Research on Reasonable Drilling Parameters of Hydraulic Reaming in Soft and Thick Coal Seam and Its Application in Field

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Abstract. In view of the fact that the outburst disaster of the soft 3# coal seam in the Sangshuping Coal Mine is mainly caused by in-situ stress, it is proposed to use hydraulic reaming, pressure relief and anti-reflection technology to remove some of the high geostress in the coal seam and improve gas drainage efficiency. Numerical simulation software was used to analyze the distribution of plastic failure and stress distribution of the coal body after reaming under the three-hole spacings of 4m, 6m, and 8m. The results show that the radius of the plastic failure zone around the borehole is about 2.2m when the rate of expanded coal chips is 3%; the width of the pressure relief area of a single reamed hole is about 3.2m. When the drilling hole spacing is 6m, it has a good pressure relief effect and reasonable amount of drilling work. After the reaming, the drainage concentration and flow rate are both improved. After reaming, the extraction concentration and flow rate have been improved. The hydraulic reaming technology can effectively solve the problem of outburst prevention in the thick seam of soft outburst dominated by ground stress in Sangshuping Coal Mine.

1. Introduction
Coal and gas outburst is a complex physical phenomenon that is combined by factors such as geostress, gas, and the physical and mechanical properties of coal [1–3]. The prevention and control of coal and gas outburst is based on the leading factors of its occurrence, and targeted treatment measures are taken. In the last century, China's coal mining depth was not large. High gas pressure in coal seams was the dominant factor leading to prominent disasters. Using a large area of pre-drained coal seam gas to reduce the coal seam gas pressure to a certain degree can effectively eliminate the prominent danger. However, with the deepening of the coal seam mining depth in China, geostress and gas pressure continue to increase, and coal and gas dynamic disasters with low gas content have occurred in some mining areas.

For the same outburst coal seam, when using protective layer mining combined with pressure relief gas drainage, the outburst prevention effect is significant, and a single downhole or through-hole drilling pre-drainage coal seam gas, even if the coal gas content is reduced to the same level The effect of prevention and control of coal and gas outburst is not ideal, the reason is that it can not effectively reduce the stress state of coal seam. China is a vast country, and the coal seam occurrence conditions in some
mining areas do not meet the mining conditions of the protective layer. The regional outburst prevention only relies on the traditional large-area pre drainage coal seam gas, which can not effectively solve the coal and gas dynamic disaster risk of the coal seam with large buried depth or high in-situ stress[4~9].

The new structure of the Hancheng mining area is highly active and belongs to a shallow source seismic activity danger zone with a ground pressure background of a magnitude 6 earthquake. The main mining 3# coal seam in the mining area had a total of about 150 outbursts, of which 60% were extruded. Due to the development of tectonic stress in the mining area and the soft and broken 3# coal seam, there have been many delayed and prominent accidents. Part of the mining area does not have the protection layer mining conditions. The single coal seam mining mainly uses traditional down-drilling and through-drilling holes for large-area pre-drainage of coal seam gas for regional outburst prevention. The pre-draining time is long and the reliability of the effect is poor situation.

According to the characteristics of coal seam occurrence and the leading factors of dynamic disaster in 3# coal seam of Hancheng mining area, the paper puts forward the Countermeasures of outburst prevention, which mainly uses hydraulic reaming technology to depressurize the coal seam, supplemented by gas extraction, and carries out numerical simulation analysis on the spacing of borehole layout, and obtains reasonable hole layout parameters, so as to provide basis for mine disaster management.

2. Simulation scheme and model establishment
The FLAC3D numerical simulation software is used to simulate the distribution of plastic failure area and the pressure relief of coal body after the coal body reaming under the condition of different spacing, which provides the basis for the coal mine to formulate the hydraulic reaming test scheme on site

The model is 20 m × 20 m in length and width, divided into three layers, the top layer is 2.5 m in height; the middle layer is 5.0 M in height; the bottom layer is 2.5 m in height. The direction of reaming is perpendicular to the coal seam. Using Mohr Coulomb constitutive model, the upper boundary of the model is set as the stress boundary, and the uniform load is applied according to the thickness of the overlying strata. According to the situation of 4321 working face, the buried depth of the simulated coal seam is 560m; the horizontal displacement and velocity of the four boundaries before and after are set as 0, and the vertical displacement and velocity of the bottom boundary are also set as 0.

It is estimated that the equivalent pore diameter of the reaming borehole is about 0.8m according to the 3% of the expanded coal rate. See Table 1 for the parameters of the model. The plastic failure distribution and pressure relief were simulated under the conditions of drilling distance of 4m, 6m and 8m.

![Figure 1. Numerical 3D model diagram](image)

Table 1. Table of coal and rock parameters used in numerical simulation

|        | elasticity Modulus /GPa | Cut Modulus /GPa | Anti-stress strength /MPa | Naimo Rub angle /° | Cohesion /MPa |
|--------|------------------------|-----------------|---------------------------|--------------------|--------------|
| Coal seam | 0.65                   | 0.35            | 0.33                      | 26                 | 0.39         |
| Rock formation | 4.35                  | 3.35            | 4.90                      | 43                 | 5.15         |
3. Analysis under different layout intervals

3.1. Analysis on the range distribution of plastic failure zone of coal body

The distribution of plastic failure is shown in Fig. 2 under the conditions of 4 m, 6 m and 8 m spacing between the final holes of the through layer drilling. It can be seen from the figure that with a certain rate of expanded coal chips (3% of expanded coal chips), the radius of the plastic failure zone formed by a single borehole is basically the same, which is about 2.1m. In the case of a distance of 4m, the plastic failure area formed by the reaming hole forms a continuous piece; in the case of a hole spacing of 6m, the distance between the plastic failure areas formed by the reaming hole is 1.8m; in the case of a hole spacing of 8m The distance between the plastic failure zones formed by the reaming and drilling is 3.8m. From the distribution of plastic failure area, although the overall pressure relief effect is good when the distance between boreholes is 4m, there may be a series of holes leading in the process of gas drainage in the later period of drilling, which is not conducive to the management of gas drainage, and the amount of drilling work is too large; when the distance between boreholes is 8m, the plastic failure range formed is not enough to relieve the overall pressure in the control range, and when the distance between boreholes is 6m, the drilling work can be considered The quantity and pressure relief effect are reasonable.

![Drilling pitch comparison](image)

Figure 2. Size and distribution of plastic failure zones around reaming holes

3.2. Pressure relief effect analysis after reaming

Take the vertical section of two adjacent drill holes in the model, and compare the third principal stress distribution in the coal body with different drill hole spacings. The stress of the coal body near the hole is reduced, and a pressure relief area is formed. As can be seen from the figure, the width of the pressure relief area formed by a single borehole is basically the same, with a stress of 3%. It moves to the deep part and forms a certain range of stress concentration area outside the pressure relief area. When the borehole spacing is 4m, the stress concentration areas formed by two adjacent boreholes overlap, which is not good for preventing geostress-dominated outburst disasters, as shown in Figure 3. When the borehole spacing is 8m, the phase The stress concentration area formed by two adjacent boreholes is far away, but the amount of coal expanded from a single borehole is limited, and it is difficult to relieve the pressure of the coal body as a whole. When the borehole spacing is 6m, the stress concentration areas formed by two adjacent boreholes are not superimposed, and the concentration areas are only adjacent to each other. In addition, the soft coal body has creep properties. In the later gas drainage process, Over time, the coal body around the hole will deform to free space, and the pressure relief effect is better than the simulation effect, as shown in Figure 4.
4. Field effect inspection and verification

According to the results of the foregoing numerical analysis, the drilling arrangement with a spacing of 6m × 6m through the high-pressure water jet reaming drilling arrangement is more in line with the actual situation of the Sangshuping coal mine.

Test the relevant parameters of reaming and ordinary drilling in the test area. The attenuation coefficient of gas flow of the borehole before reaming of 3# coal seam is 0.0796 ~ 0.1020d⁻¹, which belongs to the difficult coal seam. The gas flow attenuation coefficient is 0.0181 ~ 0.0392 d⁻¹, which belongs to the coal seam that can be pumped. The gas flow attenuation coefficient of the borehole is reduced by 30~60%. After reaming, the drilling flow rate was increased from 1.0855L/min to 2.3771L/min, and the gas emission from drilling increased by 1.3 times, as shown in Table 2. Through the comparative analysis of coal expansion rate, initial gas emission in the borehole before and after
reaming, and attenuation coefficient of borehole flow, it is concluded that the reamability of the coal seam is significantly improved by reaming with high-pressure water jets.

Table 2. Measurement results of gas emission related parameters before and after reaming

| Compare items          | Initial gas emission amount during drilling (L/min) | Attenuation coefficient of drilling flow (d⁻¹) |
|------------------------|---------------------------------------------------|---------------------------------------------|
| Unreamed drilling      | 1.0855                                            | 0.0796~0.1020                               |
| Reaming drilling       | 2.3771                                            | 0.0181~0.0392                               |

Generally, the pre-drainage concentration of ordinary boreholes in mines does not exceed 10%, and the single-hole drainage volume is 0.020m³/min. After the hydraulic expansion technology is adopted in a large area, the average drainage concentration reaches 25%, and the average single open flow rate is doubled. Both the extraction concentration and the extraction volume of the holes have been significantly increased. At the same time, a large amount of coal debris is discharged through the reaming of the high-pressure water jet, which increases the free space inside the coal seam, removes part of the stress in the coal seam, eliminates the outstanding coal body elastic energy, and has a significant effect on controlling the dominant stress of the Sangshuping coal mine.

In the case of the 4317 working face adjacent to the test working face, in the case of unprotected mining, the stripping of the pre-drained coal roadway along the layer is used to prevent outburst. When the residual gas content of the effective inspection is less than 8m³/t, the coal roadway excavation process. There are still many abnormal dynamic phenomena mainly in high stress in coal mines. The monthly footage of coal roadway excavation is only 20~30m/month, and it is difficult to ensure safe excavation, which has led to the tense situation of mining replacement for many years. After the hydraulic reaming technology measures were adopted for the through-hole drilling, no abnormal gas dynamic phenomenon occurred during the tunneling of the floor roadway along the test face, and the tunneling speed increased from the first 40~60m/month to 100~140 m/month, with an average of 120m/month, the water jet reaming and pressure relief and anti-permeability measures are applicable to the disaster management of the soft and geostress-dominant prominent 3# coal seam in Sangshuping Coal Mine.

5. Conclusion

Through-hole drilling combined with high-pressure hydraulic reaming technology can reduce the stress of the coal seam, increase the internal exposed area, and effectively improve the recoverability of soft and thick coal seams. When the rate of expanded coal debris is 3%, the radius of the plastic failure zone around the borehole is about 2.2m; the width of the pressure relief area of a single reaming hole is about 3.2m; when the final hole spacing of the borehole is 6m, a good pressure relief effect is also taken into account. A reasonable amount of drilling work. The high-pressure hydraulic reaming technology simultaneously solves the problems of coal seam gas drainage and coal seam pressure relief, which can provide reference for coal mine tunneling prevention in similar conditions.

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