 | 3.0 | 3.2 | 3.4 |
| K1 value (mL/g·min\(^{0.5}\)) | 0.29 | 0.26 | 0.29 | 0.26 | 0.33 | 0.32 | 0.33 | 0.32 |

| Cutting face of 220112 machine Lane | Amount of cuttings (kg) | 2.5 | 2.5 | 2.7 | 2.5 | 2.6 | 3.2 | 3.1 | 3.2 |
| K1 value (mL/g·min\(^{0.5}\)) | 0.22 | 0.23 | 0.21 | 0.23 | 0.23 | 0.22 | 0.23 | 0.23 |
| Amount of cuttings (kg) | 2.9  | 3.1  | 3.2  | 3.2  | 3.3  | 3.1  | 3.2 |
|------------------------|------|------|------|------|------|------|------|
| K1 value (mL/g·min⁻⁰·⁵) | 0.23 | 0.23 | 0.23 | 0.25 | 0.23 | 0.22 | 0.24 |

| Amount of cuttings (kg) | 2.8  | 3.3  | 3.1  | 3.0  | 2.9  | 3.0  | 2.8  | 3.1 |
|------------------------|------|------|------|------|------|------|------|------|
| K1 value (mL/g·min⁻⁰·⁵) | 0.24 | 0.22 | 0.20 | 0.22 | 0.21 | 0.24 | 0.25 | 0.22 |

Fig. 6 Comparison of cuttings and K1 before and after cutting

4.3. Comparison of driving speed of coal roadway before and after cutting seam
During the driving period of 220116 air tunnel, the average daily footage of the tunnel is 7.1m. After adopting the hydraulic slotting pressure relief and permeability increasing technology, the driving speed of 220112 machine tunnel has increased significantly, the average daily footage has increased to 11.7m, 1.65 times that before adopting the hydraulic slotting measures.

5. Conclusion
(1) After adopting the high-pressure hydraulic cutting measures, the radius of the seam is 2.10 m, and the cumulative coal output is 3.25 % of the raw coal in the coal lane strip. The permeability of coal seam is 25 times that in the uncut area, and the average single hole extraction volume is 3.21 times that in the uncut area. The effective radius of 30 days and 60 days after cutting is 2.3 times and 2.1 times of the original drilling. 49% of the drilling work quantity and 38% of the standard time of extraction are reduced. The driving speed of coal tunnel is 1.65 times that before adopting hydraulic cutting measures.

(2) The technology of high pressure hydraulic slotting, pressure relief and permeability enhancement can quickly eliminate the risk of outburst in the coal roadway, realize the safe and rapid driving of the coal roadway, and provide reference for the gas prevention and control work of the single outburst coal roadway driving under similar conditions.

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