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Study on AADDS Plunger Pump Driving Bearing Properties

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Abstract: The Auto Anti-Deviation Drilling System (AADDS) is a high-performance, highly automated vertical drilling hydraulic guide control system. This article takes its power extraction device - driving bearing for the study object, analyzed the single-plunger pump's principle, established the mathematical model of hydraulic guide system, applied Matlab/Simulink to simulate the pump outlet flow under different contour curve of the driving bearing. The results show the oval-shaped bearing is of high efficiency under lower drilling speed, and its performance is better than that of original eccentric-shaped and clover-shaped. *Copyright © 2013 IFSA.*

Keywords: AADDS, Hydraulic guide system, Singer-plunger pump, Counter curve, Flow characteristics.

1. Introduction

Automatic vertical drilling tool is a high technology drilling system that contains downhole closed-loop control system, can correct oblique initiatively and maintain the wall of the well vertically. At present, the main products used in the world are VertiTrak automated drilling system of Baker Hughes, Power V rotary steerable system of Schlumberger, ZBE vertical drilling systems of Smart Drilling. But they all have the disadvantages of expensive price, structural complexity, and so on.

In 2004, Wuhan University of Science & Technology and related units successfully developed the Auto Anti-Deviation Drilling System (AADDS), and manufactured a prototype [1].

2. Principle of Hydraulic Guide System

Hydraulic guide system is the core component of the AADDS [2]. Its schematic diagram is shown in Fig. 1. It's a closed system which is composed of oil storage bag, absorption check valve, single-plunger pump, pressure check valve, overflow valve, solenoid valve, driving bearing and guide hydraulic cylinder.

The hydraulic energy in the guide system comes from the mechanical energy of rotating drill collar.

The eccentric driving bearing and the float guide sleeve are installed on the drill collar which is closed to the drill, and the rotate speed difference between the drill collar and the guide sleeve drives the plunger of the pump moving continuously, providing the continuous high pressure oil to the oblique-correcting system.

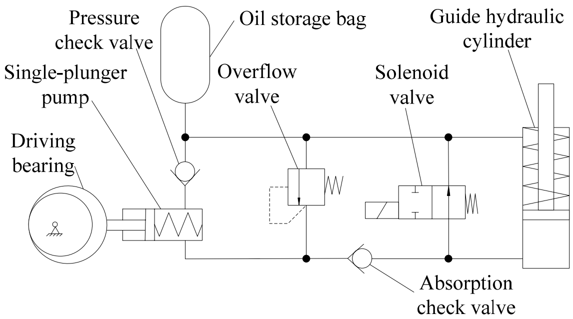

Fig. 1. Hydraulic guide system.

And the greater rotate speed difference is, the greater output flow of the pump and response performance will be. The overflow valve determines the maximum working pressure of the rodless chamber of the guide hydraulic cylinder, and limits the maximum push force of the guide piston to the wall of the well too.

The solenoid valve decides if the tool operates or not. When the well track is within the limits, the solenoid is power off, the rodless chamber of the guide cylinder connects with the oil storage bag, and the output oil from the pump directly flows into the bag, so the piston of guide cylinder does not extend under the reaction force of the reset spring. Conversely, if the control system detects the downhole inclination exceeds the limits, it sends the control signal under the control rules, and the solenoid valve energizes, then the rodless chamber of guide cylinder is cut off with the low-pressure circuit. So the guide piston will extend and support the wall of the well to force the well trackback to the correct direction finally.

Since 2008 a series of laboratory and drilling tests has been hold [3], and the test results basically meet the design requirements, but its driving bearing is eccentric-shaped, that results in the piston pump inefficiency, so it needs for further improvement.

3. System Dynamics Modeling and Analyze

Since the output pressure of single plunger pump changes with the variation of the system pressure, therefore, in order to study the output pressure and flow of the pump, we must build the dynamic model of the whole hydraulic guide system.

The kinematics equation of the single-plunger pump [4, 5] is (Assume the contour curve of the driving bearing is eccentric)

$$x_r = e[1+\cos(\omega t)] \quad (1)$$

The outlet flow of the pump is

$$Q_p = Q_z + Q_d \quad (2)$$

The dynamic equation of the overflow valve is:

$$\frac{\pi d_z^2}{4} P_0 - K_z\left(X_z + X_{z0}\right) = m_z \frac{d^2 X_z}{dt^2} \quad (3)$$

The flow equation of the overflow valve is:

$$Q_z = C_d A_z \sqrt{\frac{2|P_0|}{\rho}} \quad (4)$$

The dynamic equation of pressure check valve is:

$$\left(P_0 - P_p\right)\frac{\pi dy^2}{4} - k_y(X_y + X_{y0}) = m_y \frac{d^2 X_y}{dt^2} \quad (5)$$

The flow equation of pressure check valve is:

$$Q_y = C_d A_y \sqrt{\frac{2\left|P_0 - P_p\right|}{\rho}} \quad (6)$$

The dynamic equation of the cylinder is:

$$P_0 A_g = m_g \frac{d^2 X_g}{dt^2} + k_g(X_g + X_{g0}) \quad (7)$$

The flow equation of the cylinder is

$$Q_g = A_g \frac{dX_g}{dt} + \frac{A_g X_g}{\beta_e} \cdot \frac{dP_0}{dt} \quad (8)$$

Symbols in equations are explained in Table 1.

4. Dynamic Analysis of Single-plunger Pump

According to the equations (1)-(8) above, the simulation model of hydraulic guide system is established through Matlab/Simulink, as shown in Fig. 2.

We can start the simulation after the parameters are set. Then the outlet flow diagrams of eccentric circle pump in 60r/min (as shown in Fig. 3) and in 120 r/min (as shown in Fig. 4) can be obtained respectively.

Table 1. The meanings of the symbols in equations.

Symbol	Meaning	Symbol	Meaning
e	Bearing eccentricity distance	X_r	The piston displacement of pump
ω	The drill rod rotation speed	P_p	The rodless cavity pressure of guide hydraulic cylinder
Q_p	The flow of pump	d_y	The diameter of check valve port
Q_z	The flow of overflow valve	K_y	The spring stiffness of check valve
Q_d	The flow of pressure check valve	X_y	The displacement of check valve spool
d_z	The diameter of overflow valve port	X_{y0}	The pre-compression of check valve spring
P_o	The inlet pressure of overflow valve	m_y	The mass of check valve spool
K_z	The spring stiffness of overflow valve	A_g	The area of rod chamber
X_z	The displacement of overflow valve spool	m_g	The mass of cylinder piston rod
X_{z0}	The pre-compression of overflow valve spring	k_g	The reset spring stiffness of hydraulic cylinder
m_z	The mass of overflow valve spool	X_g	The piston rod displacement of hydraulic cylinder
C_d	The flow coefficient of valve port	X_{g0}	The piston rod initial displacement of the hydraulic cylinder
A_z	The flow area of overflow valve port	Q_g	The flow of hydraulic cylinder
ρ	The density of oil	β_e	The equivalent volume elastic modulus of oil

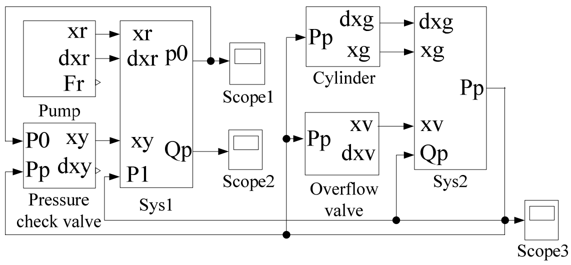

Fig. 2. The simulation model of hydraulic guide system.

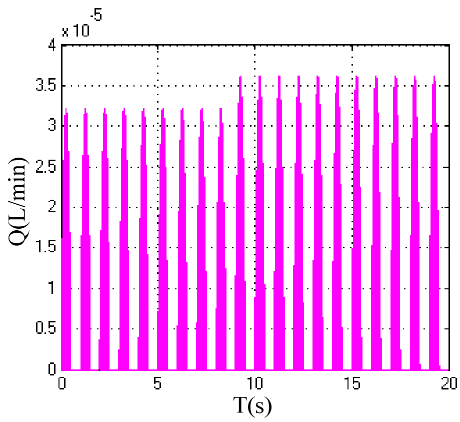

Fig. 3. Outlet flow of eccentric circle pump in 60 r/min.

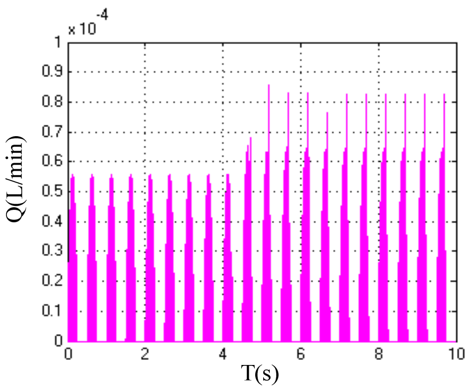

Fig. 4. Outlet flow of eccentric pump in 120 r/min.

Trough comparing the outlet flow diagrams of eccentric circle pump in 60 r/min and in 120 r/min, it can be verified that when relative speed difference between the floating guide sleeve and the drill collar increases, the output flow of the pump raises, and the response speed is better.

The pump absorbs and pressures the oil only once in one cycle of eccentric bearing's movement.

In order to improve the efficiency of piston pump, can absorb and drain oil several times as the driving bearing rotates one circle, we carried on the corresponding research work further.

4.1. If the Bearing is Elliptical

Modify the eccentric gear to ellipse-shaped that is of same stroke (as shown in Fig. 5), so the pump can blot and discharge the oil twice during one cycle.

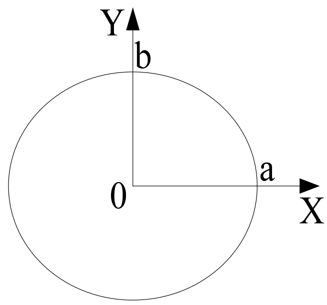

Fig. 5. The ellipse driving bearing.

Then its equation is:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1 \tag{9}$$

The plunger's displacement is:

$$X_r=\sqrt{a^2\cos^2(\omega t)+b^2\sin^2(\omega t)} \tag{10}$$

After simulation as the bearing curve is elliptical, we get the outlet flow diagram of the elliptical pump in 60 r/min as shown in Fig. 5.

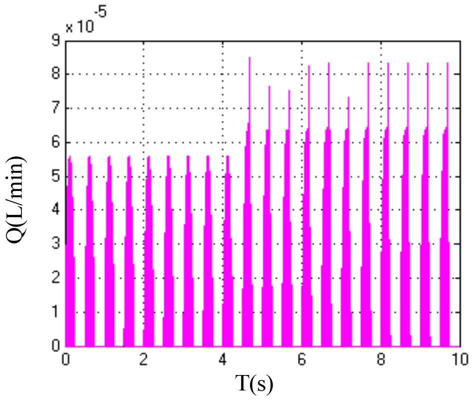

Fig. 5. Elliptical pump's outlet flow in 60 r/min.

Compare the outlet flow diagrams of elliptical pump in 60 r/min and eccentric pump in 120 r/min, we can see that their output flow and response time are almost the same. It shows that even if elliptical pump's speed is slightly low, it can also achieve the same performance as well as the eccentric circle pump in a high speed. And the strokes as the bearing is oval and eccentric are the identical. This suggests that when the installation space, plunger diameter and the stroke of pump piston rod are all same, the elliptical pump's performance is superior to that of the original eccentric circle pump.

4.2. If the Bearing is Clover-Shaped

Consider changing the shape of eccentric gear to trefoil-shaped that has the same max outside diameter (as shown in Fig. 6).

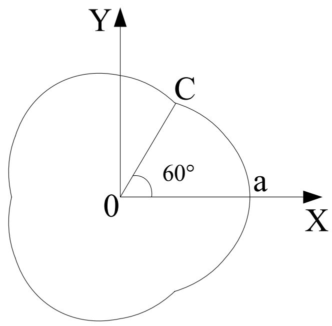

Fig. 6. Clover-shaped driving gearing.

Then it can blot and discharge the oil three times in one cycle. In this article, the trefoil shape is obtained from rotating the ellipse mentioned in 4.1 120° and 240° respectively around its center.

The displacement of the plunger is

$$X_s = \sqrt{a^2\cos^2(\delta) + b^2\sin^2(\delta)} - |OC|, \tag{11}$$

where

$$\delta = \text{mod}(\omega t, 120°) \tag{12}$$

$$|OC| = \sqrt{a^2\cos^2(60°) + b^2\sin^2(60°)} \tag{13}$$

After simulation as the bearing curve is trefoil, the pump's outlet flow in 60 r/min can be got as shown in Fig. 7.

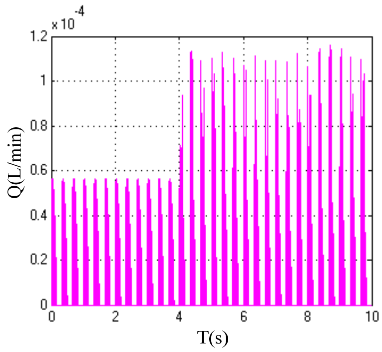

Fig. 7. Clover-shaped pump's outlet flow in 60 r/min.

Compare the outlet flow diagrams of elliptical pump in 60 r/min and trefoil pump in 60 r/min, we can see that the response speed of trefoil pump is roughly the same and the outlet flow doesn't raise obviously as that of elliptical pump, and on the contrary, its pressure fluctuation increases obviously. It is because that although the trefoil-shaped pump can blot and discharge the oil three times during one cycle, its stroke of pump piston rod is shorten, and it may affect the increase of its output flow. Therefore, we can draw a conclusion that the performance of the trefoil pump is not better than that of the ellipse pump, what's more, the four-leaf clover and five-leaf clover shaped pumps are also much worse than the ellipse pump.

5. Conclusions

Automatic vertical drilling tool is a kind of high-tech electromechanical integration system, and due to its severe working environment and various technical limitation, it's very hard to develop such equipment. Some major problems of Auto Anti-Deviation Drilling System (AADDS) has been solved, and a few experiments have also been performed, but some items, particularly the energy extraction device, need for further research.

On the basis of the mathematical modeling and with the usage of Matlab/Simulink, the performance of single plunger pump is studied as the driving bearing curve is eccentric, ellipse and trefoil respectively that of the same stroke. The simulation results show that the ellipse-shaped pump has the advantage of that of the original eccentric pump and the trefoil pump. It not only can meet the flow and pressure demands of the system, but also can satisfy the requirements of the pump that can work in a slightly small speed underground that mean less wear and longer use-life. Meanwhile, it also offers a new thinking for subsequent improvement in designing the power mechanism of the drilling correcting system.

Acknowledgements

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