Design simulation and test of hydraulic control system of RFID reamer while drilling

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Abstract. With the gradual improvement of exploration and development in deep and ultra-deep Wells, the demand for slim-hole drilling is increasing day by day. However, both the phenomenon of neck constriction and drill-jamming accident occur from time to time in the drilling process, and the annulus clearance between borehole and casing is too small, which resulting in high slurry annulus pressure loss, low displacement efficiency and poor cementing quality. Therefore, a kind of RFID reamer while drilling has come into being, the reamer blades can be controlled to open and close with the aid of RFID tag recognition technology without increasing the drilling cost, so as to complete the reaming operation while drilling. Taking the hydraulic control system as the research object, the hydraulic circuit has been designed based on AMESim software in this paper, so has its dynamic performance simulation analysis been carried out, finally, the ground test has been completed, the results show that the hydraulic control system is capable of accurately identifying the RFID tag information to drive the reamer blades to open and close, the overall pressure loss of the tool is about 1.0 MPa as the blades opened completely, which meets the requirements of field test.

1. Introduction
Reaming while drilling technology is to integrate the reaming while drilling tool and the conventional drill bit in BHA, and enlarge the borehole while drilling, so that the borehole size is larger than the inner diameter of the upper casing string, which is convenient for the later construction of drilling and well completion [1, 2, 3].

Due to the limitation of the opening methods of the reamer blades, it is hard for the conventional reamers to control blades to open and close repeatedly according to the field requirements, which affects operations such as lifting and releasing the drilling tool shock and jarring stuck pipe freeing [4], and it is also challenging for integrating multiple reamers in the drilling string to realize the composite reaming operation as designed. While the RFID technology widely used in various fields has provided a solution for the above field requirements, with contactless, dual-direction transmission, high speed and strong environmental adaptability and other advantages [5, 6]. Weatherford Company has developed a series of RFID drilling and well completion tools, mainly including switchable sliding sleeve, downhole isolation valve, circulating valve, reamer while drilling and so on [7, 8, 9]. Wei Zhou and Bo Mao et al have developed RFID oilfield drilling tool inspection system and RFID oil field water injection control...
system, respectively [10, 11], by combining stage fracturing technology with RFID technology, Hui Fang has controlled on-off solenoid valves in different intervals to achieve the purpose of stratified diversion [12]. Sinopec institute of petroleum engineering and technology has carried out the research and development of the RFID switchable sliding sleeve, of which the prototype has been trial-produced successfully, however, there are few reports on the development and application of RFID reamer while drilling in domestic and foreign oil service companies and scientific research institutions.

In these circumstances, a novel RFID reamer while drilling has been developed in this paper, and taking the hydraulic control system as the research emphasis, both the dynamic performance analysis based on AMESim software and the ground test have been carried out, the tool will help to significantly reduce the risk of drilling and well completion as well as the drilling cost, which can effectively increase the clearance between borehole and casing, thus improving the cementing quality and extending the life of oil and gas wells.

2. Overall design of RFID reamer while drilling

2.1. System constitution
Based on the investigation of domestic and foreign data, the structural characteristics of existing reamer while drilling were analyzed. Combined with the actual demand for exploration and development of both the shale gas reservoirs and low permeability oil and gas reservoirs in domestic, the overall design scheme of RFID reamer while drilling was proposed, as shown in Fig.1. The maximum reaming diameter is 252mm, and reducing to 209mm when blades closed completely, the smallest inner diameter is 54mm, and the tool has a temperature resistance of 120℃ and a pressure resistance of 70MPa, which can meet the requirements of multiple reaming in field application.

RFID reamer while drilling is mainly composed of tag control system, hydraulic control system and reaming execution system. And tag control system comprises RFID tags, RFID communication module and RFID electronic control module, RFID communication module includes antenna, RFID reader and so on, RFID electronic control module is consisted of battery pack, signal processing circuit and solenoid valve control circuit, hydraulic control system contains micro solenoid valve, reset spring and piston.

2.2. Working principle
The RFID reamer while drilling has adopted electromechanical and hydraulic integration control mode, according to the control information carried by tags, the spool movement in the micro solenoid valve is driven by the main control circuit of the RFID tag control system, so as to realize on-off of oil circuit in the hydraulic system, and then control the reamer blades to open and close. Before the tool enters the well, the tag information can be changed through the PC reader, and also the control procedures and parameters can be adjusted according to the actual field requirements.

Before reaming, the RFID tag carrying control information is released at the wellhead, when the tag is circulated to the RFID antenna along with the drilling fluid, after signal demodulation by signal
processing circuit, its internal control information is transferred to the drive circuit in the solenoid valve, which is energized to open the valve port, then reamer blades are driven by differential pressure of the BHA to open, after being completely open, the solenoid valve is powered off to start reaming operation by locking blades. After the reaming operation is completed, another RFID tag is released, then the solenoid valve is energized while the circulating displacement is reduced, thus the blades are drawn back under the action of mandrel driven by the reset spring.

3. Design and simulation of hydraulic control system

3.1. Design of hydraulic control system

The unit of hydraulic control system is composed of a single-acting spring return cylinder and a micro solenoid valve, which is coaxially connected in series with the unit of reaming execution system, the axial displacement of the mandrel is limited by the piston of hydraulic cylinder, so as to control the opening and closing of the blades, the oil circuit diagram of hydraulic system is shown in Fig.2.

Fluid chambers on both sides of the piston are connected through a two-position two-way micro solenoid valve, when powered off, it works in the right position, the oil path between the spring chamber and non-spring chamber is cut off to lock the piston. When powered on, it works in the left position, the oil path between the spring chamber and the non-spring chamber is connected, the piston moves synchronously with the mandrel under the action of either the differential pressure of the BHA or the return force of the reset spring.

According to the dimensional requirements of both the maximum outer diameter and the minimum inner diameter of the unit of hydraulic control system, the structural design of the hydraulic control system has been carried out with consideration of the processing technology and the wall thickness design criteria of the oil pipeline and the requirements of the mechanical structure for compressive resistance, tensile strength and torsional strength, as shown in Fig.3. The single-acting spring return cylinder is coaxially connected in rigid series with the mandrel, in order to simplify the processing technology of the slender oil hole, fluid chambers on both sides of the piston are connected through an external oil pipe, and the micro solenoid valve is inserted in the hydraulic control loop in the form of plug-in. The pressure is equal as two chambers are connected, the piston is in a floating state, and the blades follow the movement of the mandrel to open or close. When the two chambers are cut off, the piston is in the locking state due to the incompressibility of the hydraulic oil, in that the mandrel is locked in axial displacement.
3.2. Simulation of hydraulic control system

A calculation model has been established by simplifying the hydraulic control system, as shown in Fig.4. The stiffness of the reset spring is 36.6N/mm and the preload force is 5kN, the piston, the mandrel and its accessories have been taken as a whole, and the equivalent mass is 38kg, the outer diameter of the piston with stroke of 140mm is 100mm, the inner diameter is 70mm, and the oil path inner diameter is 6mm. On the right end face, the mandrel is under 2.6MPa differential pressure established by the BHA, data above will be used as the input parameters of the simulation model.

![Figure 4. The calculation model of hydraulic control system.](image)

As a modelling and simulation platform for complex systems in multidisciplinary fields, users can build up a complicated system model with the aid of AMESim software, which is available for simulation calculation and analysis as well as for studying the steady-state and dynamic performance of any component or system, beyond that, its all kinds of hydraulic components library and user-defined modules as well, are convenient to realize hydraulic control system simulation of RFID reamer while drilling. Therefore, based on the structural scheme and working principle of hydraulic control system, the AMESim simulation model in the process of blades opening and closing has been built respectively, as shown in Fig.5, in which the dynamic laws of the piston velocity, displacement and pressures in chambers on both sides of piston can be analyzed.

![Figure 5. The simulation model of hydraulic control system.](image)

The micro solenoid valve is powered off in the initial state, the preload force of the reset spring is 5kN, and the right end face of the mandrel is subjected to 90kN applied by differential pressure of the BHA, when powered on, it works in the left position, the oil path between the spring chamber and the non-spring chamber is connected, then the piston is pushed by mandrel to compress the spring with blades opening gradually, subsequently, the dynamic curves of the piston velocity, displacement and pressures in chambers on both sides of piston are obtained, as shown in Fig.6. According to the simulation results, in the process of blades opening, the maximum speed of the piston is 0.11m/s, and the maximum pressure in oil chambers is 7.5MPa.
The process of blades opening comes to an end when the piston driven by the mandrel reaches its limit position, the reset spring is compressed by 140mm, the solenoid valve works in the right position as powered off, thus locking the blades. The mud pump isn’t turned off before the RFID tag has been released for a while, by the time, the right end face of the mandrel is subjected to approximately 0MPa of differential pressure, then the solenoid valve is controlled to open by electronic control system, and the oil path between chambers on both sides of piston is connected, the piston together with the mandrel are driven downward by the restoring spring force to close blades gradually, subsequently, the dynamic curves of the piston velocity, displacement and pressures in chambers on both sides of piston are obtained, as shown in Fig.7. According to the simulation results, in the process of blades closing, the maximum speed of the piston is 0.15m/s, and the maximum pressure in oil chambers is 15MPa.

The simulation results show that the maximum speed of the piston is 0.15m/s, and the maximum pressure in oil chambers is 15MPa, which can provide a theoretical basis for the structural design of piston dynamic sealing, sealing ring optimization and solenoid valve parameter matching.

4. Ground performance test
In order to verify the reliability of the hydraulic control system of RFID reamer while drilling, ground performance tests on its locking and spring return functions were carried out, and meanwhile, both the action process of reamer blades and the overall pressure loss of the tool have been recorded.

The chambers on both sides of piston were vacuumed before oil injection, which can remarkably improve the oil injection efficiency, thus reducing the influence of air on the volume elastic modulus of hydraulic oil, and improving the stability of hydraulic control system. After filled with oil, oil plug and micro solenoid valve were installed, then the piston was driven by the tensile and compression testing machine to verify the working principle and sealing performance of hydraulic control system. Under the circumstance that chambers were completely cut off as the solenoid valve was powered off, being subjected to eight tons of thrust, the piston remained stationary, which indicated that the internal seal structure of hydraulic control system was intact, and the locking function is reliable without hydraulic oil leakage.
Figure 8. The physical map of ground performance test.

The system units of RFID reamer while drilling have been assembled in series to conduct ground performance test, as shown in Fig. 8. The test results showed that, the “opening” tag was released after the pump was powered on, and the blades were driven to open gradually, by the time, the overall pressure loss of the tool increased gradually, and it was finally stabilized at 2.2MPa with the blades fully opened. Subsequently, the “closing” tag was released as the pump displacement was reduced, and the blades were gradually drawn back under the action of the spring return force, which verified the reliability of the spring return function, therefore, the tool met the design requirements and meanwhile satisfied with field application conditions.

5. Conclusion
Combined with the technical characteristics and functional limitations of conventional reamers while drilling, a kind of RFID reamer while drilling has been put forward, which can meet multiple reaming requirements while drilling and effectively increase the clearance between borehole and casing, thus improving the cementing quality and extending the life of oil and gas wells.

Taking the hydraulic control system as the research emphasis, the AMESim simulation model has been set up, and the dynamic characteristics of the piston velocity, displacement and pressures in chambers were simulated, which provided a theoretical basis for the structural design of hydraulic control system and component parameter matching.

Finally, the ground performance test of the tool has been carried out, the results showed that the spring return and locking functions were reliable, in addition, it can accurately identify tag information to control the opening and closing of the blades, which met the design requirements and meanwhile satisfied with field application conditions.

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