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Design and Test of Flexible Drill Pipe for Sidetracking Horizontal Well in Digital Oilfield

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Abstract. Digital oilfield is the main means to increase production and income. Developing ultra-short radius sidetracking horizontal wells in old wells requires high-performance well trajectory control. In this paper, the ultra-short radius flexible drill pipe is designed by bionics principle, and logging tool is designed to monitor borehole trajectory in real time by using gamma ray technology. The combination of the flexible drill pipe and logging tool can realize the remaining oil recovery between dense well patterns. The dense well network determines that the drill pipe has a certain bending angle during drilling, and the remaining oil reservoir can be drilled in the shortest distance. The design of drilling tools for ultra-short radius horizontal wells for 7 "and 9-5/8" old well casings is the basis of this paper, the key is to verify the rationality of the design through experiments. The test research shows that, the strength of flexible drill pipe meets the design requirements and importing the monitoring data of gamma logging tool simulating the drilling process of the experimental well into LANDMARK software to describe the well trajectory, the radius of curvature of the deflecting section is 1.5m-2m, meeting the design expectation.

Keywords. Sidetracking, Flexible drill pipe, Test, Remaining oil, well

1. Introduction

The remaining oil exists objectively [1-4]. A new horizontal well can be formed by sidetracking the well bore of an old well, thus providing an important means for intelligent and efficient exploitation of oil and gas resources [5]. It can effectively excavate the remaining oil caused by imperfect well pattern control and injection-production system, thus reduces the production cost and improves the recovery ratio and production efficiency [6-9]. The technologies and methods are the core contents of digital oil fields and intelligent oil fields at home and abroad in recent years. In order to achieve the above purpose, it is necessary to realize the whipping in the shortest possible radius.

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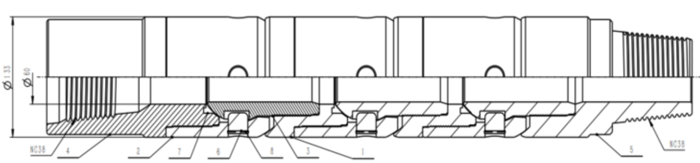
In view of this situation, it is feasible to design high deviation drilling tools with ultra-short radius (curvature radius less than 4m) [10-15]. With the expiration of the patent protection of Sandia National Laboratory's uranium fission prompt neutron logging method, the United States GeoInstruments Company has industrialized and upgraded it and rebuilt the standard model well for uranium quantitative calibration [16-17]. In 2009, the Russian All Russian Institute of Automation also launched the АИНК- Model 60 Pulse Neutron Logging Tool [18]. In 2015, with the support of the national key research and development plan, Tang Bin of East China University of Technology and others cooperated with the Nuclear Industry Aerial Survey and Remote Sensing Center to break through the key technologies and developed the first uranium vein impulse neutron logging tool with independent intellectual property rights in China [19].

2. Flexible Drill Pipe Design

The main purpose of the design of the flexible drill pipe is to exploit the remaining oil between the dense well network. The density of the well net determines that the drill pipe has a certain bending angle, and the drill tool meets the remaining reservoir in the shortest distance during sidetracking, that is, the shorter the radius of the slope curvature, the greater the advantage [5-6].

The flexible drill pipe structure determined by the above points is shown in Figure 1. The flexible drill pipe consists of eight parts: 1 connector, 2 sleeves, 3 ball heads, 4 upper connectors, 5 lower connectors, 6 torque pins, 7 aprons and 8 spring retaining rings; The upper joint 4 is connected with the outer sleeve 2 by threads, and four stepped holes are radially distributed in the outer sleeve for placing four torque pins 6. The torque pins are used to connect the ball heads to transmit torque, and a spring retainer ring 8 is arranged outside the torque pins to prevent the torque pins from falling off under the action of internal and external forces during work and causing accidents. Sealing grooves are reserved between the joints for placing sealing rings. Screw thread structure is designed outside the ball head to realize the series connection of multiple flexible drill pipes.



1. Connector; 2. Jacket; 3. Ball head; 4. Upper connector; 5. Lower connector; 6. Torque pin; 7. Apron; 8. Spring retainer.

Figure 1. Schematic diagram of flexible drill pipe structure.

The model of drill pipe used for 7” and 9-5/8” casing-pipe is the same. In this paper, the minimum limit principle is adopted in the design of drill pipe. The diameter of 7 "casing-pipe is 177.8mm, and the maximum thickness of casing-pipe is 12.5mm, so the inner diameter of casing-pipe is 152.5mm. The drill pipe diameter is 144mm, so the minimum interval Δ between the casing wall and the drill pipe is 8mm. Each rigid unit of flexible drill pipe must smoothly pass through the bending rigid virtual casing (deflection section) with a radius of curvature of R_1 and a diameter of 152.5mm without deformation. As shown in Figure 2, the limit length and limit bending angle of a single section of flexible drill pipe can be calculated according to Formula 1,2,3 and Formula 4. The minimum unit limit length is l_{max}, the bending angle of each section of flexible unit is θ,

$$\Delta = d_1 - d_2 = 8.5\text{mm} \tag{1}$$

In the right triangle OAB:

$$\left(\frac{l_{max}}{2}\right)^2 + \left[R_1 + \left(\frac{d_1}{2} - \Delta\right)\right]^2 = \left(R_1 \frac{d_1}{2}\right)^2 \tag{2}$$

The bending angle of single drill pipe is:

$$\theta = \angle AOB = \arcsin\frac{AB}{OA} \tag{3}$$

Finishing is available:

$$l_{max} = 2\sqrt{2R_1\Delta + \Delta d_1 - \Delta^2} \tag{4}$$

Where: d_1- inner diameter of casing/ mm; d_2- Drill bit diameter/mm, l_{max} - ultimate length of single unit/mm, Δ - interval between well bore and drill pipe/mm, θ - bending angle of single unit drill pipe/mm, R_1- deflection radius of curvature.

Ignoring the uncertainty of casing deformation and whipping process, according to the feasible scheme of mechanical structure. The minimum expected curvature radius can reach 1.5m-3.6m, and the interval Δ is 8mm. Considering the manufacturing process and drilling and production adaptability, the curvature radius is designed to be 1.8m, 2.5m and 3.6m. According to the formula, different curvature radius are calculated to match the ultimate length and ultimate bending angle of drill pipe unit, and different curvature radii can be given in Table 1 by the maximum value [7-10]. The flexible drill pipe is designed according to the single length and bending limit angle of the flexible drill pipe with the minimum curvature radius of 1.8m.

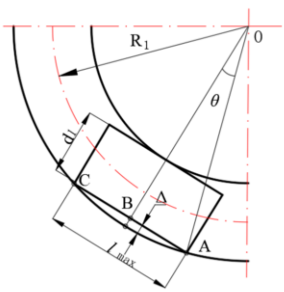


Figure 2. Calculation diagram of flexible drill pipe length

Table 1. Flexibility calculation results of single section with different curvature radius

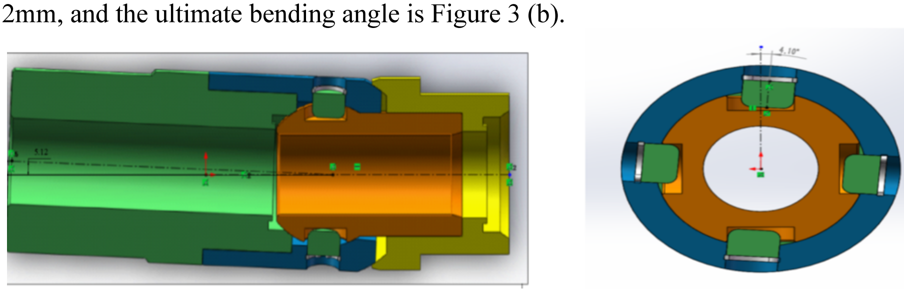
radius of curvature R_1/m	**Length of single-link rotating rod l_{max}/mm**	**Bending angle of single drill pipe θ/°**
1.8	≤344	5.4
2.5	≤404	4.45
3.6	≤483	3.8

According to the design criterion of flexible drill pipe, the snake-bone flexible drill pipe is designed by using bionics principle [11-16]. Based on the snake crawling mode, combined with the concept of bionic form and bionic mechanism, the coiled tubing is designed in flexible segments.

(1) The ball joint and jacket structure decomposes the drill pipe, and adopts four torque pins to transmit torque. At the same time, the torque pins play a role in limiting the 360° rotation of the ball joint, and the torque pins and the ball joint cooperate with each other in structural design. After the simulation in ANSYS, each section can reach the torsion angle of 4.1° in Figure 3(a), which can alleviate the buckling of drill pipe in casing. The maximum bending angle between sections can reach 5.12°, and the deflection curvature radius can reach 1.8m.

(2) High-pressure liquid is needed at the front end of window grinding and drilling bit, and high-performance O-ring is embedded in the joint of drill pipe unit to prevent the internal and external liquid from communicating and keep the pressure.

(3) In order to quickly approach the reservoir to realize the ultra-short radius deviation -1.6m curvature radius, the ultimate length of drill pipe joint is designed to be 52mm, and the ultimate bending angle is Figure 3 (b).

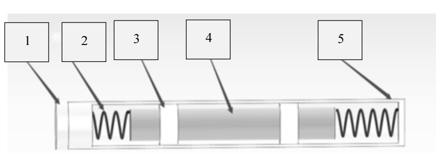


(a) The maximum bending angle (b) The maximum twist angle

Figure 3. Limit angle of flexible drilling tool.

3. Flexible Drill Pipe Test

During sidetracking, it is necessary to accurately locate the depth of the operation point relative to the log interpretation result map. In order to determine the position of the drill bit, the magnetic positioner is installed in the drill pipe to measure the position of the depth correction nipple. But the microphone nature of the stratum will never change, although various error compensation methods are used, the method of measuring drill pipe length and tracking depth on site has large error. The logging tool based on gamma technology is designed as shown in Figure 4. The effect is good in the depth determination and positioning of the deflection section, and the measurement of well deviation and azimuth after the deflection. It can also play a role in real-time monitoring.



1.End cap, 2. Spring, 3. Centralizer ring, 4. Probe tube, 5. Protective tube.

Figure 4. Gamma logging tool

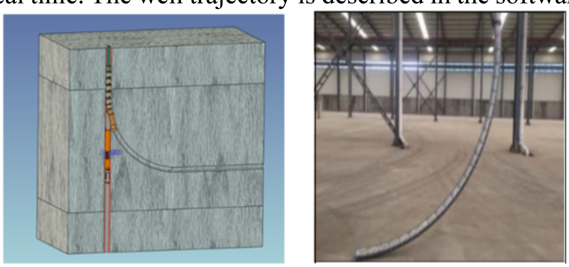
The adopted cement target plate and drilling method are shown in Figure 5. The test results of pressure, tension and torsion are respectively recorded in Figure 6. Including the tensile, torsional, compressive, wear-resistant, internal pressure and external pressure tests of various components in the drilling tool. The specific test contents and indicators are that the flexible drilling tool has an outer diameter of φ 144 and a length of 1m. The test equipment is shown in Figures 7-9, and the specific models are given in Table 2:

(1) the bottom joint of the drilling tool is sealed by the drilling tool assembly, and the internal pressure of the drilling tool is increased, with the pressure levels of 5MPa, 10MPa, 15MPa, 20MPa and 25MPa. Shown in Table 3 is the sealing pressure data of the testing drilling tool.

(2) The combination of flexible drilling tools is stuck and blocked in the well to apply pressure and tension to the drilling tools. The pressure and tension levels are 60T, 80T, 100T and 120T, and the data are recorded. The experimental results are shown in Table 4.

(3) The combined flexible drilling tool records the torsion data during drilling, and the maximum test torsion is 45,000 N/m to measure its flexibility. Shown in Table 5 is specific values.

(4) During sidetracking, the gamma logging tool is used to monitor the azimuth and bit trajectory in real time. The well trajectory is described in the software LANDMARK.



(a) Cement target plate (b) Flexible drill pipe

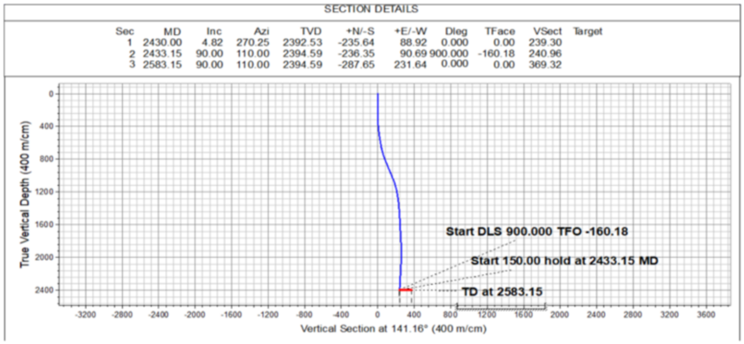
Figure 5. Schematic diagram of experimental structure

Figure 6. Tensile pressure test platform

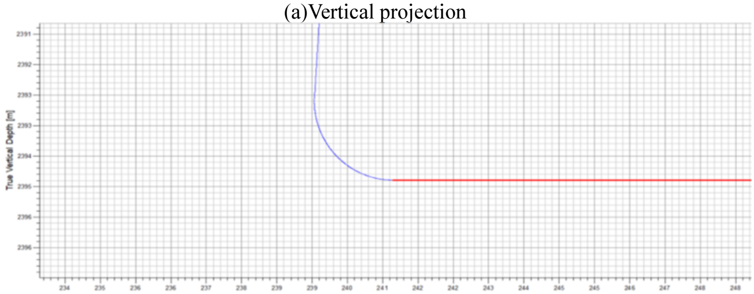
Figure 7. Small pressure drilling rig

Figure 8. Comprehensive test derrick

Figure 9. DZZR-111 hydraulic dismounting machine



(a)Vertical projection



(b)Locally enlarged vertical projection

Figure 9. Borehole trajectory in LANDMARK.

Table 2. Test Equipment and Equipment

Materials and equipment	Specification (model)	Quantity
Test shaft	Simulated borehole (cement formation)	a
Well servicing unit	Type 30, with rear output	1 set
Flexible drilling tool	13 drilling tools	1 set
One-pass shoe grinding	φ152	1 branch
One-trip cable maker	7 "or 9-5/8"	1 set
Sludge pump	0-15MPa	1 set
Hydraulic lift	20 tons	1
Hydraulic tongs	Provide for oneself	1

Table 3. Sealing test

Test item	Number of times/segments	Test pressure (MPa)	Stabilizing time (s)	Test result
Section 1 pressure	1-1	10MPa	300	No leakage
Section 2 pressure	1-2	15MPa	300	No leakage
Section 3 pressure	1-3	25MPa	300	No leakage
Section 4 pressure	1-4	29MPa	300	No leakage

Table 4. Tensile test data record table

Tensile and compressive test force (T)		Test range		Test temperature
Theory	Reality	Theory	Reality	
≤120	129	60T	40.59T	Normal atmospheric temperature
		80T	81.88T	
		100T	103.32T	
		120T	121.77T	

Table 5. Torsion test values

Test pressure kN.M			
Experimental requirements	Segmented test		Reality
Experiment torque ≤45000N/M	The first paragraph	15 kN.M	15kN.M
	The second paragraph	30 kN.M	31kN.M
	The third paragraph	45 kN.M	46kN.M

(1) Tightness. The flexible drilling tool can be sealed in the bending state, with good sealing and no leakage.

(2) Torsional performance. This experiment proves that the flexible drill pipe meets the requirement of maximum pressure resistance of 46 kN.M, the flexibility of flexible drill pipe is not lost, the performance index of flexible drill pipe is stable, and the experiment is ideal.

(3) Tensile and compressive properties. Under the pressure of the hydraulic station of 33MPa, the pulling force of the wellhead puller is 121.77T, meeting the tensile requirement of 120T, and the flexible drill pipe has not lost its flexibility. Each thread link is good and meets the experimental requirements.

(4) It can be seen in Figure 9 from the enlarged vertical profile that the radius of curvature of the deflection is within 1.5-2m, which is in line with the design expectation.

4 Conclusion

(1) Design flexible drill pipe

According to the design criterion of flexible drill pipe, the flexible drill pipe of animal spine is designed by using bionics principle. Combined with the concept of bionics in shape and bionics in mechanism, flexible sectional design of coiled tubing is carried out.

(2) Rationality test of flexible drill pipe

The bottom joint of the drilling tool is closed after the assembly of the drilling tool, and the internal pressure of the drilling tool is increased; The flexible drilling tool is stuck in the well and blocked to apply pressure, tension, pressure and tension to the drilling tool; During drilling, the flexible drilling tool recorded the torsion data, and the maximum test torsion was 45,000 N/m, and the flexible drill pipe did not lose its flexibility. Each thread link is good and meets the design requirements.

(3) Real time monitoring of gamma logging tools

The enlarged vertical profile that the radius of curvature of the deflection is within 1.5-2m, which is in line with the design expectation.

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