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Research into technology for precision directional drilling of gas-drainage boreholes

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Abstract

Purpose. In order to solve the serious problem of borehole deflection in coal mine gas drainage, the precision directional drilling tool has been developed and improved, as well as the general borehole deflection laws have been studied.

Methods. By using ordinary drilling pipes, one set of precision directional drilling tool and two sets of precision directional drilling tools, gas-drainage boreholes have been drilled in the mine and, subsequently, the borehole trajectory parameters have been measured using an inclinometer.

Findings. The borehole inclination angle first tends to decrease and then to increase, while the azimuth angle generally increases. The precision directional drilling tool is effective, especially when using two sets of drilling tools. In this case, the average 100-meter final borehole deflection is reduced by 66.0%, the average inclination angle is reduced by 52.3%, and the average azimuth angle is reduced by 46.5%.

Originality. A tool for precision directional drilling has been developed and improved, and its effectiveness has been confirmed; the general laws of borehole deflection have been summarized from the overall for subsection intervals.

Practical implications. The research results are of great guiding significance for preventing the gas-drainage borehole deflections and further research on the tool for precision directional drilling.

Keywords: *gas drainage, borehole deflection, precision directional drilling tool, borehole parameters, deflection laws*

1. Introduction

Gas disaster is one of the main disasters in coal mines. In order to ensure the safety of mine production, coal-seam gas drainage is generally used to prevent and control gas disasters [1]-[3]. Due to the influence of factors such as seam inclination, alternating soft and hard rocks, as well as different construction techniques, deflection can occur during drilling. The drilling borehole deflection leads to the deflection of the pre-drainage drilling hole from the design position, and even some drilling holes have a large deflection, resulting in a blank zone for drainage, thus influencing the degassing effect [4]-[6].

In response to the problem of borehole deflection during drilling, A. Lubinski and H.B. Woods were the first to study the factor of drill collar bending under the action of drilling pressure and suggested adding a stabilizer to the proper drill collar position to prevent deflection. In addition, they compiled a set of practical charts for calculating the position of the stabilizer installation, which served as the theoretical basis for the precision drilling technology [7]-[10]. With the continuous development of directional and horizontal drilling technologies, major breakthroughs have been made in the field of active deflection prevention, and vertical borehole systems, such as VDS and SDD, have been improved [11], [12]. Baker Hughes has launched VertiTrak system and Schlumberger has launched the PowerV system [13], [14]. These systems can effectively reduce deflections during drilling and ensure straight drilling. Canadian scholar Elisabeth Cheng has developed a theoretical model for calculating the tensile force of a drill pipe in horizontal directional drilling. In this case, the theory of flexible rod deflection was used to assess the drilling trajectory and stiffness of the drill pipe, as well as the contact force between the combination of drill pipes and the wall of the drilled borehole [15]. Spanish scholar David Bukowitz has developed a computer program based on the finite element method to predict the modes and frequencies of lateral vibrations in the assembly of the drill string bottom hole [16]. Ukrainian scholar V.I. Gulyaev studied the theoretical modeling of drill string bifurcation and buckling in deep directional boreholes, and analyzed the critical state of the drill string for various values of borehole inclination angle, drill string motion and axial rotation speed [17]. In China, C. Xiang-jun, believes that the amount of residual coal in the borehole increases with increasing drilling depth. However, this leads not only to an increase in the rotational friction of the drilling tool, but also to an increase in the inclination angle of the drill pipe, causing the deflection of the drilling trajectory [18]. S. Zhen uses stereo projection and MATLAB filtering method to prove that the inclination angle of the drilling trajectory along the seam is generally a long period or several short periods with increasing drilling depth [19]. X. Yan-peng

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conducted field tests with the developed straightening and anti-deviation device. The results show that the maximum inclination angle variation is reduced by 51%, the maximum azimuth angle variation is reduced by 44%, the final borehole deflection is reduced by 71% and the drilling quality is significantly improved [20]. H. Hu studied the principle of correcting the screw drilling tool deviation, and finally proposed a method for correcting the eccentric wedge deviation in the inclinometer auxiliary casing, thereby improving the situation of serious borehole deflection [21].

The research purpose is to develop a new type of precision directional drilling technology suitable for short-distance drilling, reducing the deflection of gas-drainage boreholes and improving the drilling quality. At present, the directional drilling rig has a good active anti-deviation effect, but its size is large, its operation is complicated, its cost is high, and it is not suitable for drilling short holes. And there are few types of passive deflection correcting devices, and their ability to control the borehole deflection is weak, making it difficult to meet the requirements of precision drilling of gas-drainage boreholes.

In order to achieve the set purpose, the following objectives are solved:

1. Research and development of a new type of precision directional drilling, which has the functions of accuracy, slag discharge and drill withdrawal.

2. Using an inclinometer to collect the test drilling parameters and original 3D trajectory mapping software to compare the data after processing, as well as summarize the general drilling deflection laws.

3. Compare and analyze the variation of deflection, inclination and azimuth angles before and after using the precision directional drilling tool to test its effect on preventing drilling deflection.

2. Methods

2.1. The experimental device

There are many reasons for the borehole deflection, including geological factors, technical factors, process factors, and so on. The force of the drill pipe is analyzed when it deviates downward under the action of its own gravity in the vertical direction; however, when the drilling depth increases, more drill cuttings remain in the borehole, which lift the drill pipe and cause the drilling borehole to move upwards [22]-[24].

The precision directional drilling tool uses a nearly full-hole drilling method. This is a device with a diameter slightly smaller than that of the drill bit diameter, installed between the drill bit and the drill pipe, which can perform the function of precise orientation. Thus, the gap between the drill pipe and the borehole wall is reduced, which ensures that the drill bit and the central axis of the drilling borehole are basically coincident. The structure diagram is shown in Figure 1.

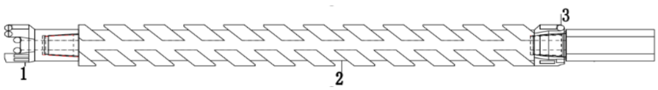

***Figure 1.** Structure diagram of the precision directional drilling tool: 1 – drill bit; 2 – the precision directional drilling tool; 3 – the reverse drill*

The precision directional drilling has the following technical characteristics.

Precision technology. The precision directional drilling tool changes the force on bit, as well as the deflection force initially acting on the bit tip and the lateral force of the seam acting on the precision directional drilling tool, thereby reducing the force on bit and ensuring that the bit will not be deflected easily. And since the diameter of the precision directional drilling tool is similar to the borehole diameter, not only can the drill bit be restrained from shaking and prevented from reaming, but the interaction force between the precision directional drilling tool and the borehole wall can also ensure that the drill bit is drilling straight.

Slag discharge technology. Precision directional drilling uses a radial groove and axial milling design combined with fluid slag discharge and mechanical slag discharge with double slag discharge. It also thoroughly mixes the drill cuttings accumulated on the underside of the borehole wall and makes it easier to discharge the drill cuttings by wind or hydraulic power, preventing drilling cuttings from building up.

Return technology. There is a reverse drill bit at the back of the precision directional drilling tool. During the withdrawal process, the reverse drill bit is drilled in the opposite direction, making it easier to complete the withdrawal.

2.2. The handling method parameter

Using a mine borehole inclinometer to measure the inclination angle, the probe tube is first connected to an intrinsically safe mobile phone via Bluetooth, inserted into the special non-magnetic drill pipe and connected to the drill bit, and then drilled normally. Each time a 1-meter drill pipe is inserted and the drilling tool is stabilized. The probe collects inclination angle, azimuth angle and the measurement point deviation data via the sensor and stores it in its own memory.

The following methods for calculating the borehole trajectory coordinates are commonly used: minimum curvature method, equal-angle full-distance method, corrected average angle method, curvature radius method, and balanced tangent method [25]-[27]. Since the calculation process of the equal-angle full-distance method is relatively simple and accurate, the equal-angle full-distance method is used to process the inclination measurement data. In addition, the actual and theoretical XYZ coordinates of each measurement point are obtained to draw 3D trajectory map. The calculation formula for equal-angle full-distance method is shown in Formulas 1-6.

$$X_n = X_{n-1} + \Delta X ; \quad (1)$$

$$Y_n = Y_{n-1} + \Delta Y ; \quad (2)$$

$$Z_n = Z_{n-1} + \Delta Z ; \quad (3)$$

$$\Delta X = \Delta l \cos\frac{\alpha_n + \alpha_{n-1}}{2} \cos\frac{\beta_n + \beta_{n-1}}{2} ; \quad (4)$$

$$\Delta Y = -\Delta l \cos\frac{\alpha_n + \alpha_{n-1}}{2} \sin\frac{\beta_n + \beta_{n-1}}{2} ; \quad (5)$$

$$\Delta Z = \Delta l \sin\frac{\alpha_n + \alpha_{n-1}}{2} , \quad (6)$$

where:

X – the X-axis coordinate of the measurement point, m;
Y – the Y-axis coordinate of the measurement point, m;
Z – the Z-axis coordinate of the measurement point, m;
α – the inclination angle of measurement point, °;
β – the azimuth angle of the measurement point, °;
Δl – the distance between the measurement points, m;

Δ*X* – the *X*-axis coordinate increment, m;
Δ*Y* – the *Y*-axis coordinate increment, m;
Δ*Z* – the *Z*-axis coordinate increment, m.

3. Results and discussion

3.1. Drilling parameter results

In total, the trajectory parameters of 6 boreholes have been measured. Thus, boreholes No. 1 and 2 use ordinary drill rods, boreholes No. 3 and 4 use a set of precision directional drilling tool, and boreholes No. 5 and 6 use two sets of precision directional drilling tools. The specific drilling parameters are shown in Table 1.

It can be found that the final deflection of boreholes No. 1 and 2 which use ordinary drill pipe is 6.78 and 7.12 m, respectively. From here it averages 6.95 m, and the average deflection per 100 m is 8.07 m. The final deflection of boreholes No. 3 and 4 which use a set of the precision directional drilling tool is 3.76 and 4.52 m, respectively. On average, it is 4.15 m, and the average deflection per 100 m is 4.41 m. The final deflection of boreholes No. 5 and 6 which use two sets of the precision directional drilling tools is 2.90 and 1.85 m, respectively. On average, it is 2.38 m, and the average deflection per 100 m is 2.74 m. It can be concluded that when using one set of the precision directional drilling tool, the average deflection per 100 meters is reduced by 45.4%, and when using two sets of the precision directional drilling tools, the average deflection per 100 meters is reduced by 66.0%.

Using the equal-angle full-distance method, the test drilling parameters have been processed, as well as the theoretical and actual drilling coordinates have been calculated. In addition, using the original software, 3D trajectory maps of boreholes No. 1-6 have been drawn. The results of calculating the borehole coordinates are shown in Table 2, and 3D trajectory maps of boreholes are shown in Figures 2a-2f.

Table 1. Parameters of boreholes

Number of boreholes	Design inclination, degree	Starting inclination, degree	Design azimuth, degree	Starting azimuth, degree	Drilling depth, m	Final borehole deflection, m	Deflection per hundred meters, m
1	24	21.6	180	185.35	80	6.78	8.48
2	29	26.46	360	360.81	93	7.12	7.66
3	50	47.61	180	180.94	91	3.76	4.13
4	17	17.33	30	37.2	97	4.54	4.68
5	35	34.73	130	134.67	91	2.90	3.19
6	2	3.06	300	315.96	81	1.85	2.28

Table 2. Results of calculating the borehole coordinates

No.	Drilling depth, m	Inclination angle, degree	Azimuth angle, degree	Measured (*X*), m	Theory (*X*), m	*ΔX*, m	Measured (*Y*), m	Theory, (*Y*), m	*ΔY*, m	Measured (*Z*), m	Theory (*Z*), m	*ΔZ*, m
1	1	21.6	185.35	-0.93	-0.93	0	0.09	0.09	0	0.37	0.37	0
	2	22.04	185.14	-2.78	-2.78	0	0.25	0.26	-0.01	1.11	1.1	0.01
						…						
	80	24.93	187.84	-70.49	-73.14	2.65	11.15	6.78	4.37	33.53	29.08	4.45
2	1	26.46	360.81	0.89	0.89	0	-0.01	-0.01	0	0.45	0.45	0
	3	25.41	360.86	2.69	2.68	0.01	-0.04	-0.04	0	1.32	1.34	-0.02
						…						
	100	29.02	368.03	81.06	83.22	-2.16	-7.23	-1.16	-6.07	44.52	41.5	3.02
3	1	47.61	180.94	-0.67	-0.67	0	0.01	0.01	0	0.74	0.74	0
	2	47.46	180.66	-2.7	-2.7	0	0.04	0.04	0	2.95	2.95	0
						…						
	80	50.84	184.14	-58.85	-61.35	2.5	2.86	0.96	1.9	69.26	67.2	2.06
4	1	17.33	37.2	0.76	0.76	0	-0.58	-0.58	0	0.3	0.3	0
	2	16.32	37.3	2.28	2.28	0	-1.74	-1.73	0.01	0.88	0.89	0.01
						…			0			0
	97	16.8	32.89	75.45	73.77	1.68	-55.55	-55.99	0.44	24.66	28.85	4.19
5	1	34.73	134.67	-0.58	-0.58	0	-0.58	-0.58	0	0.57	0.57	0
	2	33.92	134.48	-2.32	-2.31	-0.01	-2.35	-2.34	-0.01	2.26	2.28	-0.02
						…						
	91	35.65	135.07	-54.26	-52.62	-1.64	-50.86	-53.18	2.32	52.36	51.8	0.56
6	1	3.06	315.96	0.72	0.72	0	0.69	0.69	0	0.05	0.05	0
	2	2.96	315.33	1.43	1.44	-0.01	1.39	1.39	0	0.11	0.11	0
						…						
	81	3.67	316.82	59.36	58.18	1.18	54.84	56.18	-1.34	4.85	4.38	0.47

3.2. Analysis of the borehole deflection laws

According to Table 2 and Figures 2a-f, the law of variation of the borehole inclination angle and the azimuth angle can be summarized. The borehole inclination angle generally first decreases and then increases. It can be seen from the figure that the borehole trajectory deviates first downward and then upward. The borehole azimuth angle basically increases, and it can be seen from the figure that the borehole trajectory basically deviates to the right.

The maximum variation of inclination and azimuth angles of the six tested boreholes is shown in Table 3. Among them, the inclination angle variation of borehole No. 2 is the largest, equal to 9.15°; the inclination angle variation of borehole No. 6 is the smallest, equal to 4.02°.

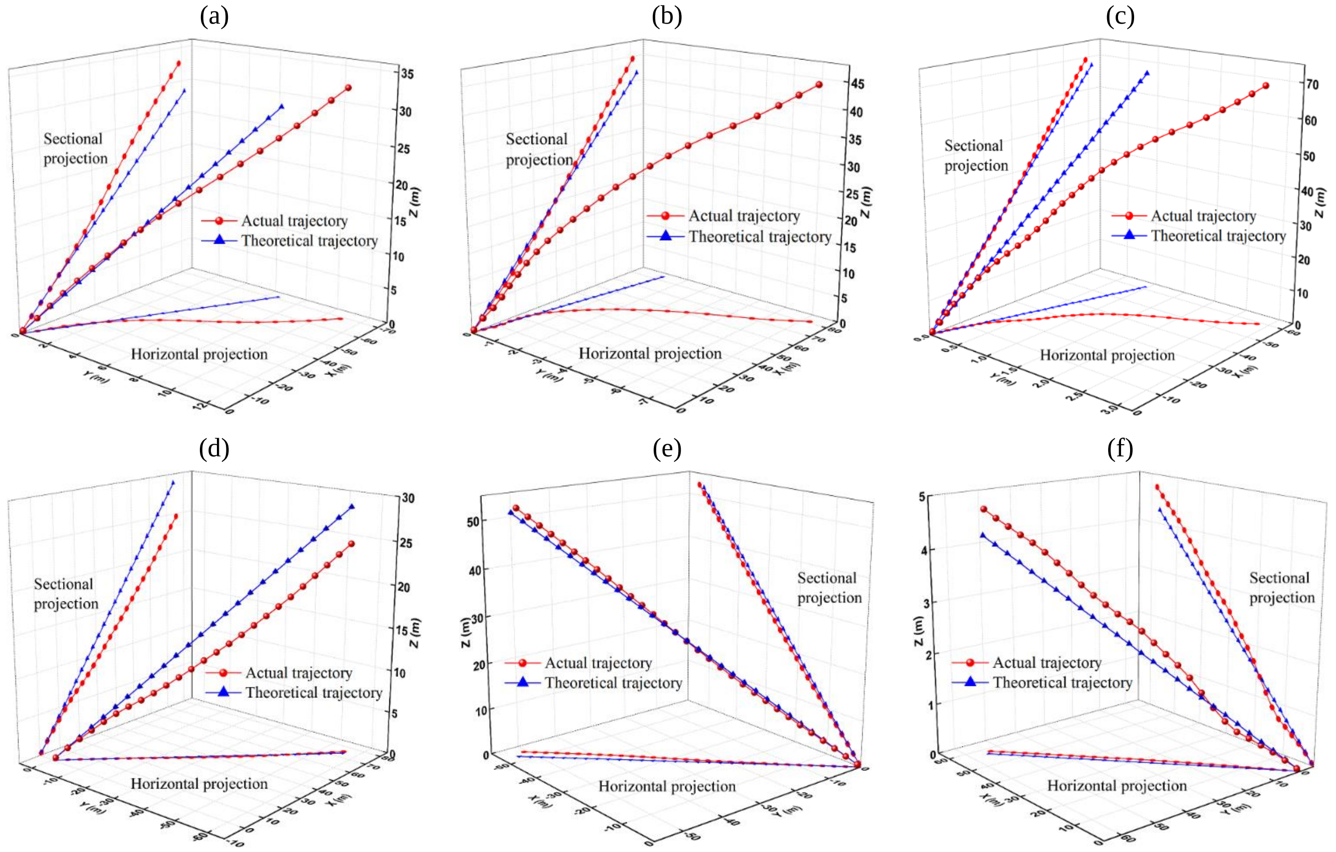

Figure 2. 3D trajectory map of boreholes: (a) No. 1; (b) No. 2; (c) No. 3; (d) No. 4; (e) No. 5; (f) No. 6

Table 3. Variation of borehole inclination and azimuth angles

Number of boreholes	Inclination angle, degree			Angle variation, degree	Azimuth angle, degree			Angle variation, degree
	Starting value	Maximum	Minimum		Starting value	Maximum	Minimum	
1	21.6	29.61	20.79	8.82	185.35	194.38	183.13	11.25
2	26.46	31.68	22.53	9.15	360.81	371.82	359.54	12.28
3	47.61	52.04	46.28	5.76	180.94	186.14	178.46	7.68
4	17.33	17.34	10.32	7.02	37.20	39.58	32.03	7.55
5	34.73	37.12	32.57	4.55	134.67	139.43	134.48	4.95
6	3.06	5.54	1.52	4.02	315.96	321.84	314.2	7.64

The azimuth angle variation of borehole No. 2 is the largest, equal to 12.28°; the azimuth angle variation of borehole No. 5 is the smallest, equal to 4.95°. From Table 3, it can be determined that the average inclination angle variation of boreholes No. 1 and 2 which use ordinary drill pipe is 8.99°, and the average azimuth angle variation is 11.77; the average inclination angle variation of boreholes No. 3 and 4 which use a set of precision directional drilling tool is 6.39°, and the average azimuth angle variation is 7.62; the average inclination angle variation of boreholes No. 5 and 6 which use two sets of precision directional drilling tools is 4.29°, and the average azimuth angle variation is 6.30°.

Therefore, when using one set of the precision directional drilling tool, the average inclination angle variation is reduced by 28.9%, and the average azimuth angle variation is reduced by 35.3%; when using two sets of the precision directional drilling tools, the average inclination angle variation is reduced by 52.3%, and the average azimuth angle variation is reduced by 46.5%. Given that the actual depth of six boreholes is 80-100 m, a depth interval of 25 m is used, and a total of four depth intervals is used to study the laws of variation of inclination and azimuth angles. The laws of variation of inclination and azimuth angles at different depth intervals are shown in Tables 4 and 5.

Table 4. Average variation value of borehole inclination angles at different depth intervals, degree

Number of boreholes	0-25 m		25-50 m		50-75 m		75-100 m	
	Average inclination angle	Average variation value	Average inclination angle	Average variation value	Average inclination angle	Average variation value	Average inclination angle	Average variation value
1	22.83	1.23	27.66	6.06	25.18	3.58	24.64	3.04
2	24.86	-1.6	29.04	2.58	31.09	4.63	30.05	3.59
3	46.98	-0.63	49.68	2.07	51.33	3.72	51.13	3.52
4	14.44	-2.89	13.06	-4.27	14.79	-2.54	16.92	-0.41
5	33.45	-1.28	35.28	0.55	36.59	1.86	35.39	0.66
6	3.27	0.21	3.79	0.73	3.33	0.27	3.1	0.04

Table 5. Average variation value of borehole azimuth angles at different depth intervals, degree

Number of boreholes	0-25 m		25-50 m		50-75 m		75-100 m	
	Average azimuth angle	Average variation value	Average azimuth angle	Average variation value	Average azimuth angle	Average variation value	Average azimuth angle	Average variation value
1	185.69	0.34	191.76	6.41	190	4.65	188.02	2.66
2	360.77	-0.04	363.94	3.13	368.11	7.3	369.11	8.3
3	181.18	0.24	182.11	1.17	184.2	3.26	184.53	3.59
4	37.44	0.24	38.78	1.58	35.86	-1.34	32.81	-4.39
5	135.78	1.11	138.02	2.35	137.59	2.92	135.38	0.71
6	319.05	3.09	317.08	1.12	315.91	-0.05	316.35	0.39

The average inclination angle variation at four depth intervals is: 0.83°, 1.29°, 1.92°, 1.74°, so the average inclination angle variation from small to large is in the interval of 0-25 m, the interval of 25-50 m, the interval of 75-100 m, and the interval of 50-75 m, respectively. The borehole inclination angles are the largest in the range of 50-75 m.

The average azimuth angle variation at four depth intervals is: 0.83°, 2.63°, 2.79°, 1.88°, so the average azimuth angle variation from small to large is in the interval of 0-25 m, the interval of 75-100 m, the interval of 25-50 m, and the interval of 50-75 m, respectively. Therefore, the borehole azimuth angles are the largest in the range of 50-75 m.

4. Conclusions

The borehole inclination angle generally first decreases and then increases, while the borehole azimuth angle basically increases. At four depth intervals, the borehole inclination and azimuth angles are the largest in the interval of 50-75 m.

The precision directional drilling tool has a good effect, especially when two sets of the precision directional drilling tools are used for gas-drainage drilling. In this case, the average deflection per 100 meters is reduced by 66.0%, the average inclination angle variation is reduced by 52.3%, and the average azimuth angle variation is reduced by 46.5%.

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Дослідження технології точного похило-направленого буріння дегазаційних свердловин

Ю. Ма, Я. Ксю

Мета. Експериментальні дослідження закономірностей траєкторії дегазаційних свердловини для вирішення проблеми відхилення свердловини при похило-направленому бурінні в умовах газообільних вугільних шахт.

Методика. Використовуючи звичайні бурильні труби, один комплект інструментів для точного похило-направленого буріння та два комплекти інструментів для точного похило-направленого буріння, у шахтних умовах були пробурені свердловини для дренажу газу і, згодом, за допомогою інклінометра були виміряні параметри траєкторії свердловини.

Результати. Встановлено, що кут відхилення свердловини спочатку мав тенденцію до зменшення, а потім до збільшення, а азимутальний кут свердловини загалом збільшувався, а у чотирьох інтервалах глибин відхилення нахилу свердловини та її азимуту було найбільшим в інтервалі 50-75 м. Доведено, що інструмент для точного похило-направленого буріння є ефективний, особливо коли використовуються два комплекти бурових інструментів. Встановлено, що середнє 100-метрове кінцеве відхилення свердловини зменшується на 66.0%, середній кут відхилення зменшується на 52.3%, а середній азимутальний кут зменшується на 46.5%.

Наукова новизна. Був розроблений та вдосконалений інструмент для точного похило-направленого буріння, а також підтверджена його ефективність; типові закономірності відхилення свердловини були приведені як для загальних інтервалів, так і для інтервалів підсекції.

Практична значимість. Результати досліджень мають велике провідне значення для запобігання відхиленням дегазаційних свердловин та подальших досліджень інструменту для точного похило-направленого буріння.

Ключові слова: *газовідведення, відхилення свердловини, інструмент для точного похило-направленого буріння, параметри свердловини, закономірності відхилення*