Study on Gas Control Technology of Large Diameter Directional Borehole

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Abstract. With the development and extension of the mine, the mine gas, water, ground pressure and fire disasters further deteriorated, seriously affecting the safe and efficient production of the mine. Combining with the actual geological conditions, this paper analyses the feasibility of large diameter directional drilling construction on the roof of working face, calculates the construction horizon of directional drilling, and through field investigation, analyses the construction effect, extraction effect and cost comparison. Comprehensive comparison shows that large diameter directional drilling on roof can shorten the construction period of gas control engineering in working face, alleviate the situation of tense replacement of working face, reduce the amount of gas control roadway engineering, and save the cost of gas control engineering.

Key words: Gas control; Large diameter drilling; gas drainage.

1. Preface

The main gas control measures adopted at 220112 working face of No. 2 level 1 coal in Xinji No. 2 Coal Mine are floor drilling, bedding drilling, high extraction roadway and buried pipe in upper corner. The main gas control measures adopted at 220112 working face of No. 2 level 1 coal in Xinji No. 2 Coal Mine are floor drilling, bedding drilling, high extraction roadway and buried pipe in upper corner. However, with the deep development and extension of the mine, the dynamic disasters of coal and rock mass such as coal and gas outburst and rock burst in the mine further deteriorate, which have a great impact on the normal replacement of the mine working face and seriously threaten the safe and efficient production of the mine. Therefore, it is proposed to study the technology of large diameter directional drilling instead of high extraction roadway in 220112 working face, so as to alleviate the tension of mine working face replacement.

2. Principle of roof directional drilling and extraction technology

2.1. Feasibility study on gas drainage by large diameter directional borehole

At present, most coal mines use high-level drainage roadway to extract gas, which is widely used and has good drainage effect, but the cost of construction and maintenance of high-level drainage roadway
is high, and the construction time is long, which affects the mine replacement. Although roof trending drilling and high-level drilling are fast in construction and quick in effect, the amount of gas extraction is relatively limited and the amount of maintenance work is large. The construction time of large diameter roof directional drilling is short, the extraction effect is much higher than that of roof trending drilling and high-level drilling, and the construction and maintenance cost is much lower than that of high-level drainage roadway. Therefore, from the technical and economic analysis, large diameter directional drilling can be applied to pressure relief gas extraction in front of work and goaf.

2.2. Selection of oriented drilling location for large diameter roof

2.2.1. Borehole horizon determination. Large diameter directional boreholes should be generally arranged in fracture zones. The height calculation formulas of fracture zones and caving zones can be found in formulas (1) and (2).

\[ H_m = \frac{m}{(K - 1) \cos \alpha} \]  
\[ H_u = 20 \sqrt{\sum M} + 10 \]  

Formula: \( m \) is mining height, \( m \); \( M \) is rock thickness, \( m \); \( \alpha \) is coal seam dip, \(^\circ\); \( K \) is expansion coefficient.

2.2.2. Borehole spacing and number. The plastic zone is formed in the surrounding rock after drilling. According to the principle of elastic-plastic mechanics, the radius \( R \) of the plastic zone is deduced as follows:

\[ R = r \left[ (1 - \sin \varphi) \frac{c \cot \varphi + \sigma_z}{c \cot \varphi} \right]^{\frac{1 - \sin \varphi}{2 \sin \varphi}} \]  

Formula: \( c \) is cohesion; \( \varphi \) is internal friction angle, \( r \) is drilling half, \( \sigma_z \) is initial geostress.

According to the experience of drilling construction, the accuracy of large diameter directional drilling can be controlled at ±1m. Therefore, considering the drilling accuracy, the drilling spacing should be no less than 2m. Considering the damage of drilling construction, the spacing of drilling holes should be no less than 2\( R \). The formula for calculating borehole spacing \( D \) of large diameter roof can be obtained by comprehensive analysis as follows:

\[ D = 2R + 2 \]  

The number of large diameter roof directional boreholes can be determined according to the single borehole extraction and gas emission from the working face.

3. Field application

3.1. Directional drilling design
Combining with the basic situation of 220112 working face, according to formula (1) and (2), the height of crack zone and collapse zone in 220112 working face is 44.6 m and 20.1 m respectively, and the diameter of large diameter borehole is 156 mm. According to formula (3), the radius of plastic zone of
borehole is $R=0.68m$. According to formula (4), the spacing of large diameter boreholes is calculated to be at least 3.36m.

Five directional drilling holes were constructed in the 220112 working face, with a diameter of 15.6 cm, a depth of 522-657 m, a distance of 1# directional drilling holes to the horizontal distance of wind tunnel is 12m, and a distance of 7m between each hole. Combining with the law of gas migration, the layout of large diameter roof drilling holes is shown in Figure 1.

![Directional drilling layout](image)

**Figure 1.** Directional drilling layout

### 3.2. Directional drilling construction
The actual drilling trajectory is shown in Figure 2.

![Vertical projection and horizontal projection of actual trajectory of borehole 1](image)

(a). Vertical projection and horizontal projection of actual trajectory of borehole 1

![Vertical projection and horizontal projection of actual trajectory of borehole 2](image)

(b). Vertical projection and horizontal projection of actual trajectory of borehole 2

![Vertical projection and horizontal projection of actual trajectory of borehole 3](image)

(c). Vertical projection and horizontal projection of actual trajectory of borehole 3
In the process of directional drilling construction, there are no safety problems; the actual drilling trajectory basically coincides with the design trajectory and meets the design requirements.

4. Analysis on Gas Drainage Effect of Large Diameter Directional Borehole

4.1. Drainage effect analysis (technically)

4.1.1. Analysis of Gas Drainage Concentration and Purity in Borehole. Figure 3 and Figure 4 are the variation curves of gas extraction concentration and purity with advancing distance of working face.

Within the working face advancing distance of 80m, the directional drilling position does not reach the height of rock fracture zone, and the drilling concentration and extraction purity are very low; after the working face advancing distance exceeds 80m, the height of roof rock fracture zone develops to 1# and 2# directional drilling, drilling extraction plays a role, and the extraction concentration increases rapidly to about 20.0%; when the advancing distance is about 105m, 3#, 4#, 5# drilling. Starting successive extraction, because the roof fissures are not developed, the extraction concentration is low;
after the mining face is 80 m, the extraction purity increases rapidly to 0.51-2.19 m$^3$/min, with an average of 1.38 m$^3$/min. With the continuous advance of the working face, the extraction purity also increases gradually.

4.1.2. Effect of gas control in working face. The statistics of extraction purity corresponding to different gas extraction measures in 220112 working face are shown in Table 1.

| Extraction methods                          | Negative pressure (KPa) | Extraction purity (m$^3$/min) | Maximum value | Average value | Proportion |
|---------------------------------------------|-------------------------|-------------------------------|---------------|---------------|------------|
| Floor roadway                               | 10                      | 4.18                          | 2.98          | 30.5%         |
| Drilling holes in roof of airway            | 16                      | 4.83                          | 3.48          | 35.7%         |
| Machine roadway bedding hole                | 16                      | 1.72                          | 1.06          | 10.9%         |
| Bedding Hole and upper corner of wind roadway | 16                     | 1.24                          | 0.86          | 8.8%          |
| Roof directional drilling                   | 10                      | 2.19                          | 1.38          | 14.1%         |
| Total                                       | -                       | 14.16                         | 9.76          | 1             |

The main pumping measures of 220112 working face are: floor roadway, fan roadway roof borehole, machine roadway bedding hole, air roadway bedding hole, upper corner buried pipe and roof directional borehole, etc. The actual maximum gas emission is 18.76 m$^3$/min and the actual maximum gas extraction is 14.16 m$^3$/min. There is no abnormal dynamic phenomenon of gas during mining, and the gas concentration of return air is 0.24%~0.44%.

4.1.3. Effect of gas control in high drainage roadway of 220116 working face. In the initial stage of 220116 working face mining, high extraction roadway is adopted, and large diameter directional drilling is adopted in 220112 working face mining. The two working faces are adjacent, and the other gas control measures are basically the same. Table 2 shows the purity of the pumping under different pumping measures at 220116 working face. Directional drilling and high extraction roadway extraction effect with working face advancing distance curve is shown in Figure 5.

| Extraction methods                          | Negative pressure /KPa | Extraction purity (m$^3$/min) | Maximum value | Average value | Proportion |
|---------------------------------------------|------------------------|-------------------------------|---------------|---------------|------------|
| Floor roadway                               | 10                     | 7.04                          | 5.01          | 43.0%         |
| Bedding holes in airway                     | 20                     | 3.24                          | 1.96          | 16.8%         |
| Machine roadway bedding hole                | 20                     | 4.17                          | 2.73          | 23.4%         |
| Machine roadway upper corner                | 20                     | 0.74                          | 0.34          | 2.9%          |
| High drainage roadway                       | 20                     | 3.05                          | 1.62          | 13.9%         |
| Total                                       | -                      | 18.24                         | 11.66         | 1             |

Table 1. Purity of gas drainage under different drainage measures

Table 2. Purity of gas drainage under different drainage measures in 220116 working face
Figure 5. Comparison of directional drilling and high drainage roadway drainage.

From Table 1, Table 2 and Figure 5, it can be seen that the maximum gas extraction purity is 2.19 m$^3$/min with an average of 1.38 m$^3$/min in 220112 working face, the maximum extraction purity is 3.05 m$^3$/min, with an average of 1.62 m$^3$/min; the directional borehole gas extraction accounts for 14.1% of the total gas extraction, and the high extraction roadway accounts for 13.9% of the total gas extraction in 220116 working face. From the analysis of the extraction amount and the proportion of total gas extraction, it can be seen that the extraction effect of the two methods is basically the same. Therefore, the roof directional drilling can be used to replace the high drainage roadway for gas extraction.

4.2. Analysis of drainage effect (Economically)

According to the actual situation of gas drainage in Xinji No. 2 Coal Mine, the construction cost of 500 m directional drilling and 500 m high drainage roadway are compared and analyzed. Table 3 shows the respective capital input of directional drilling and high-pumping roadways, and table 4 shows the respective total investment, labor cost and construction period of directional drilling and high-pumping roadways.

| Table 3. Drilling and roadway capital cost sheet |
| Extraction methods | Number of tunnel | Length /m | Unit price/ Ten thousand yuan /m | Total cost/ Ten thousand yuan | Drilling cost/ Ten thousand yuan | Total investment/ Ten thousand yuan |
|---------------------|------------------|-----------|-------------------------------|-----------------------------|-----------------------------|-----------------------------------|
| high drainage roadway | 1 | 500 | 0.8 | 400 | 0 | 400 |
| roof directional drilling | 5 | 500 | 0.065 | 162.5 | 6.5 | 169 |

Table 4. Capital, manpower cost and construction period investment of directional drilling and high drainage roadway

| Extraction methods | Total investment/ Ten thousand yuan | Manpower cost / individual | Duration / day |
|---------------------|------------------------------------|---------------------------|----------------|
| high drainage roadway | 400 | 45 | 135 |
| roof directional drilling | 169 | 17 | 123 |

Table 3 and Table 4 show that under the same construction conditions, compared with five large diameter directional boreholes with 500m roof, the total investment in construction of 500m high extraction roadway increased by 2.31 million yuan and investment increased by 136.69%; human resources increased by 28 people, saving 164.7%; construction period increased by 12 days, increasing
by 9.76%. At the same time, the cost of manpower and capital for maintenance of high extraction roadway is much higher than that of maintenance of five large diameter boreholes. In summary, using large diameter directional long borehole instead of high extraction roadway extraction can save manpower, funds, time and other costs.

5. Conclusion

(1) According to the geological conditions and mining deployment of No. 1 coal seam in Xinji No. 2 Coal Mine, the distribution of mining fissures and the law of gas migration in working face are analyzed, and the feasibility of roof large diameter borehole extraction in No. 1 coal seam working face is demonstrated by analyzing the actual construction situation of boreholes.

(2) The gas concentration of return air in 220112 working face is 0.24%~0.44%. The problem of gas emission in 220112 working face can be solved by directional drilling combined with other extraction measures.

(3) The maximum extraction purity of directional drilling in 220112 working face is 2.19 m³/min, accounting for 14.1% of the total extraction, which is basically the same as that in high extraction roadway under the same conditions. Large diameter directional drilling can replace high extraction roadway to extract goaf gas.

(4) Comparing and analyzing the construction cost, manpower cost and time cost of large diameter directional drilling and high drainage roadway under the same conditions, it is believed that arranging directional long drilling to control gas in mining face can shorten the construction period, alleviate the situation of tense replacement of working face, reduce the amount of gas control roadway engineering, and save the investment of gas control engineering cost. The construction of roadway improves the safety.

Therefore, under the same conditions, large diameter directional boreholes can be used to replace high extraction roadways for goaf and pressure relief gas extraction.

Acknowledgments

This work was financially supported by the national key research and development program of China(2017YFC0804209), Chongqing science and technology innovation project of social undertakings and people's livelihood guarantee (cstc2017shmsA90008), Special fund for science and technology innovation and venture capital of China Coal Science and Technology Group Co., Ltd.(2018MS011), General project of Chongqing Research Institute of China Coal Industry Group Co., Ltd.(2017YBXMS31), Special fund for science and technology innovation and venture capital of China Coal Science and Technology Group Co., Ltd.(2018-TD-MS076).

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