Research on high pressure hydraulic slotting technology for pressure relief and permeability increase of coal seam

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Abstract. High pressure hydraulic slotting technology is one of the technical means of pressure relief and permeability increase in high gas and low permeability coal seam area. Different coal seam conditions, the selected slotting process parameters are different. In order to obtain the reasonable parameters of high-pressure hydraulic cutting in soft coal seam, the field tests of different cutting pressure, different cutting time, different rotation speed and different cutting spacing were carried out in No.2 coal seam of Xue-hu Coal Mine. The test results show that the optimal cutting pressure is 60MPa ~ 70MPa, the cutting speed is 80R / min, the cutting interval is 2m / knife, and the coal output of single knife is controlled at about 1.6T. Tests were carried out for different spacing of boreholes, the results show that the average extraction concentration of slotted hole is 1.75 times that of common hole, and the average extraction purity is 3.25 times that of common hole.

1. Introduction
China is one of the countries with the most serious coal and gas disasters in the world. With the continuous increase of mining depth and intensity, the hazards such as in-situ stress and gas also increase, and the permeability of coal seam decreases [1-2]. In recent years, the phenomenon of coal and gas dynamic disasters in some deep mines in China tends to be complex, with fuzzy features and common causes, which can not be explained by the traditional coal and gas outburst theory [3-4]. The existing gas prevention technology and equipment can not fully meet the needs of coal and gas dynamic disaster management in deep mines.

Hydraulic slotting technology is a kind of high-tech developed rapidly in recent years. It can not only weaken or eliminate the energy power of disaster, but also change the physical and mechanical properties of coal and rock, and realize the dual effect of pressure relief and permeability increase of coal seam [5-6]. It is one of the technical development directions for the prevention and control of coal and rock power disaster. According to different coal seam conditions, in order to achieve the best effect of disaster prevention and control, the cutting process parameters are different, so it is necessary to carry out this research. In view of this problem, some scholars [7-9] have carried out relevant research and obtained some research results. The jet pressure in the test is generally medium and low pressure. Based on the high-pressure equipment, this paper explores the technological parameters of high-pressure hydraulic slotting to provide reference for the prevention and control of coal and gas outburst in deep mines.
2. The principle of pressure relief and permeability enhancement of high pressure hydraulic slotting

The technology of high pressure hydraulic joint cutting, pressure relief and permeability enhancement is to scour and strip the coal around the borehole, increase the cracks in the coal, greatly improve the gas flow state in the coal seam, create favorable conditions for gas drainage, change the original stress and crack state of the coal body, ease the stress tension state in the coal body and surrounding rock, which can weaken or eliminate the outburst dynamic state In addition, it can greatly change the physical and mechanical properties of outburst coal seam, play the role of pressure relief and outburst prevention, and improve the permeability and gas release capacity.

3. Engineering geological conditions

3.1 Slotting pressure test

(1) Statistical analysis of coal output

Three kinds of slotting pressures, 40MPa, 60MPa and 80MPa, were investigated in the experimental design. According to three kinds of slotting pressures, two boreholes were selected to carry out ultra-high pressure hydraulic slotting test in the bottom extraction roadway of 2306 air lane. The slotting time of single knife was 25min, the rotation speed was 80R / min, and the slotting distance was 2m/knife.

It can be seen from Fig. 1 that the average coal output of a single knife is 1.05t when the slotting pressure is 40MPa; 1.68t when the slotting pressure is 60mp; 2.22t when the slotting pressure is 80mp; therefore, the average coal output of a single knife increases with the increase of the slotting pressure. However, when the cutting pressure increases to 80MPa, serious hole plugging occurs.

(2) Statistical analysis of extraction net volume

The average gas drainage volume of the test borehole within 3 months after cutting the seam is shown in Fig. 2.

It can be seen from Fig. 2 that when the slotting pressure is 40MPa, the average gas extraction purity of the borehole is 0.001-0.008m³/min, 0.004m³/min; when the slotting pressure is 60MPa, the
average gas extraction purity of the borehole is 0.012-0.004 m$^3$/min, 0.007 m$^3$/min; when the slotting pressure is 80 MPa, the average gas extraction purity of the borehole is 0.005-0.013 m$^3$/min, 0.009 m$^3$/min. Therefore, the optimal cutting pressure of the super-high pressure hydraulic cutting seam in No.2 coal seam of Xue-hu Coal Mine is 60 MPa ~ 70 MPa.

3.2 Slotting time test of single knife

In the experiment design, three kinds of slotting time were investigated, which were 20 min, 25 min and 30 min respectively. According to three kinds of slotting time, two boreholes were selected to carry out ultra-high pressure hydraulic slotting test at the bottom of 2306 air lane. The slotting pressure was 60 MPa, the rotation speed was 80 R/min, and the slotting distance was 2 m/knife.

(1) Statistical analysis of coal output

Fig. 3 shows the average coal output of a single drill under different slotting times.

From Fig. 3, it can be seen that the average coal output of a single knife is 1.45 t when a single knife cuts a seam for 20 min; 1.67 t when a single knife cuts a seam for 25 min; 1.77 t when a single knife cuts a seam for 30 min; it can be seen that the average coal output of a single knife increases with the increase of cutting time. However, when the cutting time increased from 25 minutes to 30 minutes, the coal output of single knife cutting did not increase significantly.

(2) Statistical analysis of extraction net volume

The average gas drainage volume of the test borehole within 3 months after cutting the seam is shown in Fig. 4.

From Fig. 4, it can be seen that the average gas extraction purity of the borehole is 0.003 ~ 0.008 m$^3$/min and 0.005 m$^3$/min when the single knife is cut for 20 min; the average gas extraction purity of the borehole is 0.005 ~ 0.012 m$^3$/min and 0.008 m$^3$/min when the single knife is cut for 25 min; the average gas extraction purity of the borehole is 0.006 ~ 0.011 m$^3$/min and 0.085 m$^3$/min when the single knife is cut for 30 min. It can be seen that after the cutting time increases from 25 min to 30 min, the average gas extraction volume of the borehole has little change.

Therefore, the optimal cutting time of the super-high pressure hydraulic cutting is 25 min.
3.3 Slotting speed test
In the experiment design, three kinds of different slotting speeds were investigated, 40 R / min, 60 R / min and 80 R / min respectively. According to three different cutting speeds, two boreholes were selected in the bottom extraction roadway of 2306 air lane to carry out ultra-high pressure hydraulic cutting test. The cutting pressure was 60MPa, the cutting time of single knife was 25min, and the cutting interval was 2m / knife.

(1) Statistical analysis of coal output

It can be seen from Fig. 5 that the average coal output of single knife is 2.05t when the cutting speed is 40R/min, but the hole plugging is serious; the average coal output of single knife is 1.84t when the cutting speed is 60R / min, and the hole plugging phenomenon also exists; the average coal output of single knife is 1.77t when the cutting speed is 80R / min, and the slag discharge is smooth. It can be concluded that low rotation speed can increase the coal output of single drill. However, due to the low hardness of coal seam in Xue-hu Coal Mine, low rotation speed will reduce the auxiliary slag discharge capacity of drill pipe, resulting in the phenomenon of hole plugging and hole spraying. Therefore, according to the characteristics of No.2 Coal Seam in Xue-hu Coal Mine, the cutting rotation speed is 80 R / min.

3.4 slit spacing test
In the experimental design, two kinds of slotting spacing were investigated, 2m / knife and 3m / knife respectively. According to two kinds of slotting spacing, two boreholes were selected to carry out ultra-high pressure hydraulic slotting test at the bottom of 2306 air tunnel. The slotting pressure was 60MPa, the slotting time of single knife was 25min, and the rotation speed was 80R / min.

(1) Statistical analysis of coal output

Fig. 6 shows the average coal output of single cutter under different slotting spacing.

It can be seen from Fig. 6 that the average coal output of a single knife is 1.58t when the slit spacing is 2m / knife; the average coal output of a single knife when the slit spacing is 3m / knife is 1.67t.

(2) Statistical analysis of extraction net volume
The average gas drainage volume of the test borehole within 3 months after cutting the seam is
shown in Fig. 7.

![Fig. 7 Average gas drainage volume under different slotting spacing](image)

It can be seen from Fig. 7 that when the cutting gap is 2m / knife, the average gas extraction purity of the borehole is 0.007 ~ 0.011m$^3$/min, which is 0.008m$^3$/min; when the cutting gap is 3m / knife, the average gas extraction purity of the borehole is 0.004 ~ 0.009m$^3$/min, which is 0.006m$^3$/min. It can be concluded that the clearance between cuts of 2 m / knife is 33% higher than that of 3 M / knife.

Therefore, the optimal cutting distance of the super-high pressure hydraulic cutting seam in the No.2 coal seam of Xue-hu Coal Mine is 2m / knife.

4. Analysis of gas drainage effect in different borehole spacing

(1) Data analysis of 5 m × 5 m slotted test hole extraction

See Fig. 8 and Fig. 9 for the extraction data of slotted test borehole arranged at the interval of 5m × 5m.

![Fig. 8 Curve of average daily extraction concentration of 5 m × 5 m slotted test hole](image)

![Fig. 9 Change curve of daily average extraction purity of 5 m × 5 m spacing slotted test hole](image)

It can be seen from figure 8 that the average extraction concentration in 180 days of slotted test drilling with 5m × 5m spacing is 48% at the maximum, 21.2% at the minimum and 34.5% at the average.

It can be seen from Fig. 9 that the maximum average net extraction volume within 180 days for slotted test borehole with 5m × 5m spacing is 0.011m$^3$/min, the minimum is 0.001m$^3$/min, and the average is 0.0045m$^3$/min.

(2) Data analysis of 6 m × 6 m slotted test hole extraction

The extraction data of slotted test boreholes arranged at 6m × 6m spacing are shown in Fig. 10 and Fig. 11.
From Fig. 10, it can be concluded that the maximum average extraction concentration is 54.8%, the minimum is 30.5%, and the average is 45% within 150 days after the slotted test drilling with 6m × 6m spacing.

It can be seen from Fig. 11 that the maximum average net extraction volume within 150 days for slotted test borehole with 6m × 6m spacing is 0.010m³/min, the minimum is 0.003m³/min, and the average is 0.0057m³/min.

(3) Data analysis of 7 m × 7 m slotted test hole extraction

See Fig. 12 and Fig. 13 for the extraction data of slotted test boreholes arranged at a spacing of 7m × 7m.

It can be seen from Fig. 12 that the average extraction concentration in 137 days of slotting test borehole with 7m × 7m spacing is 68.2% at the maximum, 45.1% at the minimum and 55.0% on the average.

It can be seen from Fig. 13 that the maximum average extraction purity within 137 days is 0.009m³/min, the minimum is 0.004m³/min, and the average is 0.0064m³/min.

(4) Data analysis of 8 m × 8 m slotted test hole extraction

See Fig. 14 and Fig. 15 for the extraction data of slotted test boreholes arranged at a spacing of 8m × 8m.
It can be seen from Fig. 14 that the maximum average extraction concentration is 55.9%, the minimum is 24.6% and the average is 36.3% within 120 days after the slotted test borehole is arranged at a spacing of 8m × 8m.

It can be seen from Fig. 15 that the maximum average net extraction volume of slotted test borehole within 120 days is 0.010m³/min, the minimum is 0.005m³/min, and the average is 0.007m³/min.

(4) Comparison and analysis of extraction data between slotted hole and common hole
The average daily extraction data of slotted hole and common hole are shown in Fig. 16 and Fig. 17.

From Fig. 16, it can be seen that the daily average extraction concentration of common boreholes is 35.1% at the maximum, 13.0% at the minimum and 23.1% at the average; the daily average extraction concentration of slotted boreholes is 53.7% at the maximum, 22.9% at the minimum and 40.4% at the average. The average extraction concentration of slotted hole is 1.75 times of that of common hole.

From Fig. 17, it can be seen that the daily average net extraction volume of ordinary boreholes is 0.0046m³/min at the maximum, 0.0003m³/min at the minimum, and 0.0016m³/min at the average; the daily average net extraction volume of slotted boreholes is 0.0096m³/min at the maximum, 0.0016m³/min at the minimum, and 0.0052m³/min at the average. The average extraction volume of slotted drilling is 3.25 times of that of ordinary drilling.

5.Conclusion
(1) Through field test, the parameters of ultra-high pressure hydraulic slotting suitable for the characteristics of No.2 Coal Seam in Xue-hu Coal Mine are obtained: slotting pressure 60 ~ 70MPa, slotting speed 80R / min, slotting interval 2m / knife, and coal output of single knife controlled at about 1.6t.

(2) After the ultra-high pressure hydraulic slotting, the gas extraction concentration is obviously increased, and the average extraction concentration of slotted drilling is 1.75 times that of ordinary drilling.
(3) After the ultra-high pressure hydraulic slotting is adopted, the average daily extraction purity of common drilling is 0.0016m³/min; the average daily extraction purity of slotted drilling is 0.0052m³/min. The average extraction volume of slotted drilling is 3.25 times that of ordinary drilling.

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