Differential Gas Drainage Technology for Upper Corner of Working Face by High Position Directional Long Borehole

Duan Huijun1,2, Hao Shijun1,2 and Zhao Yongzhe2
1. China Coal Research Institute, Beijing 100013, China
2. Xi’an Research Institute, China Coal Technology and Engineering Group, Xi’an 710077, China
duanhuijun@ccctegxian.com

Abstract: In the mining process of high gas mining area, the gas emission from goaf is large, which leads to the gas overrun in the upper corner of the working face, and affects the safe mining of the mine. This paper studies the differential drainage of the upper corner gas by high-level directional long borehole, and then solves the problem of gas control in the upper corner. Taking a fully mechanized mining face as the research object, this paper analyzes the theoretical parameters of the overlying strata failure of the working face, and according to the production practice, the high position directional long drilling layer is arranged differently, and the influence of high position directional drilling on gas drainage effect in different layers is analyzed, and the best location in different distance and height area is obtained to guide the actual production work. The research results show that the differential drainage method of high position directional long borehole can effectively control the gas overrun in upper corner of fully mechanized mining face in thick coal seam.

1. introduction
In the production process of high gas and thick coal seams, the gas emission from the goaf of the working face accounts for a large proportion, which easily leads to gas overrun at the upper corner of the working face and affects the safe mining of the mine [1-2]. At present, some measures have been taken to control the gas in the upper corner, and some effects have been achieved in the gas drainage and control of the upper corner. However, the buried pipe and intubation drainage method can not be used as an independent means to effectively solve the problem of high gas concentration in the upper corner. In most cases, it needs to be used together with other measures, and most mines only use it as auxiliary means [3]. Conventional through layer drilling can only be drilled at a certain angle, with small borehole coverage and few effective hole sections, which requires a large number of boreholes and unstable pumping. Although high drainage roadway technology is widely used at present, it has some defects, like large amount of excavation, high cost, gas accumulation in local space and so on. High position directional drilling has become the main technical measures for gas control at the upper corner of working face at present [4]. However, due to the different geological characteristics, gas occurrence conditions, gas seepage and emission laws, and mining process conditions in different mining areas, the track horizon and layout mode of high-level directional boreholes in roof strike have great influence on gas drainage effect [5].

In view of the technical problems, like high gas emission caused by high intensity mining of low gas coal seam in Hedong mine field and frequent occurrence of gas overrun in upper corner, a typical
mine is selected to conduct research on gas control technology at upper corner of high-level directional drilling. This paper optimizes the trajectory design horizon of high-level directional drilling in different zones of working face roof, in order to obtain the reasonable vertical height location within different horizontal projection distance from the return air roadway of working face, and effectively improve the gas drainage efficiency of high-level directional drilling.

2. Principle of treating upper corner by high position directional drilling
After fully mechanized top coal caving face is mined out, the overlying rock of goaf roof will deform and even be destroyed. The continuous deformation along the strike direction will eventually form caving zone, fracture zone and bending subsidence zone. The support area, separation zone and recompaction zone will be gradually formed along with the pushing mining of working face, which is the theoretical basis for high-level directional drilling to extract gas from goaf and upper corner. With the extension of the mining distance, the central position of the stope is squeezed and compacted again, and a fully developed fracture area, called "O" ring area, is formed around it, which provides a channel and space for the gas accumulation and flow in the goaf of the working face. The high-level directional drilling is to open the drilling field in the coal seam roadway. Through the directional drilling technology, the drilling track will climb and maintain in the goaf fracture area to extract gas in the gas accumulation area.[6-7]

2# coal seam is mainly mined in the mine, and the mining method is fully mechanized caving mining. The absolute gas emission of fully mechanized mining face is 5.62 m³/min. The original gas content of 2# coal is 3.07 ~ 3.41 m³/T, and the permeability coefficient of coal seam is 0.0201 ~ 0.0217 m²/MPa²·d. The 318 working face of the mine is located in panel 2, the mining height is 3.1 m, the mining drawing ratio is 1:1, and the coal seam is nearly horizontal strike. During the coal falling period of the production shift, a large amount of gas was released analytically and gathered in the upper corner area along with the air flow, which led to the gas concentration in the upper corner exceeding 0.8%. The phenomenon of over warning and overrun occurred from time to time, and there was a big potential safety hazard.

3. Preliminary selection of high level directional drilling trajectory horizon
The basic layout principle of high-level directional drilling is: the middle and lower position of fracture zone and "O" ring area.[8-11]. The height of caving zone and fracture zone can be calculated by the following formula when the roof rock layer of working face is hard or medium hard.

\[
H_1 = \frac{1002M}{2.1 \Sigma M + 1.6} + 2.5 \\
H_2 = \frac{1002M}{1.2 \Sigma M + 2.0} + 8.9
\]

Where \(H_1\) is the height of caving zone, m, \(\Sigma M\) is the mining height of coal seam, m, \(H_2\) is the height of fracture zone, M.

According to formula (1) and formula (2), the height of caving zone in goaf of working face is \((21.36 \pm 2.5)\) m and that of fracture zone is \((65.68 \pm 8.9)\) m. therefore, the preliminary distribution range of high-level directional drilling is determined as \(21.36 \sim 65.68\) m.

The distance between the horizontal projection position of the high-level directional drilling track and the return air roadway of the working face is generally taken as the empirical value. Referring to the practical experience, the distance from twice the mining height to one fourth of the inclined length of the working face is selected, i.e. within the range of 13-70 m from the side of the return air roadway.[12]

4. Design and construction of high position directional drilling
4.1. Layout and design of high level directional drilling in working face
According to the vertical distance and horizontal distance range of high-level directional drilling, the trajectory design of high-level directional drilling is carried out in 318 working face, and the "convex"
trajectory design is adopted at the initial mining position of the cut, so as to effectively extract gas before the goaf is formed in the initial mining period, and fan-shaped layout is adopted in the subsequent drilling field. The existing water exploration chamber and transfer lane are used in the high-level directional drilling field of the working face. The spacing between the drilling fields is about 500 m, and the design depth of the high-level directional drilling is about 600 m, so that the overlapping distance of the drilling tracks between the drilling fields is not less than 80 m. Each drilling site is designed with 3-5 high-level directional boreholes. In case of scrapping due to drilling accident, directional drilling shall be conducted at corresponding positions. A total of 9 drilling sites and 38 high-level directional boreholes are designed. The design trajectory is shown in Figure 1.

4.2. Construction of high position directional drilling

The depth structure of high position directional drilling hole is generally two opening structure, the first opening is opening hole and running casing section, which is mainly used to protect the drilling hole and connect the pumping pipeline. The second opening is the extraction hole body section, that is, extending in the target layer and finishing the hole, and finally extracting the gas in the upper corner goaf. The first spud is mainly composed of three parts: the opening of Φ 101 mm PDC bit, the primary hole expanding of Φ 101 mm / Φ 153 mm PDC bit, and the second hole expanding of Φ 153 mm / Φ 193 mm PDC bit. The geological casing is run and grouted to wait for setting, so that the casing is stable on the hole wall without loosening and air leakage. The directional sliding drilling method is firstly adopted in the secondary hole body section. The drilling tool does not rotate and slide to push the screw motor at the bottom of the hole and drill bit to break the rock. After drilling to the designed hole depth and forming a hole, the directional drilling tool is put forward, and the rotary reaming drilling tool is run. The tower type reaming hole is used for guiding reaming drilling until the designed hole depth is finished.

The actual drilling track of high-level directional drilling in 318 working face was carried out in strict accordance with the design, and the final height was consistent with the designed track height. A total of 37 high-level directional boreholes were drilled in 9 drilling sites. Due to the sticking of mud rock hole, one hole was finally reduced compared with the design of 38 boreholes. The actual drilling trajectory of high-level directional drilling is shown in Fig. 2.

4.3. Location division of high level directional drilling area in working face

The 9 groups of 37 high-level directional boreholes tested in the working face are basically arranged within the scope of overburden fractures calculated and determined above. Corresponding to 3-5
high-level directional boreholes in each drilling field, the parameter range is too large to cover the effective area. However, the high-level directional drilling needs to conduct dislocation gas drainage, interception and flow field interference on the goaf and upper corner, so it is necessary to arrange the boreholes in different fan-shaped areas for drainage, especially in the upper part of the upper corner, that is, near the coal seam roof and return air roadway, there is a practical demand. In order to obtain a more accurate view of the working plane, a different borehole location will be taken from the upper section. Combined with the distribution characteristics of the movement fractures in the overlying strata of the stope, and according to the division law of the three horizontal zones, the goaf is divided into the influence area of coal wall support, the separation area and the recompaction area. Referring to the calculation results of the formula and combining with the actual drilling layout parameters, the horizontal distance projection of the boreholes is preliminarily divided into 25 m, 25-55 m, 55 m in each block, combined with the data range of caving zone and fracture zone, the pumping effect of each high-level directional drilling was investigated.

5. Analysis of drainage effect of high position directional drilling

5.1. Analysis of high level directional drilling zone extraction

According to the law of overburden movement and the division of the three horizontal zones of the stope, the high-level directional drilling has the effect of gas drainage and flow field interference on the goaf and different areas in the upper corner. In order to more accurately investigate the drilling drainage effect in different areas, the directional borehole drainage data are selected for comparative analysis in different areas. The parameters are shown in Table 1.

Table 1 Position parameters of high directional drilling in different horizontal distance zones.

| Borehole number | 2-4 | 3-3 | 4-3 | 7-4 | 7-3 | 5-4 | 8-3 | 9-3 | 5-1 | 6-1 | 7-2 | 9-1 |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| horizontal distance /m | 7   | 21.0| 19  | 25  | 35  | 40  | 35  | 50  | 55  | 62  | 72  | 64  |
| vertical distance /m | 8   | 15.0| 20  | 28  | 30  | 35  | 35  | 40  | 37  | 40  | 45  | 50  |

The pure volume of high directional borehole near range projection is shown in Fig. 3 (a). It can be seen from the figure that the net gas flow rate of 2-4#, 3-3# and 4-3# boreholes is below 0.29 m^3/min, and the drainage effect is poor. However, 7-4# hole has the highest pure extraction volume of 0.94 m^3/min, which is maintained at about 0.62 m^3/min on average. It can be found that the final hole ends of the three boreholes are basically within the caving zone, and the drainage flow is mostly air, while the hole 7-4# is located at the top of the caving zone, and the gas in the gas conducting fracture of the rock stratum is relatively concentrated, which can extract high purity gas. From this location, the borehole should be located in the high position, and the vertical distance should be 28 m.

Compared with the low distance area, the four high level directional boreholes in the middle distance projection area of the high position directional drilling hole have a certain increase compared with the low distance area, in which the average extraction pure amount of 9-3# hole is 1.74 m^3/min, and the pumping effect is remarkable, as shown in Fig. 3 (b). With the increase of vertical height of high-level directional boreholes, the pumping effect of boreholes is also increasing. The high-level directional drilling track arranged in this area has entered the fracture zone of goaf, which is located at the lower part of gas conducting fracture. With the continuous improvement of its position in the fracture zone, the corresponding gas drainage purity will continue to rise. For this reason, the vertical height of high-level directional drilling track is better in the section of 35-43 m.

If the drilling distance is too close to the high level fracture area, the directional drilling will be carried out if the drilling distance is too close. It can be seen that the net amount of 6-1# hole extraction is stable at about 1.1 m^3/min, and the effect is the best. The extraction data of 5-1# hole have certain fluctuation, but they are more than 0.80 m^3/min, and the effect is the second. However, the drainage effect of 7-2# hole near 6-1# hole is weaker than that of 6-1# hole and 5-1# hole. The reason is that the horizontal projection distance of 7-2# hole is 72 m, and the distance is the largest,
which should be located in the compaction area, resulting in the reduction of pumping volume. The vertical height of hole 9-1# is the highest, and the pumping effect is the worst in this group. The average extraction volume is only 0.49 m³/min. due to its high height, it is located above the middle of the fracture zone, and the longitudinal fractures gradually decrease, resulting in poor pumping effect, as shown in Fig. 3 (c). Therefore, the high-level directional boreholes should be located in the range of 37-45 m from the coal seam roof in the projection area.

![Diagram](image)

Fig.3 Pure flow curve of high directional drilling in different horizontal projection areas

5.2. analysis of gas concentration in upper corner of working face

318 working face has long used high-level directional drilling to extract gas from upper corner and
goaf for a long time. In the process of the above zoning test and practice, the layout layer of high-level directional drilling hole is continuously optimized to achieve the purpose of directly affecting the gas concentration in the upper corner of the low-level borehole, and the high-level directional drilling can increase the hole layout in the most effective layer, which can directly improve the gas concentration in the upper corner Directional drilling effect. Under the results of long-term continuous drainage and continuous improvement of parameters, the net amount of gas extracted by high-level directional boreholes is increasing continuously. The highest net amount of gas extracted from boreholes in a single month is 224000 m³, and the total net amount of gas extracted in the whole year is 1.857 million m³. As a result, the gas concentration in the upper corner is continuously reduced, and the number of times of exceeding the limit continues to decrease, from 12 times in the first quarter to 2 times in the first quarter, Finally, zero warning and zero overrun are realized. The gas concentration in the upper corner is kept below 0.6% for a long time. In a word, the gas drainage effect of the upper corner goaf by high-level directional drilling is remarkable, which ensures the safety production of the working face.

6. Conclusion
This paper analyzes the gas drainage principle of high-level directional drilling, calculates the design parameters of high-level directional drilling, investigates 37 high-level directional drilling holes in the working face, and obtains the better layout of high-level directional drilling holes at different horizontal distances from the return air roadway, so as to provide guidance for mine production. The continuous practice and test of high-level directional drilling and zonal drainage were carried out. The gas concentration in the upper corner of the fully mechanized working face decreased significantly. The number of early warning decreased from 11 times per quarter in the initial stage to once every quarter. Finally, the gas concentration in the upper corner remained below 0.6%. The monitoring data show that the method of high level directional drilling and zonal drainage can effectively control the problem of gas overrun in upper corner of fully mechanized mining face in thick coal seam. Aiming at the thick coal seam mining area in Hedong minefield, especially the fully mechanized mining face with gas overrun in upper corner caused by low gas content and high intensity mining, an effective gas drainage technology of high position directional drilling in different areas is formed, which provides technical reference and practical experience for gas control in upper corner of this type of mine in this area.

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Reference
[1] FANG Jun, SHI Zhijun, LI Quanxin, et al. Drilling Techology and Equipment on Directional High Level and Long Borehole with Large Diameter in Roof [J]. Mining Research and Development, 2015, 35(7): 92-97.
[2] HAO Guangsheng, CHEN Bin, SHEN Kai. Analysis on differential layout and gas drainage effect of high position directional borehole in roof of goaf [J]. Coal Science and Technology, 2018, 46(8): 101-106.
[3] SUN Rongjun, LI Quanxin, FANG Jun, et al. Construction technology and development tendency of high level borehole for gas drainage in goaf [J]. Coal Science and Technology, 2017, 45(1): 94-99, 213.
[4] DUAN Huijun. Combined Gas Control Technology and Its Engineering Practice in Upper Corner of Fully Mechanized Caving Face in Extremely Intensive Mining Condition[J]. Industry and Mine Automation, 2020, 46(02): 1-5, 38.
[5] LI Ping, TONG Bi, XU Chao. Study on hole-forming technology of high-level directional borehole in complicated roof strata [J]. Coal Geology & Exploration, 2018, 46(4): 197–201.

[6] WANG Xian, XU Chao, LI Quanxin, et al. Drilling technique research of high-level directional borehole for gas drainage in Huainan Mining Area [J]. Coal Science and Technology, 2018, 46(11): 145-150.

[7] ZHOU Yadong, GENG Yaoqiang. Gas drainage technology with longborehole with large diameter instead of high extraction lane [J]. Safety in Coal Mines, 2011, 42(10): 25-27.

[8] PENG Dong, DUAN Huijun, ZHAO Yongzhe. Layer Parameters Optimization of High—level Directional Drilling in Fully Mechanized Caving Face [J]. Coal Engineering, 2019, 51(10): 71-76.

[9] TONG Bi, XU Chao, LIU Fei, et al. Technology research on borehole in place of roadway and its engineering practice in gas drainage of Huainan Mining Area [J]. Coal Science and Technology, 2018, 46(4): 33-39.

[10] XU Chao, LIU Fei, FANG Jun. Effect analysis of gas drainage with high level directional long drilling [J]. Coal Engineering, 2017, 49(6): 78-81.

[11] WEI Hong Chao. Application of large diameter directional roof drilling in upper corner gas control [J]. Coal Engineering, 2017, 49(6): 64-67.

[12] CHEN Jigang, WANG Guangshuai, WANG Gang. Study on Goaf Gas Drainage Technology of Fully Mechanized Top Coal Caving Face [J]. Coal Engineering, 2014, 46(1): 66-67.