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Development of a New High Temperature Passive Drilling Magnetic Guidance System

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Abstract

With the increasingly severe geological environment for drilling, magnetic guidance technology that can accurately measure the trajectory of rescue Wells is more important. In order to ensure sufficient measurement accuracy and increase the operating temperature range of the equipment, a drilling magnetic guidance system prototype with wider operating temperature range was developed, and the measurement repeatability test and ground simulation experiment were carried out on the prototype. Repeatability experiment results show that the data repeatability is good; The surface experiment results show that the maximum error is <3% when the well inclination is between 10° and 50°, the distance measurement error is <7% and the Angle error is <5° when the distance is 10m, and the measurement error is <3.5% and the Angle error is <2° when the distance is 5m. The developed drilling magnetic guidance system has a wider operating temperature and a wider application range, and its accuracy meets the requirements of field use. It can be used for guiding rescue Wells. The research results provide a reference for the research of magnetic guidance technology in rescue Wells.

Keywords

Killer Well; Steerable Drilling; Magnetic Steering; Distance Measuring Tool.

1. Introduction

With the development of oil and gas exploration and development toward special oil and gas resources, the geological environment is becoming more and more complex, and the environmental challenges of high temperature, high pressure, high salt and strong corrosion are becoming more and more severe [1]. In the more and more complex drilling process, some unexpected conditions will inevitably lead to blowout and other accidents, which requires timely remedial measures to minimize the adverse effects of accidents. When other measures cannot solve the out-of-control blowout engineering accident, it is necessary to rely on the drilling of relief Wells as the last effective means, so relief Wells are one of the core technologies of necessary reserves [2-5]. However, the focus of relief well is how to accurately control the drilling trajectory of relief well so that it can accurately reach the target area of the accident well, which puts forward extremely high requirements for the measurement and control of drilling trajectory [6-8]. In order to accurately measure the distance between the accident well and the rescue well, magnetic ranging (MR) method is commonly used to solve the problem of accurate ranging between the rescue well and the target well [9][Application of magnetic guidance technology in fine control of trajectory of SAGD double horizontal Wells]. Nowadays, the successful application of tools such as RMRS, MGT and MagTraC has made the underground magnetic ranging technology develop rapidly [10]

In order to more accurately measure the distance between the rescue well and the accident well, it is necessary to use a magnetic beacon as a signal source to determine the relative position between the two Wells. However, when an accident occurs in an oil and gas well, it is inconvenient to place an

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active magnetic beacon in the accident well [11]. Using casing magnetic field as passive magnetic beacon, the magnetic field strength is not strong enough and the measuring range is small, which is more suitable for collision prevention in Wells. While active magnetic beacon such as permanent magnet subjoint adsorbs a large amount of iron filings caused by wear during well rescue, which seriously affects the measurement accuracy. In addition, the permanent magnet sub is the most widely used in active magnetic beacon while drilling. However, because the permanent magnet sub is close to the drill bit in the pipe string, it seriously affects the deviation and rock breaking ability of the drill assembly and is not conducive to the control of the wellbore trajectory [12]. However, passive magnetic guidance technology has been applied to rescue well trajectory control with certain application experience [13]. Therefore, in order to ensure the measurement accuracy of the magnetic ranging system, according to the field application requirements, this paper developed a high temperature drilling magnetic guidance system based on passive magnetic guidance technology, which uses the charging sleeve as a magnetic beacon for rescue Wells, and carried out ground experiments.

2. Prototype Development System

2.1 System Function

In order to develop the high temperature drilling magnetic guidance system, the working environment and basic functions of the magnetic guidance system are analyzed, and the basic requirements of the magnetic guidance system are determined.

The principle of passive magnetic ranging technology for connecting two Wells is shown in Figure 1. Electrify the well shaft to generate a stronger magnetic field and act as a downhole magnetic beacon. The probe pipe is placed under the rescue well, and the magnetic field data between the rescue well and the accident well is collected through the three-axis fluxgate sensor on the probe pipe, and the measurement data is transmitted to the "data acquisition and data analysis" module on the well for data analysis, so as to determine the distance between the rescue well and the accident well, and modify the drilling trajectory according to the measurement results.

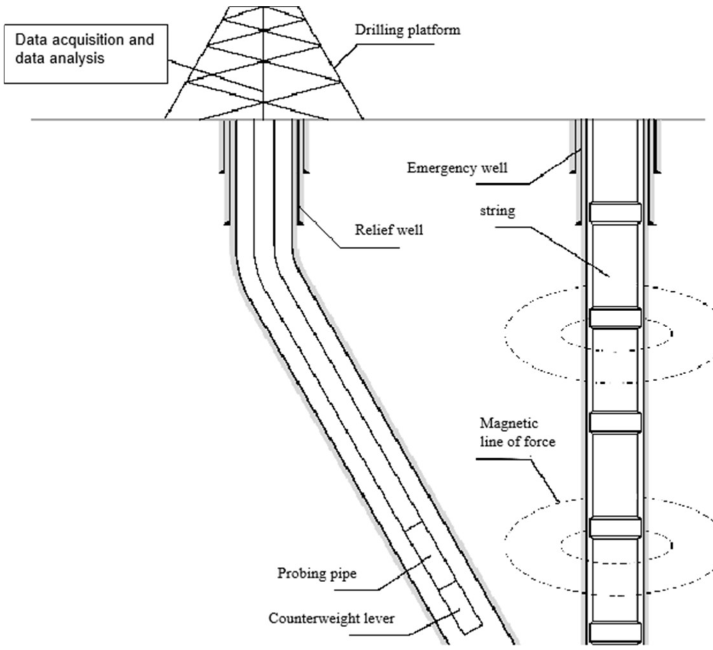

Figure 1. Principle of passive drilling magnetic guidance

The high temperature drilling magnetic guidance system developed in this paper should meet the requirements according to the working principle, as shown in Table 1[14, 15].

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Table 1. High temperature drilling magnetic guidance system needs to meet the requirements

job demands	basic requirements
Determine the relative position between the sensor and the magnetic beacon	The magnetic beacon magnetic field and geomagnetic field data are measured when the sensor position changes with the relative position of the magnetic beacon
Determine drilling trajectory	Measuring the position of the probe and the running speed
Monitor the working environment	Measuring ambient temperature
Can work in a set working environment	Structural pressure, temperature resistance of electronic components, etc
Data transmission and analysis	The collected data is processed and then transmitted to the ground for analysis

2.2 Function Realization

In order to realize the basic functions of the underground magnetic guidance system and ensure the normal operation of the underground magnetic guidance system, as shown in Table 2, the underground magnetic guidance system meets the basic requirements through the following ways.

Table 2. The basic requirements of high temperature drilling magnetic guidance system

Basic requirements	Demand	Emphasis	Implement method
Measure the magnetic field data between sensor and magnetic beacon	Relative Angle and distance between sensor and magnetic beacon	High measurement accuracy and data processing are required	Triaxial fluxgate sensor - triaxial magnetic field data determines relative position
Determine drilling trajectory	Force, velocity, acceleration	High measurement accuracy and data processing are required	1. Gravity sensor - Determine sensor attitude 2. Speed sensor - Determine the speed of the sensor 3. Acceleration sensor - Sensor attitude determination is complementary to gravity sensor
Determine the working environment	temperature		Temperature sensor - Monitors the operating temperature of the sensor
Normal operation of equipment	Pressure bearing, sealing, assembling electronic components		Determine the equipment structure according to the size limit, sensor arrangement, working environment, etc
The electronics are working	high temperature resistance	Electronic components are resistant to high temperature/heat insulation	Select high temperature resistant components and apply thermal insulation potting glue

3. Systematic Design

According to the required functions and corresponding implementation methods of the drilling magnetic guidance system, the overall design of the drilling magnetic guidance system is completed, and the design results are shown in Figure 2.

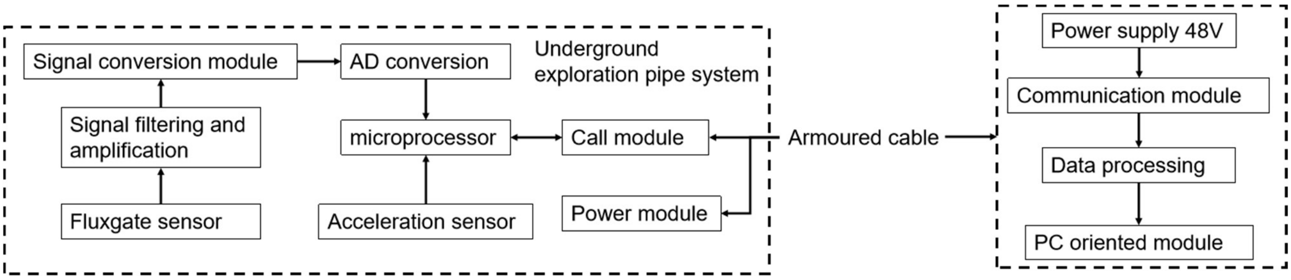

Figure 2. Overall structure diagram of drilling magnetic guidance system

As shown in Figure 2, the microprocessor in the drilling magnetic guidance system transmits the data collected by the acceleration sensor and the three-axis fluxgate sensor to the well control system through the Tonghua module. After receiving the data, the well control system transmits the data processing result to the PC guidance module, and the PC guidance module displays the analysis result of the probe data

3.1 Circuit Design

According to the field application requirements, information such as well trajectory, distance between rescue well and accident well should be obtained when drilling rescue well. Therefore, the signal acquisition module of the drilling magnetic guidance system developed in this paper mainly includes a three-axis fluxgate sensor, a three-axis acceleration sensor, a three-axis weight force sensor, a temperature sensor (to monitor whether the operating temperature of the drilling magnetic guidance system exceeds the rated range) and its related circuits.

The three-axis fluxgate sensor is selected as the magnetic ranging sensor in this paper, and its index requirements are as follows: Signal-to-noise level (< 10 nT/Hz1/2 @ 2 hz), (T) + 70 mu for measuring range, resolution (0.01 nT), sampling frequency (1 KHZ), linear error (< 0.01%), the error of three-axis orthogonal (< 0.2 °), zero temperature drift (nT / 0.5 ℃); Operating temperature range (-40℃ ~+125℃), sensor voltage conversion coefficient is 100μV/nT.

According to the field application requirements, gravity sensor and gravity acceleration sensor are installed in the magnetic guidance system to measure the well trajectory and determine the deflection Angle of different well sections.

3.2 Physical Design

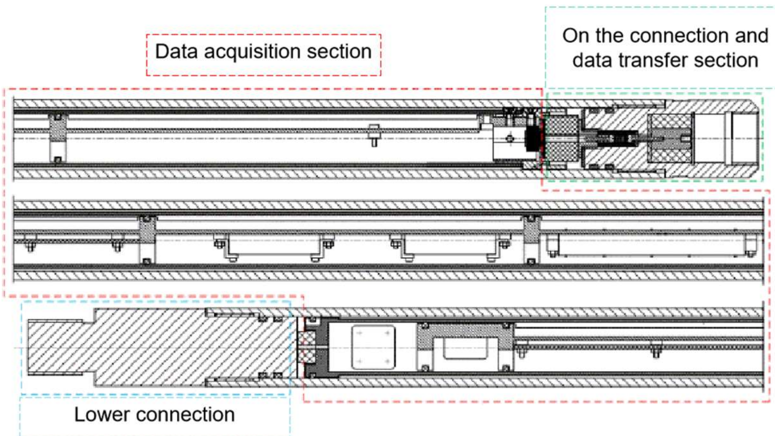

Figure 3. Introduction to the structure of the probe

The internal mechanical structure of the drilling magnetic guidance system designed in this paper is shown in Figure 3. The inside of the probe tube is mainly divided into upper connection and data transmission part, data acquisition part and lower connection part. The upper part of the connection

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is composed of non-magnetic metal, which is connected with the superior equipment through the thread and transmits the collected data to the well through the logging cable for data analysis. The data acquisition part is composed of a cage without magnetic core, sensors and related circuits and electronic components on the cage, which is used to collect the data of magnetic field, temperature, gravity and acceleration within the measurement range. The lower connection part is made of non-magnetic metal and is connected to the lower equipment such as the counterweight rod by threading.

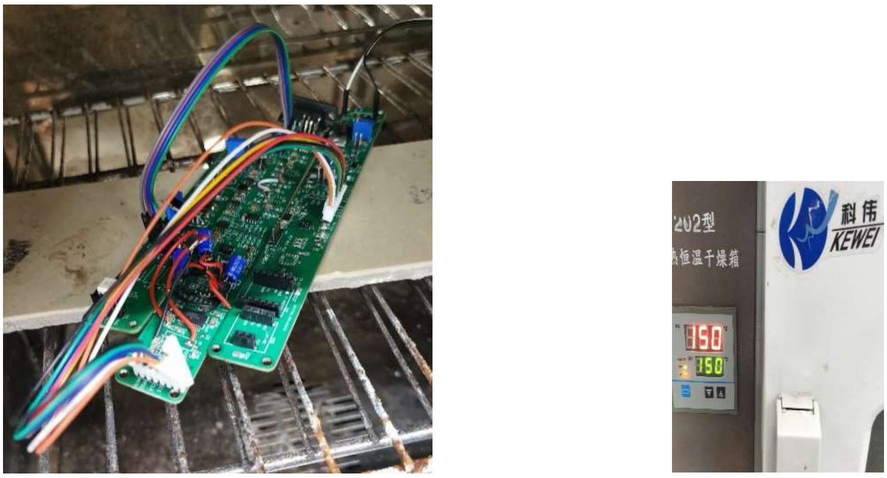
3.3 Data Transmission

The data transmission section sends real-time data uploaded by the underlying sensor once per second. Data packets are transmitted to the well control system for data analysis in the format of working rate: 115200, data bit: 8, stop bit: 1, and no parity bit.

In order to check the integrity of the transmitted data, the data is sent to the well control system in Json format, which is convenient for the well control system to use side code to parse with Json. In order to check the data error, the device will send a 1-byte check code after sending the Json data. The check code is obtained by adding all the Json strings by characters. The code on the side of the well control system should use pseudo-code to check the Json string.

3.4 Circuit Temperature Experiment

In field application, as the drilling depth of the magnetic guidance system increases, the operating temperature of the drilling magnetic guidance system will increase due to the influence of formation temperature. However, the temperature has a great impact on the normal operation of circuits and electronic components. In order to ensure that the drilling magnetic guidance system can work normally in the field application process, the temperature test of the design circuit is carried out. According to the characteristics of the underground working environment of the drilling magnetic guidance system, the circuit temperature experiment was carried out by placing the chip into the Beijing Kewei Yongxing 202-00A electric constant temperature drying oven. Figure 4(a) shows placing the chip in a constant temperature drying oven. Keep the temperature at 150℃ through the drying oven to test whether the circuit can run successfully at 150℃. Figure 4(b) shows the test circuit at 150℃ in the drying oven.



(a) (b)

Figure 4. Circuit temperature experiment

In the 150℃ constant temperature drying oven, the drilling magnetic guidance system chip can still operate normally, which proves that the drilling magnetic guidance system can work normally at 150℃.

4. Prototype Experiment and Result Analysis

In order to test whether the drilling magnetic guidance system can realize the basic function, the ground simulation experiment is established. The experiment includes power supply, drilling magnetic guidance system prototype, computer, wire, inverter, resistor, data acquisition processor and so on.

The magnetic field is generated by energizing the wire to simulate the energized accident well shaft. The magnetic field intensity of the magnetic beacon is changed by changing the resistance and voltage in the circuit. The frequency of the magnetic beacon is adjusted by the frequency converter.

Experimental scheme: Fix the wire and keep a section of the wire long and straight enough to simulate the energized bushing as a magnetic beacon for measurement. The frequency converter and the resistor are connected in series to the analog circuit of the accident well, so that the magnetic field intensity and frequency of the circuit can be adjusted by the resistor and the frequency converter. The probe tube is kept at a distance from the conductor, and the data collected by the probe tube is transmitted to the computer through the data acquisition processor to record the magnetic field intensity data measured by the drilling magnetic guidance system under this condition.

4.1 Repetitive Experiment

After the drilling magnetic guidance system prototype is successfully developed, the gravity, gravity acceleration and temperature are measured by the drilling magnetic guidance system prototype, and the repeatability and accuracy of the measuring data are tested.

4.1.1 Gravity and Gravitational Acceleration Measurement.

The prototype of the drilling magnetic guidance system was placed horizontally, rotated around the axis, and the gravity and gravitational acceleration of the prototype at different angles were recorded, as shown in Figure 5.

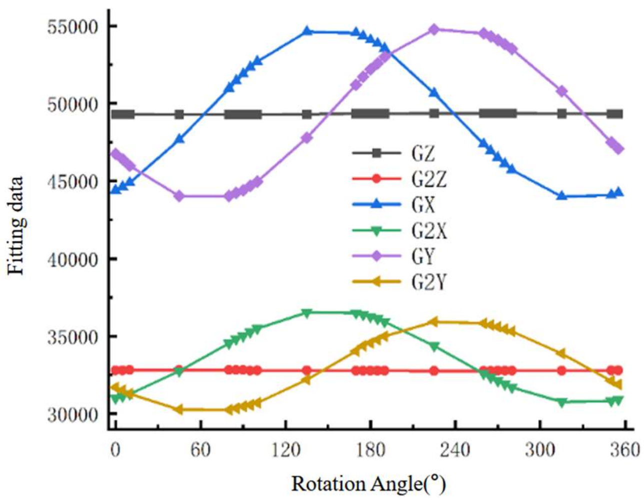


Figure 5. Gravity and gravitational acceleration measurements at azimuth

As shown in Figure 5, except for the horizontally placed Z axis, the gravity and gravitational acceleration of the X and Y axes change sinusoidal with the rotation of the prototype. The results of gravity and gravity acceleration measured by the prototype are in good agreement with the variation rules of gravity and gravity acceleration.

4.1.2 Temperature Measurement.

Temperature measurement results of the drilling magnetic guidance system prototype under different ambient temperatures were recorded, and the data results were shown in Figure 6.

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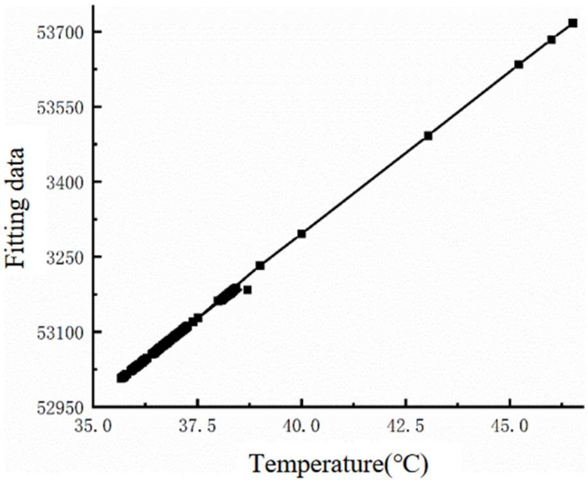
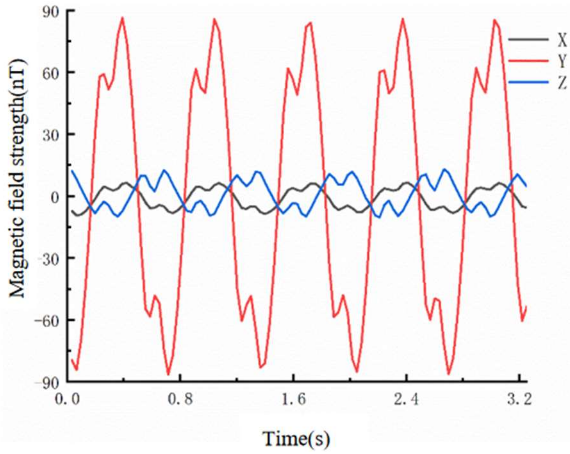


Figure 6. Temperature measurement result

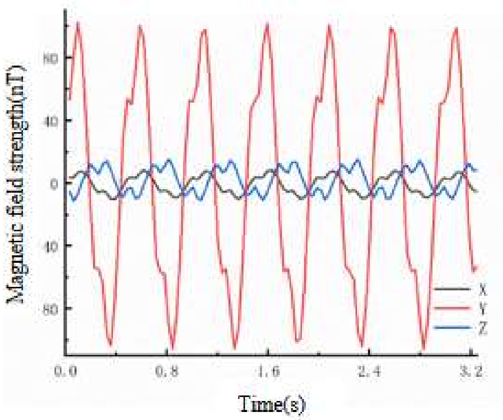
As shown in Figure 6, the temperature measurement results of the prototype presented a linear change rule with the temperature change, and were highly consistent with the temperature change rule of the prototype.

4.2 Magnetic Field Strength Measurement

The current frequency of the magnetic beacon is controlled to about 2Hz, and the measurement results of the drilling magnetic guidance system prototype under different magnetic field strengths are recorded. The measurement results are shown in Figure 7.



(a)1.5Hz



(b)2.0Hz

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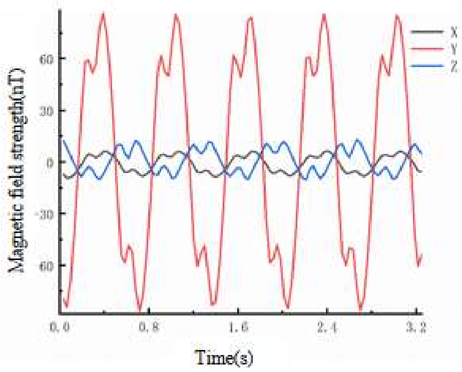

(c)2.5Hz

Figure 7. Magnetic field intensity acquisition results at different frequencies

Figure 7 shows the magnetic field strength measurement results of the prototype drilling magnetic guidance system when the frequency of the magnetic beacon is 1.5Hz, 2.0Hz and 2.5Hz respectively. It can be seen from FIG. 7 that the magnetic field intensity is consistent with the current frequency of the magnetic beacon, and shows an obvious periodic change rule. The magnetic field strength increases with the increase of current frequency.

Magnetic field intensity data under the same conditions as the prototype of the drilling magnetic guidance system were collected using the Spectramag-6 six-channel spectrum analyzer. The measurement results of the two tools are shown in Table 3.

Table 3. Comparison of magnetic field strength measurement results

Serial number	Drilling magnetic steering system prototype	Spectramag-6	Relative theoretical deviation
1	41.51	41.62	-0.25
2	36.76	37.18	-1.13
3	28.47	28.01	1.66
4	25.28	25.61	-1.28
5	21.82	21.72	0.53
6	20.60	18.93	10.6
7	19.36	19.53	-0.89
8	18.32	18.51	-1.01
9	18.16	15.09	20.33
10	12.33	9.57	-26.47
11	5.93	5.77	2.71
12	5.81	5.78	0.56
13	5.54	5.06	-8.66
14	3.03	3.57	17.71

As shown in Table 3, as the magnetic field intensity decreases, the relative deviation between the drilling magnetic steering system prototype and the Spectramag-6 measurements increases. When the magnetic field intensity of the drilling magnetic guidance system prototype is lower than 20nT, the waveform is unstable, the fluctuation amplitude is large, and the measurement accuracy is not high. When the magnetic field intensity of the drilling magnetic guidance system prototype is higher than 20nT, the overall theoretical relative error is smaller (<2%) and the acquisition accuracy is higher.

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4.3 Deflection Angle Measurement and Analysis

In order to detect the azimuth Angle and inclination Angle of the drilling magnetic guidance system prototype relative to the accident well, the single parameter measurement of azimuth Angle and inclination Angle and the comprehensive measurement of deviation Angle and distance are carried out respectively, and the measurement results are analyzed.

4.3.1 Azimuth

The drilling magnetic guidance system prototype was tilted to a certain azimuth Angle relative to the magnetic beacon and the measurement data at different angles were recorded. The measurement results are shown in Table 4.

Table 4. Azimuth measurement results

Group indication	Measured bearing	Computed azimuth	Error range
1	right29°	right27°	-6.9%
2	right30°	right31°	3.33%
3	right26°	right27°	3.85%
4	left36°	left40°	10%
5	left26°	left26°	0
6	left32°	left35°	8.6%
7	right32°	right36°	11.11%
8	right28°	right25°	-12%
9	right28°	right26°	7.8%

As shown in Table 4, the larger the azimuth Angle, the greater the error between the measurement results and the calculated results. However, the smaller the azimuth Angle of the drilling magnetic steering system prototype relative to the magnetic beacon, the more accurate the calculated results.

4.3.2 Hole Drift Angle

The prototype of the developed drilling magnetic guidance system was tilted at a certain well inclination Angle and the measurement data at different angles were recorded. The measurement results are shown in Table 5.

Table 5. Well Angle measurement results

Group indication	Measured bearing	Computed azimuth	Error range
1	10°	9.18°	-8.21%
2	14°	13.62°	-2.74%
3	18°	18.12°	0.66%
4	20°	20.02°	0.12%
5	23°	22.37°	-2.73%
6	27°	26.32°	-2.52%
7	30°	29.50°	-1.65%
8	35°	34.52°	-1.38%
9	38°	37.51°	-1.28%
10	40°	39.51°	-1.23%
11	44°	43.08°	-2.09%
12	48°	47.90°	-0.20%
13	50°	54.04°	8.07%

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As shown in Table 5, the measurement error is larger when the well inclination is >50° or <10°. However, when the well inclination is between 10° and 50°, the maximum error is less than 3%, and the measurement accuracy is high to meet the requirements of the drilling magnetic guidance system.

4.3.3 Deflection Angle and Spacing

As shown in Table 6, the prototype of the developed drilling magnetic guidance system is tilted at a certain Angle relative to the magnetic beacon to maintain a distance and record the measured data.

Table 6. Deflection Angle and distance measurement results

Group indication	Actual distance	Actual Angle	Measuring distance	Error range	Measuring angle	Error range	Requested
1	15m	left20°	13.42m	10.53%	left14.73°	5.27°	15m/±8°
2	15m	right20°	13.21m	12.2%	right22.69°	-2.69°	
3	10m	left15°	9.42m	5.8%	left19.31°	-4.31°	10m/±5°
4	10m	right15°	9.31m	6.9%	right12.87°	2.13°	
5	5m	left10°	4.83m	3.4%	left8.63°	1.37°	5m/±2°
6	5m	right10°	4.87m	2.6%	right8.18°	1.82°	
7	3m	left8°	2.93m	2.33%	left8.25°	-0.25°	
8	3m	right8°	2.89m	3.66%	right6.93°	1.07°	
9	1m	left5°	0.97m	3%	left3.82°	1.18°	
10	1m	right5°	0.98m	2%	right3.57°	1.43°	

As can be seen from Table 6, with the change of the relative position of the magnetic beacon and the prototype of the drilling magnetic guidance system, the measurement accuracy of the drilling magnetic guidance system is constantly changing, and the measurement accuracy shows that the greater the distance and azimuth, the greater the measurement error. The greater the distance between the magnetic beacon and the drilling magnetic steering system prototype, the greater the distance measurement error of the drilling magnetic steering system prototype. When the distance between the magnetic beacon and the drilling magnetic steering system prototype is 10m, the measurement error is less than 7%, and when the distance is 5m, the measurement error is less than 3.5%.

When the variation of azimuth measurement accuracy between the magnetic beacon and the drilling magnetic guidance system prototype is consistent with the variation of distance measurement accuracy, the azimuth measurement accuracy of the drilling magnetic guidance system prototype is constantly improved with the decrease of the distance between the magnetic beacon and the drilling magnetic guidance system prototype.

The greater the distance between the magnetic beacon and the prototype of the drilling magnetic guidance system, the lower the measurement accuracy of the drilling magnetic guidance system. This result is consistent with the characteristics of rapid attenuation of the magnetic field intensity after the magnetic field exceeds a certain distance, and is consistent with the results of the magnetic field intensity comparison experiment in Table 3 above. When the distance between the magnetic beacon and the drilling magnetic guidance system is less than 10m, the measurement accuracy of the drilling magnetic guidance system is high, and it can meet the requirements of guidance and ranging of rescue Wells [16].

4.4 Field Application and Analysis

After completing the laboratory test and analysis of the experimental results of the drilling magnetic guidance system prototype, it is confirmed that the prototype meets the requirements of the rescue well guidance and ranging. Next, the field application verifies the reliability of the drilling magnetic

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guidance system in practical engineering applications, and analyzes whether the drilling magnetic guidance system can meet the field application requirements.

4.4.1 Well Profile Design

At present, the pilot test well with a gas storage has to drill a new well for gas injection, halogen drainage and gas injection and production because it does not meet the requirements of wellbore tightness. Considering the requirements of the field, the principle of magnetic ranging is the same in directional connected well and rescue well, the field application experiment of magnetic guidance system is carried out by this gas storage. The cavity of the experimental well is measured, and the top position of the cavity is 1873m, the port position is 1899m, and the bottom position is 1920m. The depth of the whole cavity ranges from 1873-1920m, the height is 47m, the volume is 137774m3, the maximum radius is 61m, and the average radius is 26m. The new well structure is designed according to the test well cavity and formation conditions. The new well structure is shown in Figure 8.

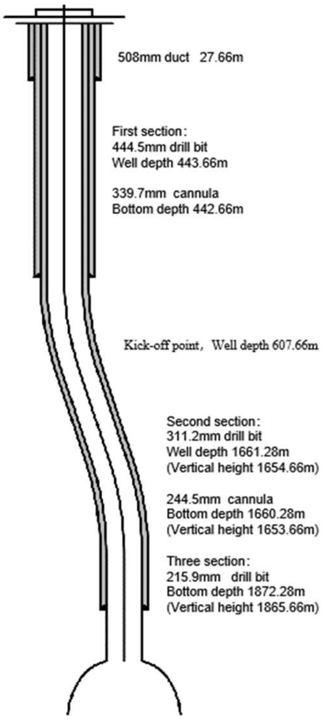

Figure 8. Well structure diagram

Combined with the relative position between the new well structure and the adjacent well, anti-collision scanning is carried out between the new well and the adjacent well, and the nearest distance between the new well and the adjacent well is 18.38m. The adjacent well is an old well with a depth of 1900m, and the collision risk is great during drilling. Therefore, in order to ensure the smooth drilling of the new well into the experimental well, the passive magnetic guidance technology is used to measure the distance between the new well and the old well after the second drilling. In addition, the field track monitoring should be strengthened, and the magnetic signal should be paid attention to. The anti-collision distance should be calculated in time in key drilling anti-collision sections. If the well distance is found to be close to each other, timely measures should be taken to ensure that no collision accidents will occur.

4.4.2 Magnetic Guidance Ranging and Analysis

The distance between the new well and the old well was measured by the magnetic guidance system, and the new well successfully connected the experimental well chamber without collision accident. The projection diagram of the new well and the old well is shown in Figure 9, and the distance between the new well and the old well in the adjacent position is shown in Table 7.

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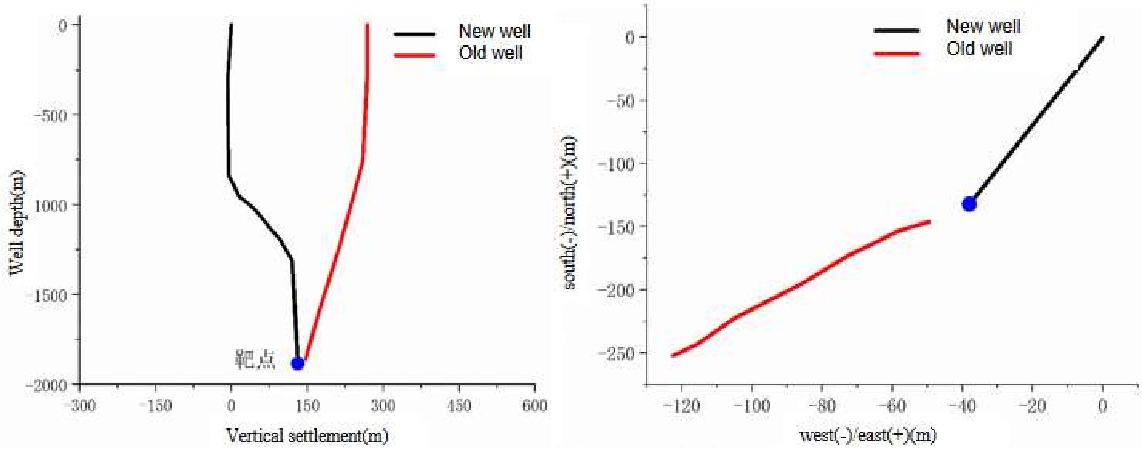

(a) Plumb projection (b) Horizontal projection

Figure 9. New well and old well projection diagram

Table 7. Distance between new and old Wells near each other

Group indication	New well		Old well		Anti-collision distance (m)
	Design sounding (m)	Design vertical depth (m)	Sounding (m)	Vertical depth (m)	
1	1687.66	1670.06	1671.63	1665.65	34.90
2	1717.66	1700.06	1701.47	1695.36	32.11
3	1747.66	1730.06	1731.39	1725.14	29.34
4	1687.66	1670.06	1671.63	1665.65	34.90

The magnetic guidance system is used to drill the connected well of the pilot test well, and to ensure the collision prevention in the drilling process. As can be seen from FIG. 9 and Table 7, the magnetic guidance system successfully connects the pilot test well and ensures the collision prevention of the adjacent well, and the field application is successful, indicating that the magnetic guidance system can meet the requirements of field application.

5. Conclusion

(1) According to the application requirements of rescue Wells, a drilling magnetic guidance system with charging sleeve as magnetic beacon under high temperature is developed. The drilling magnetic guidance system has a higher operating temperature range in addition to the two functions of inclinometer and ranging.

(2) According to the ground test results, when the inclination Angle of the prototype drilling magnetic steering system is less than 30°, the measurement accuracy is higher; When the distance is 10m, the distance measurement error is less than 7% and the azimuth error is less than 5°. When the distance is 5m, the distance and azimuth measurement error is less than 3.5%, and the azimuth error is less than 2°. However, with the reduction of deflection Angle and distance, the calculation accuracy is gradually improved to meet the requirements of field use.

(3) The magnetic guidance system was used to conduct directional drilling of the connected well of a gas storage pilot test well. The results showed that the pilot test well was successfully connected and the collision avoidance was ensured near. The successful field application proved that the magnetic guidance system met the needs of field application.

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CNPC Bohai Drilling Engineering Company "Open list" project "Wired passive Active magnetic detection guided drilling instrument development and technology research", project number: 2022ZD04F-02.

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