Selection of automatic vertical drilling system for the fourth section in Shunbei 11 well, Tarim basin, China

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Abstract: Based on the introduction of the working principles of various automatic vertical drilling systems (VDS), the latter are divided into rotary push type and sliding push type. Then the technical advantages and applicable scope of various types of drilling tools are analysed. Combined with the latest domestic application progress and typical case analysis of the vertical drilling system, the future development direction of the vertical drilling technology is predicted. The results show that, the existing vertical drilling technology can better meet the technical needs of rapid drilling in the middle-deep sections with high steep angles. While the stability of wireless information transmission and wear resistance of the push pad still need further improvement. The new type of vertical drilling system that is miniaturized (suitable for small boreholes) and resistant to high temperature and high pressure is in urgent need to fill the gaps in the market segment. Domestic independent vertical drilling systems have made great progress, some even surpass foreign products in key indicators such as temperature resistance, in addition to achieving the technical goal of anti-inclination successfully. Finally, based on the engineering geological conditions of Shunbei 11 well, feasible vertical drilling tools were recommended and achieved engineering goal finally. The research results can provide support for the drilling company to optimize the vertical drilling system based on engineering-geological conditions.

1 Introduction

The automatic vertical drilling systems are widely used in drilling high-steep formations, and they could facilitate to liberate drilling parameters (such as weight on bit and rotary rate) to achieve anti-inclination and ideal rate of penetration (ROP) [1-4]. In recent years, domestic

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and foreign vertical drilling systems have made great progress in serialized R&D and application. It would provide convenience for drilling contractor to optimize vertical drilling tools for specific engineering-geological conditions by summarizing the applicable conditions and field application experience of each vertical drilling tool.
The vertical drilling system achieves deviation correction by extending the pushing pad to the high side of the wellbore to obtain a reaction force. According to the steering mode, the vertical drilling systems can be divided into two categories. One is the rotary-steering drilling tool, such as the Power V system of Schlumberger [5], where the turntable works and the vertical drilling system rotates during steering drilling. The other is slide-steering drilling tools, such as the Verti-Trak system of Baker Hughes [6], where the turntable and drilling tool do not rotate during steering drilling. Each kind vertical drilling systems has their own advantages and is suitable for special engineering-geological conditions.

2 Working principle and technical characteristics

2.1 Rotary-steering vertical drilling system

The Power V is used as sample to introduce the working principle and technical characteristics of rotary-steering drilling tool, which was developed based on PowerDrive rotary-steering drilling system since 2002 by Schlumberger.

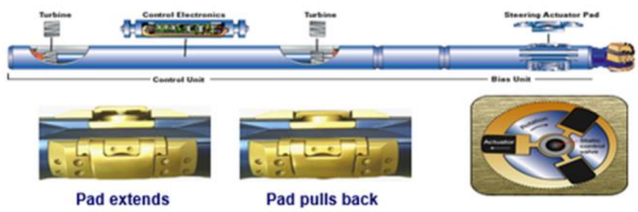

Fig. 1. The structural schematic of Power V

As is shown in Fig.1, the Power V system is mainly composed of control unit and bias unit. Where the control unit is used to perceive well deviation and azimuth, and controls the operation of the bias unit. The bias unit includes steering actuator pad and accepts instruction to provide deflection correction force. After the control unit senses the inclination trend of the well, the opening of the upper disc valve would then be fixed at the high side of the wellbore. In addition, the upper disc valve does not rotate with the rotation of the tool. The three openings of the lower disc valve communicate with the three steering actuator pad of the bias unit, and they all rotate during steering drilling. Thus, only the steering pad rotating to the high side of the shaft wall is in the extended state, supporting the wellbore to obtain deflection force.
It can be concluded that, the outside wall of drilling tool rotate during steering drilling, which can effectively reduce the risk of jamming. The automatic closed-loop control of steering method facilitates to liberate drilling parameters completely.

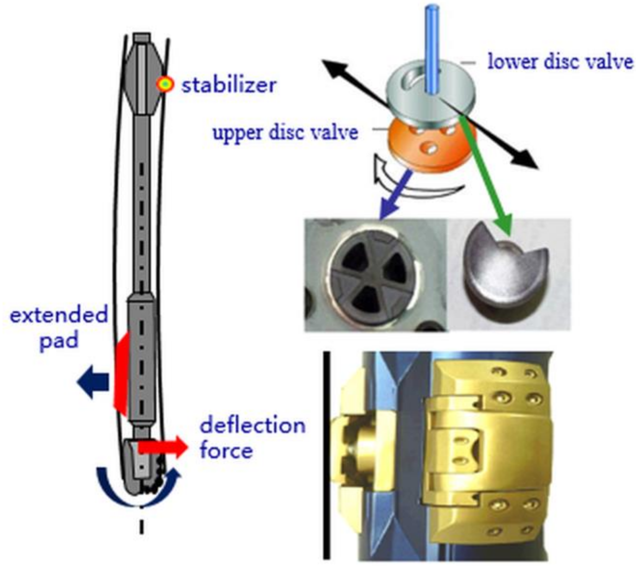

Fig. 2. The working principle diagram of Power V

2.2 Slide-steering vertical drilling system

The Verti-Trak is used as sample to introduce the working principle and technical characteristics of slide-steering drilling tool, which was developed based on Autotrak steering drilling system by Baker Hughes.

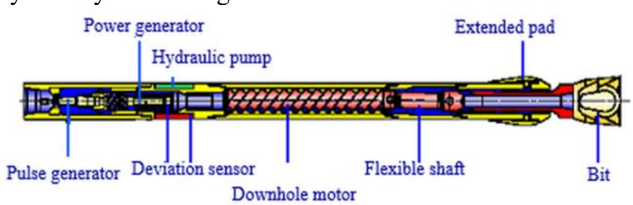

Fig. 3. The working principle diagram of Verti Trak

As is shown in Fig.3, the Verti Trak system is mainly composed of pulse generator, power generator, hydraulic pump, deviation sensor, downhole motor, flexible shaft and extended pad. During drilling, as the deviation sensor (MWD) senses deviation trend of the wellbore, the hydraulic pump would be generated automatically to push one or two pad to extend to the wall, and then deflection force is generated to offset deviation. MWD date would be transferred to ground by the pulse generator to enable engineers to track and monitor the well trajectory. After the wellbore is steered to vertical, all the three steering pad would extend to wall exerting equal force to maintain vertical drilling trend.

The deflection force of this kind vertical drilling system is generated by the hydraulic pump and does not depend on the drilling fluid, and the downhole motor would increase RPM (rotation per minute) to facilitate higher ROP. On the other side, the risk of jamming is higher since the outside wall of this kind drilling tool does not rotate during steering drilling, and this kind drilling tool is not applicable during plugging due to the smaller diameter of inside nozzles. In addition, this kind vertical drilling system is also not suitable in long wellbore since it would be difficult to transfer load in slide-steering drilling.

3 Development progress of vertical drilling systems

After years of research and development, vertical drilling systems have formed a serialized product, which can better meet the technical needs of anti-deviation and fast drilling. At present, the Power V vertical drilling system is most widely used in China, and its detailed tool parameters are shown in Table 1 [7-10]. The tool parameters of other manufacturers that are suitable for the same size borehole are close to those parameters listed in Table 1, and will not be repeated here. What should be addressed is the maximum temperature resistance (in Table 3 for details) when selecting vertical drilling tools for deep formations with high temperature. It can be seen from Table 2 that the Power V system occupies the largest market in China, and the domestic ZS-VDS and BH-VDS are in the second echelon and have achieved significant progress.

Table 1. Parameters of Power V

Tool series	**PowerV 475**	**PowerV 675**	**PowerV 825**	**PowerV 900**	**PowerV 1100**
Diameter of tool	Φ120.7 mm	Φ171.5 mm	Φ203.6 mm	Φ228.6 or Φ244.5 mm	Φ279.4 mm
Diameter of wellbore	Φ139.7 ~Φ165.1 mm	Φ215.9 ~Φ250.8 mm	Φ266.7 mm	Φ304.8~Φ374.7 mm	Φ393.7~Φ469.9 Φ508~Φ660.4 mm
Maximum dogleg	8°/30m	8°/30m	5°/30m	5°/30m	4°/30m or 2°/30m
Maximum torque	5420 Nm	21700 Nm	21700 Nm	65000 Nm	65000 Nm
Maximum load	1500 kN	4900 kN	4900 kN	6200 kN	10140 kN
Maximum WOB	223 kN	290 kN	290 kN	290 kN	290 kN
Maximum RPM	220RPM	220RPM	220RPM	220RPM	220RPM
Maximum Plugging	142.6 g/l	142.6 g/l	142.6 g/l	142.6 g/l	142.6 g/l

agent concentration					
Flow rate	7~25l/s	15-60 l/s	20-80 l/s	20-95 l/s	20-95 l/s
Temperature resistance	150℃ (normal)				
	175℃(high temperature resistance, which is not imported into China)				
Pressure resistance	138 MPa	138 MPa	138 MPa	138 MPa	138 MPa
Pressure drop of bit	4.5~5.2 MPa	4.5~5.2 MPa	4.5~5.2 MPa	4.5~5.2 MPa	4.5~5.2 MPa
Solidconcentration in drilling fluid	< 0.3%	< 0.3%	< 0.3%	< 0.3%	< 0.3%
Upper buckle	NC38	NC50	6-5/8″REG	6-5/8″REG	7-5/8″REG
Lower buckle	3-1/2″API REGBOX	4-1/2’REG (215.9mm) 6-5/8’REG (241.3mm)	6-5/8″REG	6-5/8″REG	7-5/8″REG
PH of drilling fluid	PH9.5-12.0	PH9.5-12.0	PH9.5-12.0	PH9.5-12.0	PH9.5-12.0

Table 2. Development progress of vertical drilling systems

Name	**manufacturer**	**Diameter of wellbore**	**Deflection force**	**Type**	**Field application**
Pover V	Schlumberger	139.7-711.2	Pressure drop of drilling fluid at bit	Rotary steering	500+
ZS-VDS	China University of	215.9-571.5			60+

	Petroleum (East China)				
Strap-Down VDS	Shengli Oilfield Service Corporation	215.9、311.2			10+
CUGB-VDS	China University of Geosciences （Beijing）	215.9			Field test
Verti-Trak	Baker Hughes	203.2-711.2			Industrial application
V-Pilot	Halliburton	311.2			Industrial application
VectorEXAKT	National oil well	406-444.5	Electronically controlled hydraulic	Slide steering	1
BH-VDT	Bohai drilling	311.2-444.5			100+
AVDS	Western Drilling	311.2、406			About 10
Verti Servo	Eighteen Space Institute	311.2-444.5			About 10

4 Field application cases

4.1 In high-steep formation

It is the basic function for vertical drilling system to increase ROP in addition to anti-deviation. The formation dip of a oilfield in Tarim basin ranges from 15°to 80°, and many products (including Power V, Verti-Track, ZS-VDS, BH-VDT, VectorEXAKT, AVDS and Verti Servo) have been used in the second section with 406 mm wellbore, and most could achieve anti-deviation goal successfully. In technical view, the Pover V system ranks top, and it could improve the wellbore quality and cut drilling schedule significantly. In the best case, the ROP increase 8 times and the drilling schedule decreases from 130 days to 30 days under comparable conditions.

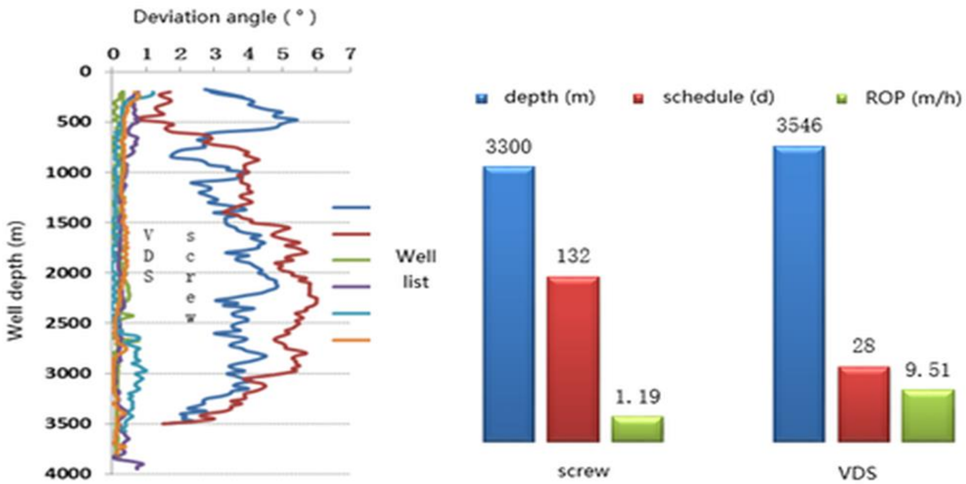

Fig.4 Comparison of Power V and screw in high-steep formation

4.2 In complex formation

All VDS get deflection force by extending pad, which would increase the jamming risk in complex formation with high necking down possibility. The Power V system has also been used with oil-based drilling fluid in salt formation, and the deviation angle was successfully controlled to no larger than 1°in addition to 4 times ROP. In the same formation, the slide-steering tools could not be used due to larger jamming risk.

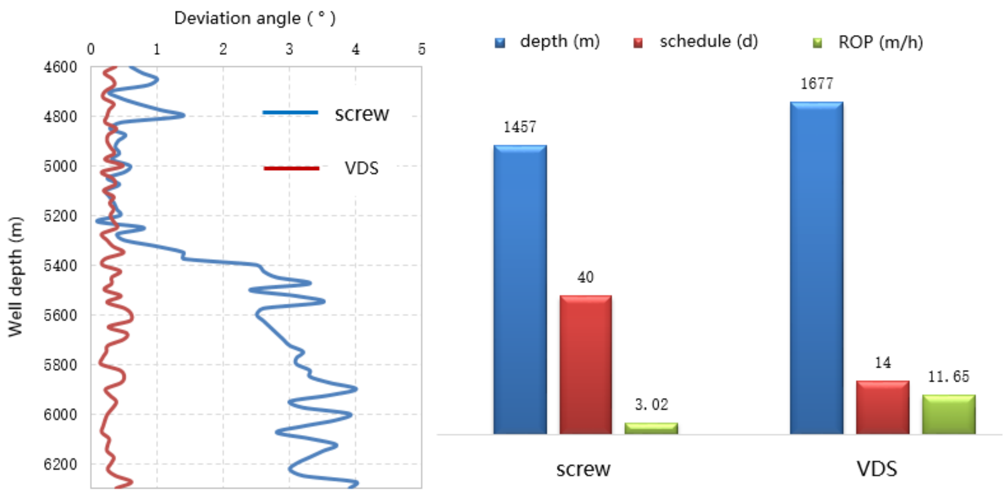

Fig.5 Comparison of Power V and screw in salt formation

4.3 In deep formation with high temperature

Although Schlumberger have developed Power V with 175℃ temperature resistance as reported, those imported into China are limited to 150℃. In a field application case, the Power V failed to control the deviation and then was tripped up. The recorded highest down-hole temperature is 157℃ and the control unit of Power V was burned out (Fig.6). The application results indicate that, the selection of vertical drilling system should pay enough attention to the temperature resistance.

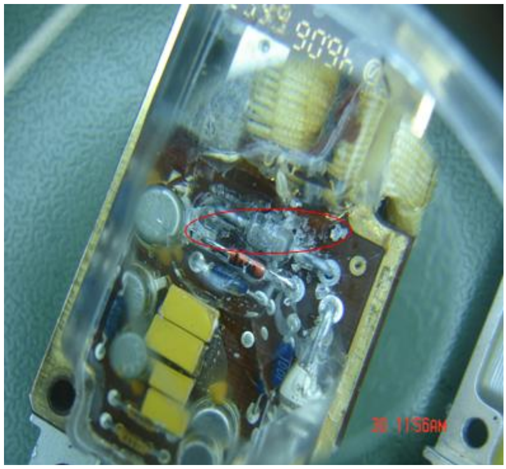

Fig. 6. The burned out Power V under 157 ℃

The temperature resistance of ZS-VDS developed by China University of Petroleum is marked over 200℃. ZS-VDS has also been used in field application with largest well depth equaling 7000 m, and the down-hole temperature reaches 166°C, which both makes the record in China until the end of 2019.

5 Selection of VDS for the fourth section in Shunbei 11 well

The fourth section in Shunbei 11 well was designed to drill with the diameter of 241.3 mm from 7071 m to 8365 m, and the down-hole temperature is assumed to ranges among 136~175°C according to neighboring wells. The highest deviation angle of formation reaches 39.8°, and neighboring drilling cases indicate that it is difficult to drill vertical wellbore fast with screw in this area, the oil company decided to use VDS to achieve anti-inclination and larger ROP. The geological engineer predicts multiple sets of diabase intrusions in the mention section, which would increase the jamming risk significantly and need further address.

Table 3. Analysis of the feasibility of VDS for the fourth section in Shunbei 11 well

Name	**manufacturer**	**Diameter of wellbore**	**Temperature resistance**	**Type**	**Feasibility analysis**
Pover V	Schlumberger	139.7-711.2	150℃	Rotary steering	Limited feasible
ZS-VDS	China University of Petroleum (East China)	215.9-571.5	>200℃		feasible

Strap-Down VDS	Shengli Oilfield Service Corporation	215.9 、311.2	125℃		unfeasible diameter
CUGB-VDS	China University of Geosciences (Beijing)	215.9	>200℃		
Verti-Trak	Baker Hughes	203.2-711.2	150℃	Slide steering	unfeasible diameter or high risk of jamming
V-Pilot	Halliburton	311.2	>200℃		
VectorEXAKT	National oil well	406-444.5	150℃		
BH-VDT	Bohai drilling	311.2-444.5	150℃		
AVDS	Western Drilling	311.2、406	>200℃		
Verti Servo	Eighteen Space Institute	311.2-444.5	150℃		

The analysis result indicate that, (1) the ZS-VDS is feasible for the whole fourth section and (2) Power V is feasible for only the upper section with formation temperature does not exceed 150 °C.

Based on the analysis results, the operator finally selected Power V system to drill upper section with consideration of wider utilization and higher reliability than ZS-VDS, and has achieved anti-inclination (the deviation decreases to lower than 1°) and larger ROP. In addition, jamming did happen when drilling with screw in the lower section after the Power V was tripped out, and larger loss was avoided without using VDS with slide-steering working method.

6 Conclusions

The vertical drilling system and technology has made great progress, and could meet the basic need of rapid drilling in deviated formation. While the stability of wireless information transmission and wear resistance of the push pad still need further improvement. The new type of vertical drilling system that is miniaturized (suitable for small boreholes) and resistant to high temperature and high pressure is in urgent need to fill the gaps in the market segment. The selection of VDS should pay enough attention to the engineering-geological conditions (including formation temperature, wellbore diameter, jamming risk) of the target zone.

Acknowledgments

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