Research Article

Speculum Observation and Trajectory Measurement in Gas Extraction Drilling: A Case Study of Changling Coal Mine

Enbiao Zhao,¹ Kangnan Li ,¹ Xin Yang ,² and Nan Deng³

¹Beijing Key Laboratory for Precise Mining of Intergrown Energy and Resources, China University of Mining & Technology (Beijing), Beijing 100083, China

²School of Civil and Resources Engineering, University of Science and Technology Beijing, Beijing 100083, China

³China Coal Research Institute, Beijing 100013, China

Correspondence should be addressed to Kangnan Li; knli541@126.com and Xin Yang; xinyangbk89@163.com

Received 22 February 2021; Revised 14 March 2021; Accepted 24 March 2021; Published 1 April 2021

Academic Editor: Yi Xue

Copyright © 2021 Enbiao Zhao et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Coal will still be China's basic energy for quite a long time. With the increase of mining depth, gas content and pressure also increase. The problems of gas emission and overrun affect the safety and efficient production of coal resource to a certain extent. In this work, the field test of gas drainage borehole peeping and trajectory measurement in coal seam of Changling coal mine are carried out. These coal seams include C_5^b coal seam, upper adjacent C_5^a coal seam, C_6^a coal seams, C_6^c in lower adjacent strata, and C_5^b coal seam in high-level borehole. The view of gas drainage borehole peeping and trajectory measurement in the working seam, upper adjacent layer, lower adjacent layer, and high position are obtained. It is found that the hole collapses at the position of about 20 m in both adjacent strata and high-level boreholes, and there are a lot of cracks in the high-level boreholes before 12 m. The deviation distance of high-level borehole is large, and the actual vertical deviation of upper adjacent layer is small. Finally, the strategies to prevent the deviation of drilling construction are put forward. It includes four aspects: ensuring the reliability of drilling equipment, reasonably controlling the drilling length, standardizing the drilling, and reasonably selecting the drilling process parameters.

1. Introduction

For quite a long time in the future, coal is still China's main energy and important chemical raw materials, supporting the rapid and stable development of China's national economy [1–5]. More than 90% of China's coal mines are mainly underground mining. The complex coal seam occurrence conditions bring serious threat to coal mine safety production, even inducing personal injury [6–10]. In recent years, relying on scientific and technological progress, coal mine safety production situation continues to improve. Coal mining enterprises have higher requirements for gas drainage technology and pay more attention to the related problems of drainage drilling.

The curvature of drilling trajectory in extraction will lead to the blank area in the coal seam extraction, which greatly affects the gas drainage effect and may lead to coal-gas outburst, gas explosion, and other gas accidents. The main rea-

sons are geological factors and technological factors [11–14]. The main geological factors are the anisotropy of rocks and the interbedding of soft and hard rocks. Coal rock with bedding, schistosity, and other structural characteristics has obvious anisotropy in drillability, which easily leads to borehole bending. In addition, the technical reasons such as uneven drilling foundation, too long drill pipe, incorrect vertical axis installation, and the technological reasons such as too much bit pressure, too high drilling speed, and too much flushing fluid will lead to the bending of the drilling hole. These will lead to the deviation of the final hole position from the target location. Borehole peeper can be used to detect coal seam structure, geological structure, roadway roof separation, borehole quality, and roadway grouting effect. Especially in the study of fracture zone development law, it can be displayed intuitively and clearly through the display, and it can also measure the trajectory of gas drainage borehole [15–17].

Scholars in various countries have done a lot of research on the principle and prevention of gas drainage borehole bending. Polak et al. [18, 19] established a new theoretical model of drill pipe and hole wall contact. Through the field test, it is found that the model can better estimate and predict the contact force and corresponding deformation of drill pipe, which provides a basis for controlling the drilling direction of drill pipe. Lueke et al. [20, 21] analyzed in detail the influence of geological conditions, drill pipe pressure, bit structure, borehole diameter, drilling depth, and other factors on borehole deviation during drilling. Based on the field test, it is proposed that the deviation prevention device can be installed at the appropriate position to reduce the deviation of the borehole. Based on the angular displacement sensor and communication module, Manacorda et al. [22] proposed and designed a bit radar equipment for directional drilling. The device can transmit the actual position of the bit in real time, which provides a reference for effectively controlling the drilling direction. Matheus et al. [23, 24] analyzed the shortcomings of existing drilling trajectory control and presented an adjustment method combining drill pipe control and prediction. It focuses on the application value of new rotary steering system (RSS) in drilling, providing a new method to control the movement of drill pipe in real time during drilling. Li [25] used wireless digital compass inclinometer to measure the coordinates of the drilled hole in Chambishi mine, Zambia. He calculated and compared the actual coordinates with the design coordinates to get the final offset. Liang et al. [26] analyzed the causes of borehole deviation from three aspects of geological factors, technological factors, and operation technical factors, summarizing the regularity of borehole deviation and the measures to prevent borehole deviation. Zhu et al. [27] invented a compound drilling device for deviation prevention and straight drilling while drilling, which can effectively improve the drilling speed and the ability of deviation prevention and correction in vertical wells and monitor the deviation change in real time with high stability and low cost. Ding et al. [28] analyzed the problems and error sources in the past drilling construction and gave a method for calculating the trajectory of borehole. Wang et al. [29, 30] proposed and designed angle compensation correction method and designed the evaluation index of borehole correction effect in view of serious deviation of pressure relief gas drainage borehole trajectory in 2603 working face of Liyazhuang coal mine. Zhao et al. [31] analyzed the geological, technical, and technological factors the causing borehole bending in drilling engineering construction. They put forward the preventive measures of correctly installing construction equipment and adopting reasonable drilling tool structure. Zhao [32] presents that the main factors of borehole bending can be attributed to three aspects: formation structure, drilling pressure, and equipment installation. He put forward corresponding preventive measures according to different reasons.

In order to investigate the development and trajectory of gas drainage borehole fracture zone in coal mine, the Changling coal mine is taken as a case. By peeping at the high-level boreholes of C_5^b coal seam, upper adjacent layer C_5^a coal seam, lower adjacent layer C_6^a and C_6^c coal seam, and

C_5^b coal seam high-level drilling in Changling coal mine, the development law of borehole fracture zone was investigated, and the trajectory of construction holes of 1250 and 4000 drilling rigs was measured to determine the trajectory of gas drainage holes and explore the deviation law of drilling trajectory.

2. General Situation of Mine and Layout of Boreholes

2.1. General Situation of Mine. Changling coal mine is located in the southeast of Zhaotong City, Yunnan Province. The designed production capacity of the mine is 0.6 million t/a. Mining depth is from +1800 m to +1400 m elevation. The mining area is 11.399 km². The mine is divided into two levels of mining. The first level elevation is +1560 m, and the second level elevation is +1520 m. The mine is divided into five mining areas, and the mining sequence is 101 mining area, 102 mining area, 201 mining area, 202 mining area, and 203 mining area. Plan of excavation engineering in mining area is shown in Figure 1. There are only three minable coal seams in the mine, namely, C_5^b , C_6^a , and C_6^c . The dip angle of coal seam is 2 degrees to 10 degrees, and most of them are below 8 degrees with small coal seam spacing. The coal seam characteristics are shown in Table 1.

2.2. Drilling Layout. The design technical parameters of C_5^b coal seam gas drainage borehole are shown in Table 2. The layout of coal seam boreholes is shown in Figure 2.

There are six construction boreholes in the C_5^b coal seam. Two short boreholes in the working seam, numbered $C_5^b-C_{1-1}$ and $C_5^b-C_{1-2}$, are used for the drilling peeping and trajectory measurement. Two long boreholes in the working seam (constructed by 4000 drilling rig), numbered $C_5^b-C_{2-1}$ and $C_5^b-C_{2-2}$, are used for the drilling peeping and trajectory measurement. Two high-level boreholes, numbered $C_5^b-A_{3-1}$ and $C_5^b-B_{2-1}$, are used for borehole peeping and trajectory measurement. Two construction boreholes in the C_5^a coal seam, numbered $C_5^a-C_{2-1}$ and $C_5^a-C_{2-2}$, are used for the borehole trajectory measurement. Two construction boreholes in the C_6^a coal seam, numbered $C_6^a-C_{2-1}$ and $C_6^a-C_{2-2}$, are used for the borehole trajectory measurement. Two construction boreholes in the C_6^c coal seam, numbered $C_6^c-C_{2-1}$ and $C_6^c-C_{2-2}$, are used for the borehole trajectory measurement.

3. Overview of Test Equipment

3.1. Drilling Equipment

3.1.1. ZY-1250 Full Hydraulic Drilling Rig for Coal Mine. ZY-1250 full hydraulic drilling rig for coal mine is composed of seven parts: pump station, operating platform, power head, frame, column, and drilling tool. It is mainly suitable for drilling gas drainage holes, drainage holes, coal seam water injection holes, grouting fire prevention holes, geological exploration holes, and various engineering holes in coal mines. It is suitable for all kinds of coal seams and strata with rock firmness coefficient f less than or equal to 8. The cross-

FIGURE 1: Excavation plan of 101 mining area of Changling coal mine.

sectional area of roadway for drilling rig is more than or equal to 6.5 m^2 .

3.1.2. LD4000ZYWL00II (SZ2) Crawler Full Hydraulic Drilling Rig for Coal Mine. LD4000ZYWL00II (SZ2) crawler full hydraulic drilling rig for coal mine is mainly composed of bottom car, support rotation, work surface, frame, operation platform, pump station, gripper, guide sleeve, pipeline system, drilling tool, rear water braid, and other components. It is mainly used for drilling gas drainage hole, grouting fire prevention hole, coal seam water injection hole, outburst prevention and pressure relief hole, geological exploration hole,

and other engineering holes. It is suitable for all kinds of coal seams and strata with rock firmness coefficient f less than or equal to 10. The drill can walk independently and turn in place. The cross-sectional area of roadway for drilling rig is more than 9 m^2 . Or the width is more than 3 m, and the height is more than 3 m. The pump station converts the electric energy into hydraulic energy, and the pressure oil from the oil pump drives the motor and the propulsion cylinder to complete various actions of the drilling rig. The hydraulic system adopts the linkage oil circuit. Through the setting of each function selection valve, by operating the rotation and advance/retreat handle, it can realize the positive/negative

TABLE 1: Coal seam characteristics.

Coal seam	Coal seam thickness			Layers of gangue $\frac{\text{Maximum} - \text{Minimum}}{\text{Average}}$	Thickness of gangue (m) $\frac{\text{Maximum} - \text{Minimum}}{\text{Average}}$	Apparent density (t/m^3)	Recoverable range and reserve ratio
	Minimum	Maximum	Average				
C_1	0.8	1.05	0.89	-1 – 3/2	-0.03 – 0.14/0.08	1.70	Sporadic recoverable with 2% reserves
C_5^a	0.8	1.42	1.09	-0 – 3/1	-0 – 0.29/0.03	1.60	The recoverable area is 23%, and the reserves account for 5.3%
C_5^b	0.86	5.51	2.75	$-\frac{0-18}{3.3}$	$-\frac{0-6.9}{0.16}$		The whole area is recoverable, accounting for 69.7% of the total reserves
C_6^a	0.8	2.48	1.28	$-\frac{0-9}{2}$	$-\frac{0-0.56}{0.14}$	1.65	Recoverable area 50%, reserves 13%
C_6^c	0.8	1.56	0.97	-0 – 5/0.7	-0 – 0.45/0.05	1.65	Recoverable area 52%, reserves 10%

TABLE 2: Basic parameters of coal seam gas drainage borehole.

Number	Coal seam	Place	Dip angle ($^\circ$)	Azimuth ($^\circ$)	Drilling depth (m)	Aperture (mm)	Drilling type
$C_5^b-C_1$ 1	C_5^b	152106 track lane, which is 1000 m and 1030 m away from the gateway	-3	350	70	75	Down bedding
$C_5^b-C_1$ 2			-3	350	70	75	
$C_5^b-C_2$ 1		152106 track lane, which is 500 m and 530 m away from the gateway	-3	350	100	94	
$C_5^b-C_2$ 2			-3	350	100	94	
$C_5^b-A_3$ 1	C_5^b	152105 track lane, which is 300 m away from the gateway	+14	230	80	75	High-level drilling
$C_5^b-B_{2-1}$		152105 track lane, which is 200 m away from the gateway	+14	285	80	75	
$C_5^a-C_{2-1}$	C_5^a	152106 track lane, which is 500 m and 530 m away from the gateway	+3	350	70	75	Up crossing
$C_5^a-C_{2-2}$			+3	350	70	75	
$C_6^a-C_{2-1}$	C_6^a	152106 track lane, which is 500 m and 530 m away from the gateway	-10	350	70	75	Down crossing
$C_6^a-C_{2-2}$			-10	350	70	75	
$C_6^c-C_{2-1}$	C_6^c	152106 track lane, which is 500 m and 530 m away from the gateway	-15	350	70	75	Down crossing
$C_6^c-C_{2-2}$			-15	350	70	75	

rotation, forward/backward of the power head, the loosening/clamping of the chuck and gripper, and the corresponding linkage functions.

3.2. Drilling Peeping and Trajectory Measurement System. The ZKXG30 mine drilling imaging track detection device is a high-tech equipment for comprehensive detection of drilling. The product integrates the functions of drilling photography, peeping (video), imaging, and track measurement and completes the workload of the previous four tests in one test. Meanwhile, it can obtain drilling dynamic video, local high-definition photos, full drill hole wall expanded plan, and drilling space track, which is efficient and fast. The instrument includes low-power embedded dual core processor, high-definition high-speed digital camera, and military grade high-precision space angle measuring device, which is supplemented by advanced control algorithm and image processing algorithm and other software systems to

realize all functions synchronously. The product design fully considers the actual working environment of the coal mine and strives for simple operation, stable system performance, simple, and reliable. The system structure of the ZKXG30 mining borehole imaging track detection device (track) is shown in Figure 3.

4. Test Principle and Steps

4.1. Introduction of the Device Structure. The ZKXG30 mine drilling imaging track detection device (track) is mainly composed of host, probe, and sounder. The host is mainly composed of internal system, external interface, and battery pack. The external interface includes probe port, sounder port, operation control knob interface, and charger interface. The internal system mainly includes ARM dual core processor and data storage unit. The internal system is connected with external components through external interfaces. Under

(a)

(b)

(c)

FIGURE 2: Continued.

FIGURE 2: (a) Layout of boreholes for peeping and trajectory measurement in C_5^b coal seam. (b) Layout of high-level boreholes peeping and trajectory measurement in C_5^b coal seam. (c) Layout of trajectory survey boreholes in C_5^a coal seam. (d) Layout of trajectory survey boreholes in C_6^a coal seam. (e) Layout of trajectory survey boreholes in C_6^c coal seam.

FIGURE 3: ZKXG30 mining borehole imaging track detection device (track) system structure diagram.

the control of the software system, the functions of track acquisition, display, storage, and data transmission are realized. The principle block diagram of the instrument is shown in Figure 4.

4.2. Test Principle. The ZKXG30 mining borehole imaging track detection device mainly includes ZKXG30-Z mining

borehole imaging track detection device host, ZKXG30-T/T(a)/T(b) mining borehole imaging track detection device probe, ZKXG30-S mining borehole imaging track detection device depth encoder, and other main components, as well as video transmission cable, signal cable, push rod, and other accessories. The sounder is used to record the depth of the probe in the borehole. ZKXG30-T(b) mine drilling imaging

FIGURE 4: Block diagram of host structure.

trajectory detection device has a built-in LED white light emitting diode (with brightness adjustment circuit), and a camera, which is used to capture the hole wall image, and a built-in high-performance three-dimensional electronic compass, which is used to measure the drilling azimuth and inclination of the probe position. The ZKXG30-T(a) mine drilling imaging trajectory detection device has built-in high-performance three-dimensional electronic compass, which is used to measure the drilling azimuth and inclination of the probe position. The video signal, control signal, and compass digital signal in the probe are transmitted to the host through the mine intrinsically safe communication cable. The host receives the probe signal and the depth pulse signal of the sounder, calculates the depth position of the probe, and processes the video signal such as image recording, matching, and splicing. Video recording can be full hole or partial. Video and image matching and splicing are carried out simultaneously. As the probe continues to move into the hole, the whole hole wall is automatically matched and spliced into a complete plane expansion. While processing the image, the host computer can display the real-time monitoring image and the stitched unfolded image and can switch the display of borehole trajectory projection. The saved data can be played back and browsed. After connecting with PC, the instrument can be used as a U disk, which is convenient to copy and paste files.

4.3. Test Steps

4.3.1. Drilling Preparation. The diameter of the drilling probe shall not be less than 30 mm, and the depth shall be within 100 m, so as to ensure that the drilling has a certain elevation angle. Therefore, the water can flow out freely and keep as straight as possible to avoid step holes. After drilling, it needs to be placed for 10 minutes. After the fog in the hole disap-

pears, it can be detected to ensure that the probe window will not condense water vapor.

4.3.2. Technical Staffing. At least 3 field operators are required for drilling exploration in deep roadway, excluding drilling personnel. One probe operator is responsible for using the push rod to push the probe slowly and smoothly into the drilling hole. Another cable operator is responsible for passing the cable through the depth decoder at a constant speed, and the last one host operator is responsible for controlling the host.

4.3.3. Device Connection. Connecting probe: both ends of the cable are fixed with 7-core waterproof plug. The plug is connected with the probe, and the plug cap is tightly fixed with the probe

Detector installation: the tripod is stably placed under the air port, and the probe cable is installed on the pulley

Connecting to the host: the other end of the 7-core video cable is connected to the host signal interface, and the 4-core cable connects the detector interface with the host deep interface

4.3.4. Equipment Operation. The equipment operation includes (1) power on self-test; (2) adjust the screen brightness; (3) drilling imaging detection device connection probe debugging: (a) turning on the host and entering the imaging detection mode, (b) setting the parameters, (c) menu selection, (d) adjusting the inner diameter and pulse distance, and (e) image acquisition; and (4) drilling track detection device connection probe debugging: (a) turning on the host and enter the track detection mode, (b) parameter setting, and (c) image acquisition, as shown in Figure 5.

FIGURE 5: Image acquisition interface.

5. Test Results and Countermeasures

5.1. Drilling Peep Results. The peep results of this coal seam, upper adjacent layer, lower adjacent layer, and high-level gas drainage boreholes are shown in Figures 6–10.

Through peeping at the coal seam, upper adjacent layer, lower adjacent layer, and high-level gas drainage boreholes, the results show that the integrity of the boreholes in the coal seam is well. There is no obvious macrocracks, but there is water accumulation. Although the water in the borehole is ventilated and drained after the completion of drilling construction, there is still a certain length of water immersion in the depth of the down bedding drilling, which will directly affect the gas drainage effect. Due to the influence of drilling opening at 0–1 m of the hole opening in the lower adjacent layer, the hole collapse is very serious. The integrity of the borehole at 1–6 m is good, but the surrounding fissures are obviously developed. The borehole at 8–10 m begins to collapse obviously, and the borehole at 10 m completely collapses. The overall quality of the borehole is very poor. Compared with the lower adjacent layer, the integrity of the upper adjacent layer is better. However, there are obvious through type axial fractures. The borehole is completely collapsed at about 18 m.

There are a lot of cracks in the high-level borehole before 12 m. When selecting the high-level borehole for gas drainage, attention should be paid to the sealing distance of the borehole greater than 12 m. Otherwise, the gas concentration will decrease, and the gas drainage efficiency will be affected. The hole collapse occurred at the position of about 20 m in both adjacent strata and high-level boreholes, and the high-level boreholes collapsed seriously, which basically blocked the boreholes. In the follow-up gas drainage process, it will affect the drainage flow in varying degrees, resulting in the decline of drainage efficiency.

5.2. Prevention Measures of Hole Collapse. In view of the above experimental results, the prevention of hole collapse can be carried out from the following aspects. In the specific construction, according to the drilling speed, drilling pressure, rock powder, backwater, and lithology changes, the accurate judgment is made. Usually, clean water can be used as the flushing fluid. If the condition is not allowed and only circulating water can be selected, the bottom of cage should be kept in a clean state to avoid contamination by debris and rock powder, which will lead to the drill bit buried and paste, and eventually collapse. The drilling speed and feed pressure of the drilling rig should also be well controlled. If the rock stratum is relatively soft, the speed and pressure should be appropriately reduced according to the actual situation, and the footage height should also be appropriate. In case of hole collapse, the lithology and specific location of the starting section should be judged quickly and accurately, and the effective measures should be taken in time.

The operator should have practical experience and skilled technology, and be able to find the hole collapse in time, and adjust the drilling feed pressure and speed according to the coal and rock conditions. If the coal and rock are relatively soft, the drilling pressure and drilling speed should be appropriately reduced, the lifting frequency of drill pipe should be increased, and the coal and rock powder in the hole should be discharged in time, so as to reduce or avoid the drilling accidents.

According to the hardness of the rock in the hole, the bit type is selected to improve the drilling efficiency. When the rock is soft and the water invasion time is long, the hole collapse is easy to occur. The work should not be stopped during the shift handover, so as to facilitate the rapid construction and reduce the probability of hole collapse.

In the process of drilling, if the rock is soft, the drilling speed should be slowed down at this time, and the hole

FIGURE 6: View of gas drainage borehole in C_5^b coal seam.

should be swept repeatedly after passing through the soft rock to avoid sticking. If the rotary resistance is large and the pump is choked, the feed pressure should be stopped to ensure the water circulation. Then, the drilling tool is moved up and down, continuing to work after removing obstacles. When there is abnormal phenomenon, it is forbidden to lift the drilling tool by force.

When drilling stops, the drilling tool is lifted to a height of 3 m to 5 m from the bottom of the hole. When there is clear

water in the hole, it can be stopped, so as to avoid the phenomenon of buried drilling. When drilling again, the drilling slag in the hole should be washed clean, and the process speed of drilling to the bottom of the hole should be slowed down. It can work normally after reaching the bottom of the hole.

5.3. Trajectory Measurement Results. The three-dimensional schematic diagram of peeping results of borehole

FIGURE 7: View of gas drainage boreholes in lower adjacent layer C_6^a coal seam.

trajectory measurement is shown in Figure 11, and the horizontal projection, East-West projection, and North-South projection are shown in Figures 12–14.

The trajectory measurement of gas drainage boreholes in C_5^a , C_5^b , C_6^a , and C_6^c coal seams was carried out on site, including 6 boreholes in C_5^b coal seam and 2 boreholes in each adjacent coal seam. The trajectory measurement results and trajectory deviation of gas drainage boreholes in working seam, upper adjacent layer, lower

adjacent layer, and high position are shown in Table 3. The average values of deviation of borehole inclination, azimuth deviation of borehole, and vertical height deviation are listed in the table. In the data, a positive sign indicates upward deviation, and a negative sign indicates downward deviation. The actual measurement results show that the dip angles of the boreholes in the coal seam, the high-level boreholes, and the upper adjacent layers all deviate downward, while the dip angles of the boreholes

FIGURE 8: View of gas drainage boreholes in lower adjacent layer C_6^c coal seam.

in the lower adjacent layers deviate upward. The azimuth deviation of high position borehole is the largest and that of upper adjacent layer borehole is the smallest. The deviation distance of high-level borehole is the largest, and the average vertical height of downward deviation is 5.8 m. The actual vertical height deviation of upper adjacent layer is the smallest, and the average vertical height of downward deviation is 0.8 m.

5.4. Prevention Measures of Deviation in Drilling Construction. In view of the above experimental results, we think that the prevention of drilling construction deviation can be carried out from the following aspects.

- (1) *Ensure Reliable Drilling Equipment.* Good equipment is the premise of accurate drilling construction. Reasonable drilling rig and BHA (bottom hole

FIGURE 9: View of C_5^a gas drainage borehole in upper adjacent layer.

assembly) should be selected according to the geological conditions, and the drilling rig and BHA should be maintained regularly to ensure the stable and reliable state of drilling equipment. Drilling deviation correction technology should be actively applied to reduce the bending degree of drilling as much as possible

(2) *Reasonable Control of Drilling Length.* “Borehole deviation” increases with the increase of borehole depth, and long borehole is easy to form gas drainage goaf at the bottom of borehole. Therefore, from the perspective of controlling borehole deviation, the design and construction length of borehole should be reduced as far as possible on the

FIGURE 10: View of high-level borehole in C_5^b coal seam.

FIGURE 11: Main control page of borehole track of gas drainage.

FIGURE 12: Horizontal projection of gas drainage borehole.

FIGURE 13: East-West projection of gas drainage borehole.

premise of ensuring full coverage of borehole control area

- (3) *Scientific and Standardized Drilling.* The deviation of drilling angle is one of the main reasons for the deviation of drilling. We should change the traditional opening method of manual measurement such as compass and slope gauge and try to use advanced equipment and technology to locate the hole
- (4) *Reasonable Selection of Drilling Parameters.* According to the different geological conditions, mechanical properties of coal and rock mass, and drilling construction process parameters, the drilling construction process parameters such as feed force, rotation speed, and flushing fluid flow are reasonably selected to reduce the drilling deviation

FIGURE 14: North-South projection of gas drainage borehole.

TABLE 3: Gas drainage borehole trajectory measurement results (average value).

Borehole type	Deviation of borehole inclination (°)	Azimuth deviation of borehole (°)	Vertical height deviation (m)
This coal seam drilling	-2.4	+1.8	-3.3
High-level drilling	-4.2	+2.2	-5.8
Upper adjacent layer drilling	-0.6	-0.6	-0.8
Lower adjacent layer drilling	+1.8	+1.3	+2.5

6. Conclusions

In this work, the field test of gas drainage borehole peeping and trajectory measurement in coal seam of Changling coal mine are carried out. The conclusions are as follows.

- (1) By peeping at the boreholes of C_5^b coal seam, upper adjacent layer C_5^a coal seam, lower adjacent layer C_6^a and C_6^c coal seam, and C_5^b coal seam high-level drilling in Changling coal mine, it can be concluded that the integrity of boreholes in this coal seam is good. There is no obvious macrocracks, but there is water accumulation. The phenomenon of hole collapse occurs at the position of about 20 m in both adjacent strata and high-level boreholes, which will directly affect the gas drainage effect. There are a lot of cracks in the high-level boreholes before 12 m. When high-level boreholes are selected for gas drainage, the sealing distance should be greater than 12 m.
- (2) The dip angles of the boreholes in the coal seam, the high-level boreholes, and the upper adjacent layers all deviate downward, while the dip angles of the bore-

holes in the lower adjacent layers deviate upward. The deviation distance of the high-level boreholes is the largest. The average vertical height of the downward deviation is 5.8 m. The actual vertical height deviation of the upper adjacent layers is the smallest, and the average vertical height of the downward deviation is 0.8 m.

- (3) Through the experiment, we put forward four strategies to prevent the deviation of drilling construction: ensuring the reliability of drilling equipment, reasonably controlling the drilling length, standardizing the drilling, and reasonably selecting the drilling process parameters.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors certify that they have no conflicts of interest.

Acknowledgments

This research was funded by the National Natural Science Foundation of China (51874314, 52004291, 51974161).

References

- [1] D. Jia, Y. Qiu, C. Li, and Y. Cai, "Propagation of pressure drop in coalbed methane reservoir during drainage stage," *Advances in Geo-Energy Research*, vol. 3, no. 4, pp. 387–395, 2019.
- [2] K. Wang and F. Du, "Coal-gas compound dynamic disasters in China: a review," *Process Safety and Environmental Protection*, vol. 133, pp. 1–17, 2020.
- [3] H. Wang, B. Tan, Z. Shao, Y. Guo, Z. Zhang, and C. Xu, "Influence of different content of FeS_2 on spontaneous combustion characteristics of coal," *Fuel*, vol. 288, p. 119582, 2021.
- [4] S. Liu, X. Li, D. Wang, and D. Zhang, "Experimental study on temperature response of different ranks of coal to liquid

- nitrogen soaking,” *Natural Resources Research*, vol. 30, no. 2, pp. 1467–1480, 2021.
- [5] W. Liang, Y. Zhao, J. Liu, D. Elsworth, Z. Feng, and J. Cai, “Advances in in-situ modified mining by fluidization and in unconventional geomechanics,” *Advances in Geo-Energy Research*, vol. 5, no. 1, pp. 1–4, 2021.
 - [6] F. Du, K. Wang, X. Zhang, C. Xin, L. Shu, and G. Wang, “Experimental study of coal-gas outburst: insights from coal-rock structure, gas pressure and adsorptivity,” *Natural Resources Research*, vol. 29, no. 4, pp. 2481–2493, 2020.
 - [7] F. Du and K. Wang, “Unstable failure of gas-bearing coal-rock combination bodies: insights from physical experiments and numerical simulations,” *Process Safety and Environmental Protection*, vol. 129, pp. 264–279, 2019.
 - [8] C. Xin, F. Du, K. Wang, C. Xu, S. Huang, and J. Shen, “Damage evolution analysis and gas-solid coupling model for coal containing gas,” *Geomechanics and Geophysics for Geo-Energy and Geo-Resources*, vol. 7, no. 1, 2021.
 - [9] J. Liu, X. Liang, Y. Xue, K. Yao, and Y. Fu, “Numerical evaluation on multiphase flow and heat transfer during thermal stimulation enhanced shale gas recovery,” *Applied Thermal Engineering*, vol. 178, p. 115554, 2020.
 - [10] H. Wang, X. Fang, F. Du et al., “Three-dimensional distribution and oxidation degree analysis of coal gangue dump fire area: a case study,” *Science of the Total Environment*, vol. 772, 2021.
 - [11] Y. Cai, F. Xi, and H. Cheng, “Causes and prevention measures of borehole bending,” *Shangpin yu zhiliang*, vol. 7, pp. 85–86, 2011.
 - [12] C. Dong, “Directional drilling technology and development tendency in underground mine,” *Coal Science and Technology*, vol. 43, no. 5, pp. 106–110, 2015.
 - [13] W. Wang, “Harm and preventive measures of borehole bending in coalfield geological drilling,” *Heilongjiang Science*, vol. 5, no. 5, p. 170, 2014.
 - [14] L. Du, “Analysis on the causes of borehole bending and its preventive and corrective measures,” *Public Communication of Science & Technology*, vol. 5, no. 7, pp. 182–189, 2013.
 - [15] Y. Chen and T. Yan, “Computer system of the function of tracking well trajectory and predicting hitting the target of drill holes,” *Earth Science-Journal of China University of Geosciences*, vol. 22, no. 4, pp. 432–435, 1997.
 - [16] X. Li, Z. Cao, and Y. Xu, “Characteristics and trends of coal mine safety development,” *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, pp. 1–19, 2020.
 - [17] K. Wang and F. Du, “Experimental investigation on mechanical behavior and permeability evolution in coal-rock combined body under unloading conditions,” *Arabian Journal of Geosciences*, vol. 12, no. 14, 2019.
 - [18] M. A. Polak and A. Lasheen, “Mechanical modelling for pipes in horizontal directional drilling,” *Tunnelling and Underground Space Technology*, vol. 16, no. 1, pp. 47–55, 2001.
 - [19] E. Cheng and M. A. Polak, “Theoretical model for calculating pulling loads for pipes in horizontal directional drilling,” *Tunnelling and Underground Space Technology*, vol. 22, no. 5–6, pp. 633–643, 2007.
 - [20] J. S. Lueke and S. T. Ariaratnam, “Surface heave mechanisms in horizontal directional drilling,” *Journal of Construction Engineering and Management*, vol. 131, no. 5, pp. 540–547, 2005.
 - [21] J. S. Lueke, “Surface heave associated with horizontal directional drilling construction techniques,” University of Alberta, Alberta, Canada, 2005.
 - [22] G. Manacorda, M. Miniati, A. Simi et al., “A bore-head GPR for horizontal directional drilling (HDD) equipment,” in *Proceedings of the 15th International Conference on Ground Penetrating Radar*, pp. 745–750, Brussels, Belgium, 2014.
 - [23] J. Matheus, M. Ignova, and P. Hornblower, “A hybrid approach to closed-loop directional drilling control using rotary steerable systems,” *IFAC Proceedings Volumes*, vol. 45, no. 8, pp. 84–89, 2012.
 - [24] C. Figueredo, “Enhanced RSS technology pushes drilling envelope,” *Journal of Petroleum Technology*, vol. 66, no. 3, pp. 32–35, 2014.
 - [25] J. Li, “Analysis on the causes of borehole deviation,” *Science and technology of West China*, vol. 12, no. 2, pp. 9–11, 2013.
 - [26] W. T. Liang, W. P. Zou, K. Han, and Z. J. Gu, “Analysis of reasons for declination of drillhole,” *Mining Engineering*, vol. 7, no. 2, pp. 65–67, 2009.
 - [27] B. Zhu, Z. Du, and Z. Dang, “Compound drilling device for deviation prevention and straight drilling while drilling: China,” 2011, 201874461.
 - [28] Z. Ding and K. Zhou, “The analysis of gas drainage drilling skew law in a coal mine,” *Coal Mine Modernization*, vol. 6, pp. 89–91, 2014.
 - [29] H. Wang, S. Li, H. Shuang, Z. Du, L. You, and L. Liu, “Pressure-relief gas drainage technique by high level borehole in lateral high drainage roadway,” *Journal of Central South University (Science and Technology)*, vol. 47, no. 4, pp. 1319–1326, 2016.
 - [30] H. Wang, Z. Du, Q. Fan, H. Shuang, J. Xie, and L. You, “Inclination measuring and deviation correction technology of pressure released gas drainage borehole in external dislocated high level gateway,” *Coal Science and Technology*, vol. 43, no. 8, pp. 77–81, 2015.
 - [31] T. Zhao, “Causation of borehole deviation and measures to prevent and rectify,” *Coal geology of China*, vol. 21, no. S1, pp. 62–63, 2009.
 - [32] Z. Zhao, G. Liu, Z. Duan, and Y. Zhao, “Causes and preventive measures of borehole inclination,” *Ground Water*, vol. 6, pp. 96–98, 2007.