Overview of the Development of Rotary Steerable Systems

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Abstract: Rotary steerable system remains the development focus of current drilling technology. It is essential for China’s unconventional Oil and Gas development. This paper outlines the research and development history, classification, development status of the rotary steerable system, and summarizes the advantages and disadvantages of different systems. Moreover, the prospects of the intelligent RSS technology is explored, and the outlook for the future development of the steerable drilling technology is presented.

1. Introduction

With the continuous decline of conventional oil and gas production, exploration and development have gradually turned to unconventional, offshore and deepwater operations and became increasingly difficult; as a result, demands for improved technologies and equipment remain high. Unconventional oil and gas exploration often uses complicated trajectory wells such as Extended Reach Drilling (ERD), multi-lateral horizontal, and sidetracking wells. More specifically, shale gas drilling often utilizes horizontal drilling, rotary steerable systems (RSS), and other technologies.

Rotary steerable systems are widely used in drilling applications. Three different mechanisms are currently used by rotary systems to control the direction in which the bit drills: push-the-bit [1]–[3], point-the-bit [4], and hybrid steering tools [5], [6]. The point-the-bit RSS tools have better navigation control in the situations where the hydraulic limitation is present because of high mud weight in deep gas drilling environment or in soft formations where other technologies have difficulties in achieving planned trajectories.

This paper aims to present an overview of current RSS technologies and provide insights into the future RSS development in China.

2. Current Status of RSS

RSS tools can be classified into Push-the-bit and Point-the-bit according to the action of the steering mechanism, and the hybrid mechanism uses both push and point technologies. Moreover, these two steering technologies can be further divided into mechanical and hydraulic according to the offset mechanism. As Figure 1 shows, the RSS technologies can be categorized with different characteristic features such as non-rotating and strapdown, dynamic and static, and internal push and external push force.
At present, foreign oilfield service companies such as Schlumberger, Baker Hughes, Halliburton, and Weatherford have their RSS tools, which have been widely used in oilfield services. Schlumberger's RSS PowerDrive system dominates over 1/3 of the market. Other representative tools include Baker Hughes’ AutoTrak X-treme system and Halliburton’s GeoPilot system. Table 1 provides the details of the classification of the RSS technologies.

Table 1. Classification of the RSS technologies

| Company       | RSS       | Push-the-bit | Point-the-bit |
|---------------|-----------|--------------|---------------|
| Schlumberger  | Archer    |             | ✓             |
|               | Xceed     | ✓            |               |
|               | PD X6     | ✓            |               |
|               | ICE       | ✓            |               |
| Haliburton    | Geopilot  |              | ✓             |
| Baker Hughes  | Autotrac  | ✓            |               |
| Weatherford   | Revolution| ✓            |               |
|               | Magnus    | ✓            |               |
|               | Vector    | ✓            |               |
| NOV           | Terravici |             | ✓             |
| Terravici     | Terravici |              | ✓             |
| Gyrodata      | Well Guide|              |               |
| APS           | SureSteer | ✓            |               |
| Sanvean       | Scott     | ✓            |               |

Some Chinese research institutions and oilfield service companies also started independent research and development and made some technological breakthroughs in the same period. However, compared with the level of foreign service companies, there is still a significant gap. So far, there is no Chinese RSS tool, which has reached the commercial service level at a worldwide level yet. The research work on RSS in China started in the 1990s, and many research institutions and universities have been involved in the research and development of this technology. With the support of the national "863" project, the research institutes of the China Petroleum & Chemical Corporation Shengli Petroleum Administration Drilling Institute, China National Offshore Oil Corporation, and other scientific research institutions and related colleges and universities have conducted systematic research on RSS systems. Some breakthroughs have been made in the technology. Prototypes were developed, and field tests were conducted; however, the efforts are still required to improve the reliability of the tools for commercial services.

3. Comparison of RSS tools
At present, foreign oilfield service companies such as Schlumberger, Baker Hughes, Halliburton, and Weatherford, have their RSS technologies. A comparison of these RSS technologies is given in Table 2.
Table 2. Comparison of advantages and disadvantages of different RSS technologies

| Type of RSS          | Name of RSS          | Advantages                                                                 | Disadvantages                                                                 |
|----------------------|----------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Static push the Bit  | Auto Trak RCLS       | (1) For high-angle directional wells, ultra-large displacement directional wells, and highly challenging horizontal wells, drilling costs are relatively low. (2) Less harmful vibration and harmful heat generated during drilling, and longer tool life. (3) Real-time direction control accuracy is high and reliable. | (1) In soft formations or wells with enlarged holes, lack of adequate support, the ribs are prone to stick; (2) Due to the significant friction, challenging to transfer weight on bit. (3) The miniaturization is impossible, the structure is complicated, and DLS is relative low. |
| Dynamic push the Bit | PowerDrive X6        | (1) As the component rotates, the friction is reduced, and the problem of WOB transfer is improved; (2) The structure is relatively simple; (3) Good directional performance and high drilling efficiency. | (1) Wears on drill bits and its bearing are severe, resulting in a short working life of the drill tool; (2) When the drilling hydraulic pressure difference is small, it will cause the problem of insufficient thrust. (3) During the drilling process, the ribs will generate harmful heat due to dynamic friction while maintaining the extrapolation. |
| Static biased extrapolation pointing | Well-Guide RSS Revolution Geo-Pilot Power Drive-Direct | (1) The bending degree of the rotating mandrel can be adjusted to obtain the expected build rate; (2) Since it is not necessary to push the ribs against the wellbore to change the direction, its guiding effect is not affected by the formation environment; (3) More regular holes can be drilled, reducing spirals and protrusions. | (1) Since the rotating mandrel is subject to high strength alternating stress, the mandrel is prone to fatigue damage; (2) Because of its many rotating parts and high requirements for component resistance, the manufacturing cost and drilling cost of drilling tools are relatively high. |
| Dynamic point the bit | Still experimental, not yet in production | (1) The number of downhole motors can be reduced to a certain extent, and a more significant weight on the bit can be used; (2) Since there is no rest point on the wellbore wall, the wear rate of the biasing mechanism can be reduced; (3) Low friction and torque, high mechanical drilling speed and the lateral load on the drill and its bearings are small. | (1) The drilling cycle is long, the structure is complicated, and the production cost of drilling tools is high; (2) Because the dynamic biasing mechanism is to work continuously, the service life of the drilling tool is high. |

Table 3 presents the comparison of different 4.75 inch RSS tools with the high DLS capacity. 4.75 inch RSS tools are of smallest OD but highest DLS in drilling application. Among all the tools, Archer from Schlumberger can deliver 18 deg/100 ft DLS, which is the highest. The eXact tool from Baker Hughes is tailored for high-temperatures and high-pressure applications. The sensor distances from bits are between 5.9 and 11.25 ft. Most of these tools can rotate up to 250 rpm. Figure 2 shows the performance of these tools in a pentagon view.
Table 3. Comparison of different 4.75 inch RSS with the high DLS capacity

| Company          | RSS Series         | Max DLS (°/100ft) | Maximum temp (degC) | Max pressure (psi) | Sensor distance (ft) | Max RPM (rpm) |
|------------------|--------------------|-------------------|---------------------|-------------------|---------------------|---------------|
| Baker Hughes     | 4.75” AutoTrak eXact | 12                | 165                 | 30,000            | 5.9                 | 250           |
| Gyrodata E       | Well-Guide 4-100    | 12                | 150                 | 20,000            | 11.25               | 250           |
| Halliburton      | Geo-Pilot XL RSS 5200Series | 14             | 150                 | 20,000            | 10                  | 250           |
| Schlumberger     | PowerDrive Archer 475 | 18               | 150                 | 20,000            | 8.2                 | 250           |
| Weatherford      | Revolution 475 RSS  | 10                | 150                 | 25,000            | 9                   | 200           |

Figure 2. Comparison of performance indicators of 4.75 inch RSS tools

At present, RSS tools are essential to oil and gas drilling activities; however, only a few companies have RSS technologies. Therefore, in order to maintain and expand the current international market leader position, major oilfield service companies continue improving efficiency and market shares. The market share of several major oil service companies in the directional drilling market is shown in Figure 3. Schlumberger takes around 1/3 of the market, and the 2nd place is Haliburton, with 17% market share.

Schlumberger owns push-the-bit, point-the-bit, and hybrid RSS technologies. Figure 4 provides a comparison of the technical specification of different RSS families from Schlumberger.

Figure 3. Comparison of the market shares of rotary steering tools by oil service companies
Figure 4. Comparison of the technical specification of different 4.75 inch RSS from Schlumberger

4. Prospects of RSS Technology
The prospects of RSS developments are forecasted as below.

4.1. Near-bit measurement technology.
In the current oil extraction process, the measurement of bit parameters directly affects the optimization of the drilling process. Therefore, near-bit parameter measurement technology is an essential direction for the development of new and automated drilling technologies. This technology installs a sensing device inside the drill bit and transmits the geological data in the formation of the drill bit to a control unit, which might reside in RSS tools. The combination of the near-bit measurement and RSS technologies can achieve the purpose of optimizing the drilling path.

4.2. Smart drill pipe technology.
In the actual oil extraction process, in order to ensure the safety and stability of the drilling process, relevant personnel must monitor the real-time data during drilling, which requires a higher data transmission rate. Therefore, in order to ensure the overall rate and stability of data transmission, to provide strong support for improving drilling data analysis capabilities, to meet drilling data analysis, and to ensure productive drilling data, the development and application of intelligent drill pipe technology are extremely important. With higher data transmission, more data of status and surveys from RSS tools can be seen on the surface; surface crews will be able to make an appropriate decision based on data analysis.

4.3. High Dogleg Severity RSS
High DLS RSS tools are of significance for unconventional oil and gas drilling. With higher DLS, RSS tools can shorten curve sections and have a higher exposure path of the reservoir. Foreign oilfield service companies have owned the technology; China still needs to invest in the development of high DLS RSS tools.

5. Conclusion
In summary, China has made considerable development and progress in RSS technology. However, there is still a significant gap compared with foreign technologies after years of research and development efforts by researchers in China. Chinese oil and gas companies heavily depend on imported foreign products.

This paper reviewed the development status of current RSS tools and future trends. The review of the RSS can improve the understanding of the technologies and promotes the future innovation of researchers and engineers.

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