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A Review of Micro Plunger Pumps for Downhole Rotary Guidance Systems

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Abstract

The current rotary-guided drilling method has excellent guiding performance and is very suitable for drilling large displacement wells and long horizontal sections of horizontal wells. The modern rotary guidance system that has been developed is guided by the hydraulic system, the wing rib pushes against the reaction combined force formed by the wellbore to produce guidance for the tool, the hydraulic module is the core part of this kind of downhole rotary guidance system, and the axial piston pump, as the hydraulic power source of the hydraulic system, determines the accuracy and efficiency of the whole rotary guidance hydraulic system. Under the conditions of working environment and media pollution, the hydraulic axial piston pump will have some deviation in its working performance and efficiency after working for a period of time, which will reduce the working capacity and life of the system, and even make the system unable to work safely.

Keywords

Downhole Rotary Guidance Systems; Micro; Plunger Pump; Hydraulic System.

1. Introduction

The current rotary-guided drilling method has excellent guiding performance and is very suitable for drilling large displacement wells and long horizontal sections of horizontal wells. CNOOC has carried out research work on rotary-guided drilling technology to reduce drilling costs. The modern rotary guidance system that has been developed is guided by the hydraulic system, the wing rib pushes against the reaction combined force formed by the wellbite to produce guidance for the tool, the hydraulic module is the core part of this kind of downhole rotary guidance system, and the axial piston pump, as the hydraulic power source of the hydraulic system, determines the accuracy and efficiency of the whole rotary guidance hydraulic system. Under the conditions of working environment and media pollution, the hydraulic axial piston pump will have some deviation in its working performance and efficiency after working for a period of time, which will reduce the working capacity and life of the system, and even make the system unable to work safely. Therefore, it is necessary to make reasonable use of hydraulic CAT (Computer Aided Testing) technology to design a fast and efficient hydraulic system to optimise the performance of the plunger pump, so as to improve the reliability of the whole system.

The rotary guided drilling system can continuously and accurately change the drilling direction in the preset borehole drilling trajectory under the condition of rotating the drill column to improve the accuracy of the borehole drilling trajectory, which is commonly used in the guided drilling of horizontal wells, three-dimensional multi-objective wells, and other special working conditions. The control system of the whole system is used to control the actuator for guiding, which allows the rotary bit to drill in the direction of the specified drilling trajectory. There are many more mature rotary guidance systems at home and abroad, such as PowerDrive of Schlumberger enterprise, Welleader of domestic CNOOC, etc.

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Compared with the traditional transmission method, hydraulic transmission has the advantages of small equipment space, large speed range, stepless speed regulation, high power, convenient installation and so on. Hydraulic transmission technology has been more widely used in aerospace, machinery, agriculture and forestry and other directions. The working medium of the entire hydraulic transmission system for the flow of liquid, can change the mechanical energy of the motor into the pressure energy of the working fluid, the use of connecting pipelines and valves, in the implementation of the part of the pressure energy of the working fluid can be changed into the load of the mechanical energy required by the hydraulic system. The complete hydraulic transmission system by the power part, control part, the executive part, auxiliary part and the working medium and other five major combinations.

At present, many domestic and foreign construction machinery mostly use the hydraulic system for transmission, in the whole equipment in the most central position, therefore, the hydraulic transmission system and its core components of the design and research is of great significance [7]. Axial piston pump for the entire hydraulic system in the 'heart' position, can give the entire hydraulic system to generate power source, for the hydraulic system in the key components. Modern hydraulic system is widely used, large load capacity, light weight, structural arrangement of the installation space is not a big demand, in the mechanical and military industry and a variety of engineering machinery, will find the existence of hydraulic pumps.

The current development trend of directional drilling has four main stages: the primary stage through the slope builder and measuring instrument hydrofluoric acid bottle; the low stage of directional drilling through the downhole motor with bent joints and the measuring instrument is an electronic measuring instrument; the intermediate stage of directional drilling through the guiding motor and the accompanying drilling measuring instrument; and the advanced stage of directional drilling through the rotary guiding system and accompanying drilling logging instrument. Motivation for the R&D and development of rotary guidance systems. Initially, the production demand for RSS was to solve the problems of high friction in large displacement wells and difficulty in borehole cleaning, and this method was gradually used in conventional directional and horizontal wells due to its high drilling efficiency. With the continuous development of rotary guidance technology, the rotary guidance system has been used in the beginning for 'special applications' such as large inclined wells, ultra-deep wells, horizontal wells, difficult directional wells, large displacement wells and horizontal branching wells, as well as the drilling of complex structural wells and special process wells in the late stage of oilfield development, and gradually moved towards conventional applications, and has become the most widely used method in many different complex structural wells on the sea and land. The core drilling system of many different complex structural wells on land and sea. Through more than 30 years of development, the technology has been upgraded to At-bit Steerable System (ABSS), which is called 'the third key technological innovation in directional drilling' by SLB. The rotary guidance drilling system can continuously and accurately change the drilling direction in the preset borehole drilling trajectory under the working condition of rotating drill column, which improves the accuracy of the borehole drilling trajectory, and has been commonly used in the guided drilling of horizontal wells, three-dimensional multi-objective wells, and other special working condition wells.

2. Research Status

2.1. Domestic and International Piston Pump Research Status

Currently in the study of piston pumps is mainly the design of its key structure and parameter optimisation, Harvey.W and Janny.R [1][2] research and design of swash plate axial piston pumps began, the optimal design of the structure of the piston pump has been continuously research and advancement. The optimization aspects mainly include the structural

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improvement of the slide shoe, the optimization of the plunger itself, the optimization of the flow distribution disc structure, the optimization of the hydraulic cylinder body structure, and other friction vice structural improvement and parameter optimization. At present, there is a great deal of progress in the research of foreign countries in the swash plate axial piston pumps, which gives theoretical support and experimental research guidance to the domestic and international research and design of high-precision swash plate axial piston pumps.

Foreign countries have advanced technical support in the field of hydraulics, there are a number of representative companies, similar to the United States Parker, Germany, Rexroth and Japan Yuken Company, etc. And foreign research on piston pumps for the high precision axial piston pumps. And abroad for the piston pump has carried out a lot of optimisation and new structure direction of the research.

The famous German university RWTH Aachen University will use the hydraulic simulation software DSHplus and dynamic simulation software ADAMS together to design the model of swash plate axial piston pump, the model can be used to study the pressure in all directions inside the pump and the actual changes in the flow field, through the ADAMS to establish the mechanical module model for kinematics and dynamics simulation simulation, the hydraulic part of its calculation of fluid pressure, the friction part of its calculation of The hydraulic part calculates the pressure of the fluid, and the friction part calculates the friction force and wear characteristics of the different friction parts, and the joint simulation enables the data between the two platforms to be transferred together, and the working characteristics of the nine-plunger piston pump are studied and analysed, and the control of mechanical noise is improved and optimised, and the flow rate pulsation is optimised to be smaller. At the same time, a test platform was built to test the simulation results [3].

Due to the advanced technical support, there are many representative companies in the field of hydraulics, such as Parker Company in the United States, Rexroth Company in Germany and Yuken Company in Japan, etc. And many researches have been carried out in the direction of optimization and new structure for piston pumps. Kumar used computational fluid dynamics software to simulate the swash plate axial piston pump, optimize the type of damping groove of the slide shoe, and take the static pressure support slide shoe structure as the object of analysis, and the study shows that the oil film in the slide shoe shows a linear change between the support force on the bottom of the slide shoe and the hydraulic pressure, and the leakage pressure and hydraulic pressure of the slide shoe are also linearly related. pressure and hydraulic pressure are also linear relationships[4].

Parker enterprise through ADAMS and EASY5 combination of simulation prototype on the swash plate axial piston pump to complete the joint simulation simulation, analysis of the swash plate axial piston pump movement conditions and the form of each component force, differentiated while analyzing the performance of the pump's pressure changes and the form of force in the movement of the plunger vice, for the structural design and parameter optimization of axial piston pumps to provide a new design method and research direction [5].

Noah D. Manring, a famous scholar at the University of Missouri in the United States, has improved the structural types of the distributor disc and the slide shoe. In order to increase the volumetric efficiency of the pump, the improved flow distribution disc uses the form of controlling the volume change of the discharge port of the piston pump. In the improved slide shoe structure, two different forms of slide shoe structure, conical and spherical, were separated from the concave structure of the slide shoe connected to the plunger head to analyze its performance, and the study showed the variation of the oil film thickness of the slide shoe vice to withstand the pressure during the working process and the minimum thickness of the oil film to be able to withstand the pressure [6].

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Palmberg scholars from the famous Linköping University in Sweden used the pre-compressed volume method to design and improve the structure type of the flow distribution disc, which has a certain vibration damping effect, and can reduce the pressure peaks caused by the sudden change in the pressure of the plunger chamber from the pressure chamber to the discharge chamber, and also reduce the flow pulsation in the flow distribution disc caused by the backflow of the liquid. And also studied and analysed the mismatch angle on the flow distribution vice to reduce the noise of the influence of the law, that is, for the adjustment of the hydraulic cylinder body on the intersection of the upper and lower dead center line and the hydraulic cylinder body of the central axis of the angle of the adjustment and improvement of the output flow [7].

The famous Columbia University in the United States studied the ideal conditions of the liquid and the actual conditions of the liquid of the output flow characteristics of the piston pump, complete the model when analyzing the compression of the oil and the pump's internal oil leakage of the impact of the use of numerical calculations to adjust the flow rate of the size of the pulsation rate, able to derive a different number of plungers of the piston pump of the output flow rate of the pulsation rate, so that it can be the ideal conditions and the actual conditions of the The size of flow pulsation rate for pumps with odd and even number of plungers. After studying and analyzing the flow pulsation in terms of flow pulsation, it was concluded that for liquids under ideal conditions, the flow pulsation rate of piston pumps with even number of plungers is higher than that of piston pumps with odd number of plugs, and the flow pulsation of piston pumps with odd number of plugs is small, but for the liquid model in real situation, the study structure is just the opposite, and the flow pulsation of piston pumps with even number of plungers is smaller [8].

U.S. Kim et al [9] research and optimization of the output displacement of 75 ml / r swash plate axial piston pumps, able to make the swash plate to actively regulate the form of vibration, while testing the pump under normal operating conditions of the noise size, to achieve the optimization can be more effective in reducing the noise of the piston pump in normal operation. Germany Rexroth also studied the axial piston pump vibration damping and noise reduction performance, design and improve the piston pump housing, while verified through practical tests [10].

2.2. Domestic and Foreign Micro-Piston Pump Research Status

Miniature pumps have demonstrated a wide range of potential applications in several fields due to their compact size, light weight, low energy consumption, high pressure, excellent self-priming performance and high-power density.

Tanaka et al. analysed the opening and closing transients of centrifugal pump flow distribution valves by high-speed camera and found that rapid opening and closing of the valve spool causes air pockets and separation of the water column, which can lead to pressure and flow pulsations in the pump [11].

Oshina et al. analysed the flow of a hydraulic cone valve and also analysed the flow characteristics and cavitation of a hydraulic seat valve along with noise experiments[12].

Chiu et al. developed an electromagnetically driven miniature piston pump with a novel mechanism. The novel mechanism is an axial hollow piston with a membrane used as a check valve. The operation of this novel pump is driven by an electromagnetic force, which produces a reciprocating motion by periodic switching of the magnetic poles [13].

Chen et al. investigated the sealing and cavitation characteristics of a miniature ultra-high pressure single piston pump and an aero-piston pump. It was shown that adjusting the valve opening of a reasonable distribution valve helps to reduce cavitation and noise, while low-temperature fluids cause severe cavitation [14].

Cao Wenbin et al. studied the volumetric efficiency of miniature high-pressure piston pumps based on AMESim, and compared and analysed the specific effects of different spring stiffness

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and opening pressure on the volumetric efficiency of miniature high-pressure piston pumps [15].

Since the 1950s, foreign research on miniature pumps has been over the years, the technology is becoming more mature, the market has launched a number of series of miniature pump products.

As shown in Fig. R and RG series radial piston pumps produced by HAWE enterprises in Germany, with a displacement range of 0.21 to 10 ml/, the maximum speed of up to 1450 r/min, and its working pressure is between 25 and 70 MPa.

The TFH series of axial piston pumps [16]were researched and developed from Takako Enterprises, Japan, and the finished product of their development is shown in Figs. 1-12. These pumps have a displacement ranging from 0.4 to 6.3 mlr, with speeds varying from 2,000 to 3,000 r/min, with maximum pressures up to 20 MPa, with volumetric efficiencies of more than 95 per cent, and with the weight of the lightest model at 270 g, and with diameters of only 30 mm.

The PB series of axial piston pumps [17], produced and developed by the French company LEDUC, as shown in the figure, have a displacement range of 0.012 to 0.07 ml/r, and are capable of reaching speeds of up to 5000 r/min and a maximum pressure of 30 MPa. One of these models, the PB33HP, has a displacement of 0.045 ml/r, a pressure capable of reaching 90 MPa, a weight of 330 g, a diameter of 32 mm, and an axial length of 68 mm.

(a)HAWE Radial piston pumps

(b)Takako Axial Piston Pumps

(c)LEDUC Axial Piston Pumps

(d)Parker Miniature Piston Pumps

Fig 1. Miniature Piston Pump Products

The H-series axial piston pump researched and manufactured by Parker Enterprises in the United States employs five plungers [18], and its development object is shown in Fig. 1-14, with displacements ranging from 0.156 to 0.865 ml/r, with a maximum capacity of 4,500 rpm, a top pressure of 27.6 MPa, and a volumetric efficiency of more than 90%, which makes it suitable for application scenarios with high pressures, small flow rates, and small volumes. In addition, Parker's CP Series axial piston pumps contain three plungers, and this tubular construction has

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a displacement range of 0.17 to 0.33 ml per rev, a maximum speed of 5,000 rpm, and the same top pressure of 27.6 MPa.

3. Summary

Rotary Steering System Micro Piston Pump (RSSM) is a kind of high efficient hydraulic transmission device, which is widely used in oil and gas exploration, mechanical automation and deep well drilling. Its main function is to provide stable power drive through the conversion and transmission of hydraulic pressure to ensure high precision control and stable operation of rotary steering system under complex geological conditions.

Miniature piston pumps have higher power density and smaller size compared with traditional hydraulic pumps, which makes them show unique advantages in scenarios that require compact design and high efficiency drive. Rotary guidance systems play a critical role in deep well drilling and directional drilling in particular by precisely controlling the direction of the drilling tools, which can effectively improve drilling efficiency and reduce the risk of bit deflection. The miniature plunger pump provides the required high-pressure power source for this system, and its working principle is to convert the energy of hydraulic fluid into mechanical motion through the reciprocating motion of the plunger, which in turn drives the rotary guidance system for precise control.

However, rotary guided system miniature piston pumps still face some technical challenges in practical applications. Firstly, as the working environment of miniature piston pumps is mostly high temperature, high pressure and the existence of vibration and shock load conditions, which puts forward high requirements on the sealing, durability and stability of the pump. Secondly, the manufacturing precision and wear resistance of miniature pumps need to be continuously improved to cope with the wear and tear problem in long-time high-load operation. Further technological breakthroughs can be made by optimising the pump body structure, adopting new high wear-resistant materials and improving sealing technology to improve the comprehensive performance of the system.

Looking ahead, with the continuous development of hydraulic technology and material science, rotary guided system miniature piston pumps are expected to make breakthroughs in the following directions: firstly, the application of intelligent control system will further improve the pump's operating efficiency and adaptive capacity, which can automatically adjust the working state under different drilling conditions; secondly, miniature pumps based on new composites will have better performance in terms of high temperature, corrosion and wear resistance, which will extend the pump's service life. have better performance and prolong the service life of the pump; finally, the further development of miniaturised design will make the pump play a greater role in space-restricted environments, especially in deep-sea drilling or applications in extreme environments.

In summary, the rotary guide system miniature piston pump has a wide range of application prospects as an efficient hydraulic drive device. With the continuous progress of technology, it will play an increasingly important role in improving drilling efficiency, reducing operating costs and extending equipment life.

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