Review of the Development of Rotary Steerable Systems

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Abstract: The rotary steerable system is essential for the development of unconventional oil and gas in China, and remains the core of the current oil drilling technology 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
Oil and natural gas are strategic resources related to the national economy. The rapid development of my country's economy has also driven the growth of energy consumption. The demand for oil and gas in China has increased year by year, but with the continuous decline in the production of conventional oil and gas resources in China, it is almost exhausted, and China's deep petroleum and natural gas resources have great potential [7], accounting for 52% and 28% of the total geological resources, which can become the future. Energy breakthrough [8,9], so in recent years, oil and gas exploration and development has gradually turned to low permeability, deep and ultra-deep layers, deep ocean water, shale oil and gas and other unconventional oil and gas fields [10]. However, as the development in these extreme regions becomes more complicated, the requirements for technology and equipment become stricter, and improvements and upgrades to technology and equipment are urgently needed. 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.

The rotary steering system is widely used in the field of oil drilling. There are three kinds of steering mechanisms for the rotary steering system to control the drilling direction of the drill bit: 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 article aims to conduct an overview of the current RSS technology to guide the future development of RSS in China.

2. Current Status of RSS
The rotary guide system generally includes two main parts: the control platform and the biasing mechanism. The control platform is the "brain" of the rotary guidance system and controls the direction of the bias mechanism, which can be divided into a geostationary platform and a strapdown type. The guidance module is an "actuator" for tool bias guidance. 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 categorized into mechanical and hydraulic according to the offset mechanism. As Figure 1 shows, the RSS technologies can be classified with different characteristic features such as non-rotating and strapdown, dynamic and static, and internal push and external push force.

![Diagram of RSS work mechanism](image)

**Figure 1. Classification of RSS tools**

According to the Spears market survey, since mid-2012, rotary steering technology has occupied more than 50% of the directional drilling market, and by 2019 this proportion will increase to more than 70%. Table 1 provides the details of the classification of the RSS technologies.

| Company       | RSS      | Type of offset mechanism | Control platform type |
|---------------|----------|--------------------------|-----------------------|
| Schlumberger  | Archer   | Hybrid                   | Geostationary         |
|               | Xceed    | Point-the-bit            | Strapdown             |
|               | PD X6    | Push-the-bit             | Geostationary         |
|               | ICE      | Push-the-bit             | Strapdown             |
| Haliburton    | Geopilot | Point-the-bit            | Strapdown             |
| Baker Hughes  | Autotrac | Push-the-bit             | Geostationary         |
| Weatherford   | Revolution| Point-the-bit            | Geostationary         |
|               | Magnus   | Push-the-bit             | Strapdown             |
| NOV           | Vector   | Push-the-bit             | Strapdown             |
| Terravici     | Terravici| Point-the-bit            | Strapdown             |
| Gyrodata      | Well Guide| Point-the-bit            | Geostationary         |
| APS           | SureSteer| Push-the-bit             | Strapdown             |
| Sanvean       | Scott    | Push-the-bit             | Geostationary         |

In the 1990s, many universities and petrochemical enterprises in my country began the R&D of rotation-oriented technology. So far, my country's scientific research institutions have achieved some remarkable results. However, there are few rotary guidance systems put into commercial service, and there is still a big gap compared with the level of foreign service companies. Therefore, the rotary steerable technology in the development of unconventional oil and gas fields in my country relies on foreign oil service companies. Scientific research institutes such as China National Offshore Oil Corporation, China National Petroleum & Chemical Corporation Shengli Petroleum Administration Drilling Research Institute and related universities have carried out systematic research on the RSS system with the support of the national "863" plan. China's relevant research institutions have made some breakthroughs in this technology. First, they developed and developed tool prototypes and conducted a series of field tests on them; however, the efforts are still required to improve the reliability of the tools for commercial services.
3. Comparison of RSS tools

At present, the RSS technology of foreign oilfield service companies such as Schlumberger, Halliburton, Baker Hughes and Weatherford is relatively mature and advanced. A comparison of these RSS technologies is given in Table 2.

| Type                        | RSS                      | Advantages                                                                                                                    | Disadvantages                                                                 |
|-----------------------------|--------------------------|-------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Static push the Bit         | Auto Trak RCLS           | (1) For highly difficult horizontal wells, large-angle directional wells and ultra-large displacement directional wells, the drilling cost is lower. (2) Long tool life. (3) High precision of real-time direction control. | (1) In wells where the borehole is enlarged, or the formation is soft and lacks sufficient support, the ribs tend to stick. (2) The structure is complex, and the DLS is low. (3) Due to the high friction, it is difficult to transfer weight to the drill bit. |
| Dynamic push the Bit        | PowerDrive X6            | (1) As the component rotates, the friction is reduced. (2) The structure is relatively simple. (3) Good directional performance. | (1) If the drilling pressure difference is small, it will cause insufficient thrust. (2) The severe wear of the drill bit and its bearing will lead to a shortened service life of the drill. |
| Static biased extrapolation | Well-Guide RSS, Revolution| (1) The guiding effect of the tool is not affected by the formation environment. (2) More regular holes can be drilled to reduce spirals and protrusions. | (1) Due to a large number of rotating parts of the mandrel and the strict resistance requirements for the parts, the manufacturing cost and drilling cost of the drilling tool are relatively high. (2) The mandrel is easily damaged by fatigue. |
| Static biased push-in pointing | Geo-Pilot, Power Drive-Direct |                                                                                                                                  |                                                                                  |

Table 3 shows the comparison of key indicators of different 4.75-inch RSS tools. In drilling applications, the outer diameter of the 4.75-inch RSS tool is the smallest, but the DLS value is relatively high. Among the tools listed below, the PowerDrive Archer 475 from Schlumberger can provide DLS at 18 degrees/100 feet, which is currently the highest DLS value. In terms of maximum withstand temperature and pressure, Baker Hughes' 4.75” AutoTrak eXact is the highest. It can be seen that Baker Hughes' eXact tool is tailor-made for high temperature and high-pressure applications, and is more suitable for drilling in high temperature and high-pressure environments than other companies' tools. Operation; in terms of sensor placement, Baker Hughes' eXact tool has a sensor distance between 5.9 and 11.25 feet. Most of these tools can be rotated to 250 rpm, only Weatherford's Revolution 475 RSS can only reach 200 Rpm. Figure 2 shows the performance of these tools in a pentagon view.

| Company          | RSS Series              | Max DLS (*/100ft) | Maximum temp (degC) | Max pressur (psi) | Sensor distance (ft) | Maximum 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 in the exploitation of oil and gas resources. However, this key technology is only mastered by a few foreign oil service companies. Therefore, to maintain its leading position and expand the company’s international market, major oil service companies have continuously upgraded their technologies and replaced their tools. The market share of several major oil service companies in the directional drilling market is shown in Figure 3. From the perspective of market share in 2019, Schlumberger, Baker Hughes and Halliburton, the three major international oil service companies, account for more than 50% of the global directional drilling market. Among them, Sri Lanka with a complete rotary steering tool system Lemberger alone holds nearly 27% of the directional drilling market share. As shown in Figure 4, the types of tools for commercial rotary steering systems that are currently owned by several major international oil service companies are sorted out, and their maximum dogleg capabilities are compared.

Figure 3. 2019 Petroleum Service Company’s Rotary Steering Tool Market Share Comparison

Figure 4. Comparison of the maximum dogleg of the RSS of the major oil service companies
4. Prospects of RSS Technology
The prospects of RSS developments are forecasted as below.

4.1. Instrumented RSS system
At present, because most of the rotary steering tools put into use do not have geological evaluation functions, they can only be used in conjunction with geological evaluation instruments, and the geological properties measured by the geological evaluation instruments are used for geological guidance. Nowadays, there are many drilling service companies in the world working on the development of rotary steering tools with geosteering capabilities. In 2016, Schlumberger launched the EMLA (Electro-Magnetic Look-Ahead) prototype with a probing distance of 30m. EMLA is integrated into the PowerDrive X6 push-on tool to make the rotary guidance system and test instrument highly integrated [11].

4.2. Drilling automation
Currently, foreign companies with RSS tools, logging-while-drilling tools (MWD) and logging-while-drilling tools (LWD) have concentrated their scientific research on developing RSS tools with closed-loop automatic control [12]; the automatic control includes automatic vertical control [13], automatic inclination control and azimuth control [14]. The development of rotary steering systems abroad has become a systematic and automated trend [15]. The development of automation takes closed-loop controlled navigation as the mainline of research [16]. With the help of systematic development, future directional drilling will necessarily include surface and downhole systems—fully automatic track closed-loop control.

5. Conclusion
This article summarizes the current development status of RSS tools and gives some suggestions for its future development direction. I hope that the review of RSS in this article can improve the understanding of RSS technology and promote the future innovation of researchers and engineers.

In summary, the research and development of the rotary steering system play a vital role in my country's unconventional oil and gas development. After years of research by Chinese scholars, China has made considerable development and progress in RSS technology. However, a comprehensive analysis of China's RSS technology has revealed that there is still a significant gap compared with foreign technologies. China's oil service companies always rely heavily on imported international products.

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