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Analysis of motion characteristics of fully rotating internal steering drilling tools

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Analysis of motion characteristics of fully rotating internal steering drilling tools

Guangwei Zhang, Yang Qiao*, Lin Xiang, Situ Gao, Fan Tian, Weikang Tian

School of Xi'an Shiyou University, Shaanxi, China.

*Corresponding author e-mail: 1624127021@qq.com

Abstract. The fully rotary internal steering drilling tool is a key execution component of the rotary steering drilling system, which is a new type of dynamic directional downhole closed loop rotary steering drilling tool. The study was aimed to investigate the motion of fully rotary steering drilling tool. According to the corresponding spatial mechanism, the kinematics model of the fully rotary built-in steering drilling tool was established, and the kinematics analysis of the system was carried out. The validity of the model was verified by comparing with the simulation results of SolidWorks. The basic kinematic parameters of the key components, such as inner and outer eccentric annulus, angular velocity and displacement of drill are obtained theoretically, and the kinematic characteristics of the guiding mechanism are revealed. In this paper, the relationship between rotational speed, eccentricity and trajectory of drill was studied, and the variation of various parameters in the system with time is obtained, which provides a theoretical basis for well trajectory control of fully rotary built-in steel drilling tools.

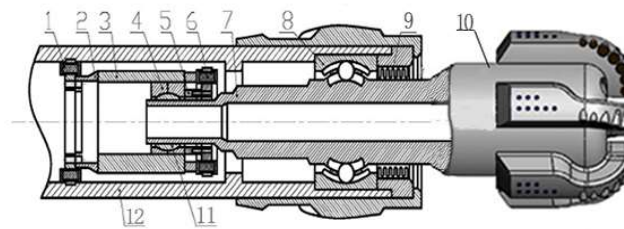
1. Introduction

In recent years, with the increasing demand for unconventional wells such as horizontal wells and extended reach wells, the rotary steering drilling has been more and more widely used[1]. The fully rotary internal steering drilling tool is a key execution component of the rotary steering drilling system, which is still on the stage of theoretical research in China[2–4], the authors systematically studied the kinematics characteristics of this new guided drilling tool and laid a theoretical foundation for the development of fully rotary built-in steering drilling tools.

2. The structure of fully rotary built-in drilling tool

The fully rotary built-in drilling tools are usually composed of sever motor, eccentric annular set, guide spindle, guide section and rotary outer casing. The structure is shown in Figure.1. The eccentric annular set are the main component of steering executive unit, including two interwork eccentric annular[5]. The guiding function of drilling tool is mainly realized by the relative motion of eccentric annular. The sever motors are used to drive the inner eccentric annular and external eccentric annular respectively. the rotary outer casing rotates with the drill string, which joins the upper drill string and the lower one, and the rotary outer casing is a key bridge for the drill string to exert weight and torque drill. the guide section is the fulcrum of the guide spindle and is also the force bearing point of torque transmission between rotary outer casing and guide spindle[6].





1.sever motor of external eccentric annular 2.flange 3.external eccentric annular 4.inner eccentric annular 5.flange 6.sever motor of inner eccentric annular 7.guide spindle 8.guide section 9.seal structure 10.drill 11.ball seat 12.rotary outer casing

Figure 1. The structure model of fully rotary built-in drilling tool

3. The structure model of fully rotary built-in steering drilling tool

Figure.2(a) shows a simplified model of fully rotary built-in steering drilling tool, including five mechanisms. 1 is the external eccentric annular, 2 is the inner eccentric annular, 3 is the bearing, 4 is the guide spindle, 5 is the frame. D is the cylinder pair (four-stage pair), E is the sphere-pin pair (four-stage pair), A and B are the revolute pairs (five-stage pair), and C is the spherical pair (three-stage pair). According to the formula [7], we can obtain the degree of freedom of the spatial mechanism. As follows:

$$\begin{aligned}
 F &= 6n - (5p_5 + 4p_4 + 3p_3 + 2p_2 + p_1) \\
 &= 6 \times 4 - (2 \times 5 + 2 \times 4 + 1 \times 3) = 3
 \end{aligned}
 \tag{1}$$

4. Kinematic analysis

Fully rotary built-in steering drilling tool generates eccentric vector by changing relative position of inner and external eccentric annulars and changes spatial attitude of drill [8]. Kinematics characteristic analysis is the theoretical basis of steering drilling, and the kinematic parameters could provide reference for the control theory of well trajectory.

The geometric centers of inner and external eccentric annular and eccentric annulus are O_2 , O_1 and O , respectively. θ_1, θ_2 denote the rotation angles of inner and external eccentric annulus. e represents the magnitude of eccentricity vector. The angular velocities are ω_1 and ω_2 , and the angular velocity of the rotary outer casing is ω . The distance between guide section A and eccentric annulus is l , and the distance between guide section and drill is l_1 . $\vec{O_1O}$ denotes the eccentricity vector, its magnitude is ρ , the angle between the guide sector and the X-axis is θ , the angle between the projection of the guide axis on the xO_1y plane and the X-axis is α . Establish the spatial coordinate system as shown in Figure 3.

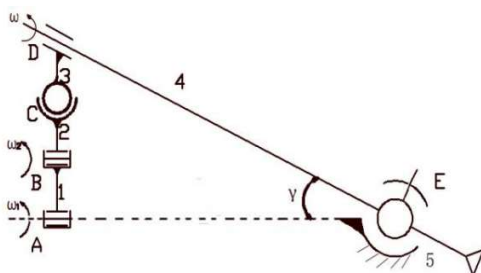


Figure 2. Spatial mechanism model

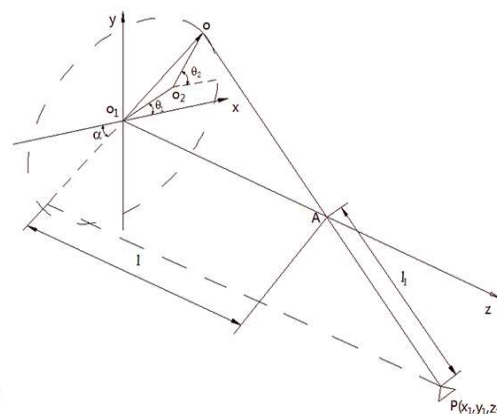


Figure 3. Spatial location diagram of drilling tool

The coordinate of point O is:

$$\begin{cases} x = e(\cos \theta_1 + \cos \theta_2) \\ y = e(\sin \theta_1 + \sin \theta_2) \end{cases} \quad (2)$$

It can be converted to polar coordinate as follow:

$$\begin{cases} \rho = 2e \cos\left(\frac{\theta_2 - \theta_1}{2}\right) \\ \theta = \frac{\theta_1 + \theta_2}{2} \end{cases} \quad (3)$$

The space coordinate P(x1, y1, z1) of the drill can be expressed as:

$$\begin{cases} x_1 = \frac{\rho l_1 \cos \alpha}{\sqrt{\rho^2 + l^2}} \\ y_1 = \frac{\rho l_1 \sin \alpha}{\sqrt{\rho^2 + l^2}} \\ z_1 = l + l_1 \frac{l}{\sqrt{\rho^2 + l^2}} \end{cases} \quad (4)$$

because the rotary outer casing rotates relative to the geodetic coordinate system, and its angular velocity is w. Therefore, in the geodetic coordinate system, the coordinates of point O are changed to :

$$\begin{cases} \rho = 2e \cos\left(\frac{\theta_2 - \theta_1}{2}\right) \\ \theta = \frac{\theta_1 + \theta_2}{2} - wt \end{cases} \quad (5)$$

In the equations (5), take a derivation of the time t.

$$\frac{d\rho}{dt} = -e(w_2 - w_1) \sin \frac{\theta_2 - \theta_1}{2} \quad (6)$$

$$\frac{d\theta}{dt} = \frac{w_1 + w_2}{2} - w \quad (7)$$

Make $d\rho/dt=0$, $d\theta/dt \neq 0$, the tool angle is constant, and the condition of adjusting the tool face angle is $\omega_1 = \omega_2 \neq \omega$. Let $d\rho/dt \neq 0$, $d\theta/dt=0$, the tool face angle is constant, and the condition of adjusting the tool angle is $(\omega_1 + \omega_2)/2 = \omega$, and $\omega_1 \neq \omega_2$. Then, the condition that the tool angle and the tool face angle are constant is $\omega_1 = \omega_2 = \omega$. the eccentricity $e=10\text{mm}$, $l_1=253\text{mm}$, $l=310\text{mm}$, angular velocity of rotary outer casing $\omega=8/3\pi \text{ rad/s}$. The trajectory curves of drill and eccentric annulus in Rectangular coordinate system under four conditions are obtained by using MATLAB programming, as shown in Figure.4.

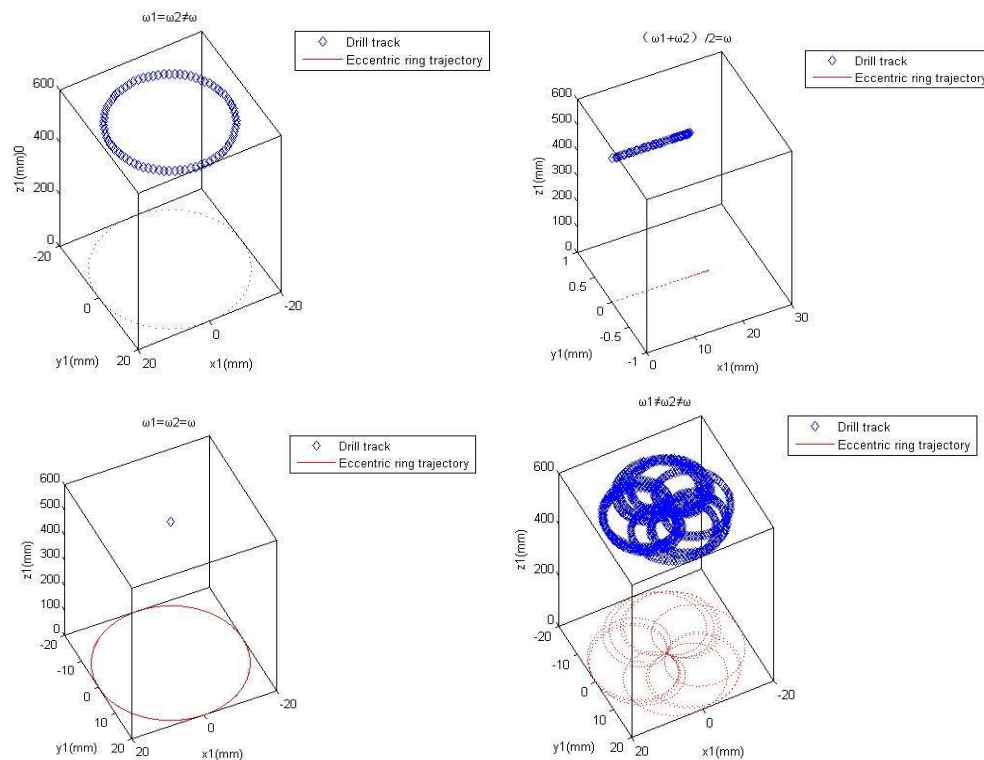


Figure 4. Trajectory curve simulation of drill bit and eccentric ring

According to the trajectory curve of drill, when $\omega_1 = \omega_2 \neq \omega$, the trajectory of the drill is a round on the plane, the trajectory of eccentric annulus is also a round on the plane. As shown in Fig. 4(a), the drill tool works in the adjustment tool face angle mode. when $(\omega_1 + \omega_2)/2 = \omega$ and $\omega_1 \neq \omega_2$, the trajectory of the drill and the eccentric annulus are both a straight line on the plane, as shown in Fig. 4(b), the drill works in adjustment Tool angle mode. when $\omega_1 = \omega_2 = \omega$, the trajectory of the drill is a point in space, and the trajectory of the eccentric annulus is a round on the plane, as shown in Fig. 4(c), the drill works in steady-drilling mode. when $\omega \neq \omega_1 \neq \omega_2$, the trajectory of the drill and the eccentric annulus are both a spiral on the plane, as shown in Fig. 4(d), the drill works in the adjustment tool angle mode.

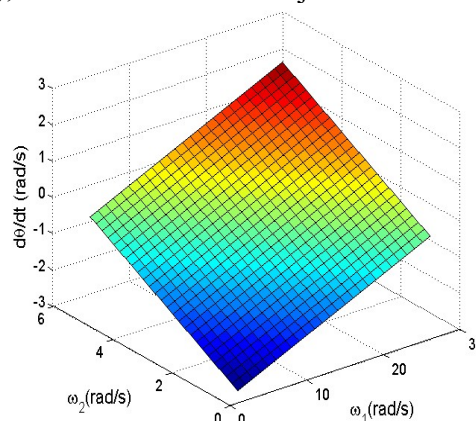


Figure 5. Tool face angle adjustment speed

The adjusting angular velocity of tool face angle is shown in equation (7). The relationship between the angular velocities of the two driving motors and the angular velocities of adjusting the tool face

angle is shown in Fig. 5. From this graph, it can be seen that the adjusting angular velocity of the tool face angle increases with the increase of the angular velocity of the two driving motors, and exhibits a linear correlation. According to $d^2\rho/dt^2=0$, the adjusting angular acceleration of tool face angle is 0. The adjusting tool angle speed is as shown in equation (6), and the adjusting acceleration is as follows:

$$\frac{d\rho^2}{dt_2} = -\frac{1}{2}e(w_2 - w_1)^2 \cos \frac{w_2 t - w_1 t}{2} \quad (8)$$

It can be known from equations (6) and (8) that at a certain determined time, the tool angular adjustment speed and acceleration of the drill can be determined according to the two motor rotational angular velocities ω_1 and ω_2 . The tool angle adjustment speed and acceleration have symmetry in turn for ω_1 and ω_2 . In other words, once ω_1 is set, the tool angular adjustment speed and acceleration change with ω_2 , and ω_2 take the same value as ω_1 .

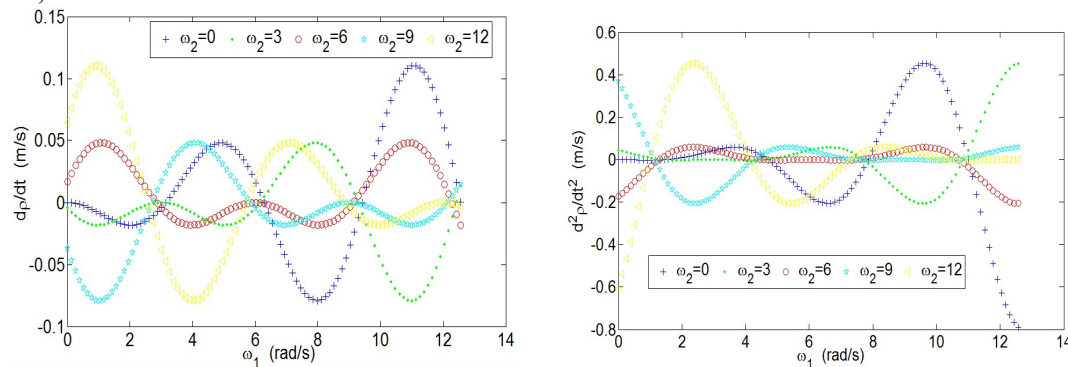


Figure 6. Speed and acceleration of tool angle adjusting

5. Conclusion

In this study, the characteristics and requirements of internal and external eccentric mechanism and steering spindle of fully rotary built-in steering drilling tool are described, the spatial mechanism model and kinematics model of this mechanism are established, besides, the motion characteristics of its trajectory are analyzed.

Based on MATLAB, the trajectory of the drill is theoretically simulated, and the parameters in the equations can be changed arbitrarily. The trajectory of the eccentric mechanism and the drill can be observed intuitively and rapidly. According to the simulation and analysis of drill and eccentric mechanism, the formation process of drill trajectory can be seen intuitively, which has practical guiding significance for actual drilling process.

Through the kinematics analysis of the fully rotary built-in steering drilling tool, the movement track and tool angle, the speed and acceleration of tool face angle adjustment are obtained. The correctness of adjusting conditions of tool angle and tool face angle is verified by kinematics simulation, and the condition of deterministic motion and the correctness of motion principle of the drilling tool designed are explained.

Acknowledgments

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References

- [1] JIANG Wei,JIANG Shiquan,FU Xinsheng.Application research and development of rotary steering drilling technology[J],Natural Gas Industry,2013,04:75-79.
- [2] JIANG Wei,JIANG Shiquan,SHENG Limin.Research and application of rotary steering drilling tool system[J].Oil drilling process,2008,30(05): 21-24.
- [3] XIONG Jiyou,WEN Jiewen,RONG Jiguang.New progress in research on rotary steerable drilling technology[J].Natural Gas Industry,2010,30(4):87-90.
- [4] LIU Xinhua,DONG guanghua,ZHAO Hongshan.Rotary guided downhole tool control system design and laboratory test[J].Oil drilling technology,2011,39(5) : 86-90.
- [5] JUNICHI S, STEVE J. Rotary Steerable System Enhances Drilling Performances on Horizontal Shale Wells [J]. SPE 131357, 2010.
- [6] ZHANG Guangwei.Development status of controllable bending joints based on rotary directional drilling[J].Drilling process,2009,32(2):23-25.
- [7] SUN Huan.Mechanical principle[M].Bei Jing:Higher education press,2006.
- [8] WANG Keke.Design and simulation analysis of closed loop controllable bending joints[D].Xi 'an Shiyou University,2013.