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Control technique on navigating path of intersection between two horizontal wells

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A B S T R A C T

The intersection between two horizontal wells is a form of U-shape well. Being efficient, economical, advanced and environmentally friendly, it holds broad application prospects in exploitation of resources and crossing of pipe lines and tunnels under rivers. However, it is very difficult to achieve intersection between two horizontal wells by conventional techniques due to borehole position uncertainty. In order to solve this problem, control technique on navigating path was put forward. It mainly consists of position locating technique, profile design method, trajectory control method and relative position error analysis. Firstly, the measurement of relative position between the bit and the intersection point was carried out by RMRS in closed-loop mode rather than traditional open-loop mode. Then the profile of the intersection between two horizontal wells was designed according to the ranging scope of RMRS, guide process and borehole position uncertainty. After that the trajectory control model in the intersecting process was established on the basis of an analogy between the intersection of the two horizontal wells and the plane landing process. Finally, the relative position error analysis was carried out according to the guide process of RMRS. The development of control technique on navigating path make it more feasible to achieve intersection between two horizontal wells, which will have a great reference value for in-depth study and field application in the future.

1. Introduction

U-shaped wells technology means to connect two or more wells, which are hundreds of meters away from each other on the ground, hundreds or even thousands of meters underground using directional drilling and horizontal drilling technology (Gao et al., 2011). It is mainly used in exploitation of salt mineral (Peng et al., 2009), heavy oil (Poloni et al., 2010; Nie et al., 2012; Ibatullin et al., 2009), coal-bed methane (Cunnington and Hedger, 2010; Shen et al., 2012; Zhang et al., 2013), alkaline mineral, underground gasification mining of coal bed (Liu et al., 2005) and crossing of pipe lines and tunnels under rivers etc. It has been proved by practices that: the application of U-shaped wells technology can increase the production rate, recovery ratio and decrease the cost; U-shaped wells technology works better than others in extracting heavy oil; U-shaped wells technology is an important potential access to develop gas hydrate; U-shaped wells technology or similar technologies must be used to cross pipe lines and tunnels under rivers (Mullin et al., 2013; Li and Dai, 2008).

The U-shaped wells can be divided into three types according to types of the two wells connected: intersection between a horizontal well and a vertical well, intersection between a horizontal well and a directional well and intersection between two horizontal wells. The object of this study is the last one. In order to solve the problem of low intersection accuracy between two horizontal wells, control technique on navigating path of intersection between two horizontal wells is put forward as follows: a technique confirming the relative position between two wells by collecting information from a target well in an intersection well or in the other way around to guide an intersection well to joint with a target well accurately. This technique mainly consists of position locating technique, profile design method, trajectory control method and relative position error analysis.

A detailed theoretical analysis about the main content of control technique on navigating path of intersection between two horizontal wells and corresponding examples will be given in this article.

2. Position locating technique

Measuring tools are essential to achieving accurate connection of two wells underground. As a traditional measurement tool,

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MWD cannot meet this demand due to the measurement accuracy and its lag, uncertainty of target connection and calculation error of trajectory measurement (Lee and Brandao, 2005). Therefore, the magnetic ranging tool is introduced to achieve a connection mechanically and hydraulically between two wells in the final stage. Rotating magnetic ranging system (RMRS) is chosen to measure the relative position after an analysis of existing commercial magnetic ranging tools (Kuckes et al., 1996; Oskarsen et al., 2009; Al-Khodhori et al., 2008).

2.1. Working principle

RMRS mainly consists of a magnetic sub, a probe and a ranging software. It is able to detect the distance between two adjacent wells while drilling and control the trajectory of complex-structure wells accurately. RMRS for Intersection between two horizontal wells is shown in Fig. 1. The magnetic sub near the bit is a short non-magnetic drill collar embedded with several permanent magnets perpendicularly. It rotates with the drill string to generate the alternating magnetic field which serves as magnetic source of RMRS. The probe consists of a sensor package composed of a tri-axial fluxgate sensor and a tri-axial accelerometer sensor. It is used to detect the direction it points in the wellbore and the induction density of alternating magnetic field generated by rotating magnetic sub (Diao et al., 2012). After calculating the relative position with ranging software based on the magnetic signal data, the horizontal wells can be accurately connected by continuously adjusting the trajectory.

2.2. Calculation of the relative position

As shown in Fig. 2, three coordinate systems are established. *O*–*NED* is a geodetic coordinate system, where *O* is the origin, *N* points north, *E* points east and *D* points to the geocenter. Taking *p*, the center point of magnetic sub which can be regarded as the current bottom hole, as the origin, the right-hand Cartesian coordinate system *p-xyz* can be established at the bottom hole, where *z* points to the drilling direction, *x* points to the high-side direction of the wellbore and *y* is determined by the right-hand rule. Taking *t*, the intersection point, as the origin, the right-hand Cartesian coordinate system *t-XYZ* can be established, where *Z* points to the extension direction of the horizontal well, *X* points to the high-side direction of the wellbore and *Y* is determined by the right-hand rule.

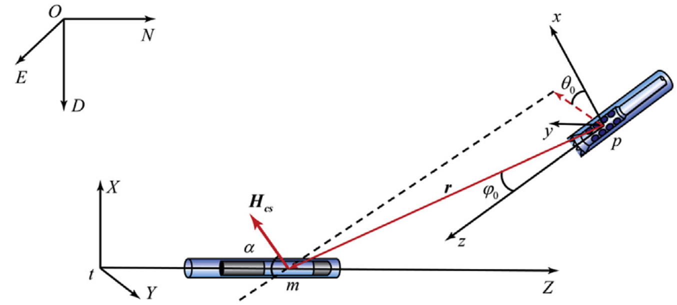

Fig. 2. Establishment of coordinate systems.

$m(r,\theta_0,\varphi_0)$, the center point of probe, measured by RMRS is the position of the measure point *m* in the local coordinate system *p-xyz*, where *r* is the relative distance, *m*; θ_0 is the relative tool face, (°); and φ_0 is the relative azimuth, (°).

α is the angle between $\mathbf{H}_{cs}$ and *z*-axis, then:

$$\tan\alpha = \frac{\sqrt{H_{csx}^2 + H_{csy}^2}}{H_{csz}} = \frac{3\sin 2\varphi_0}{3\cos 2\varphi_0 - 1} \tag{1}$$

where $\mathbf{H_{csx}}$, $\mathbf{H_{csy}}$ and $\mathbf{H_{csz}}$ represent components of the reference field $\mathbf{H}_{cs}$ in *x*, *y* and *z*-axis respectively.

$$\tan\ \theta_0 = \frac{H_{csy}}{H_{csx}} \tag{2}$$

The magnetic field at any point $m(r,\theta_0,\varphi_0)$ is elliptically polarized due to the dynamic rotation. The relationship between the minimum magnetic field strength and the distance *r* is expressed as follows:

$$r = \sqrt[3]{M/4\pi H_{min}} \tag{3}$$

The relative distance *r*, relative azimuth φ_0 and relative tool face θ_0 between any point and the origin in the rotating magnetic dipole coordinate system can be determined by Eqs. (1)–(3).

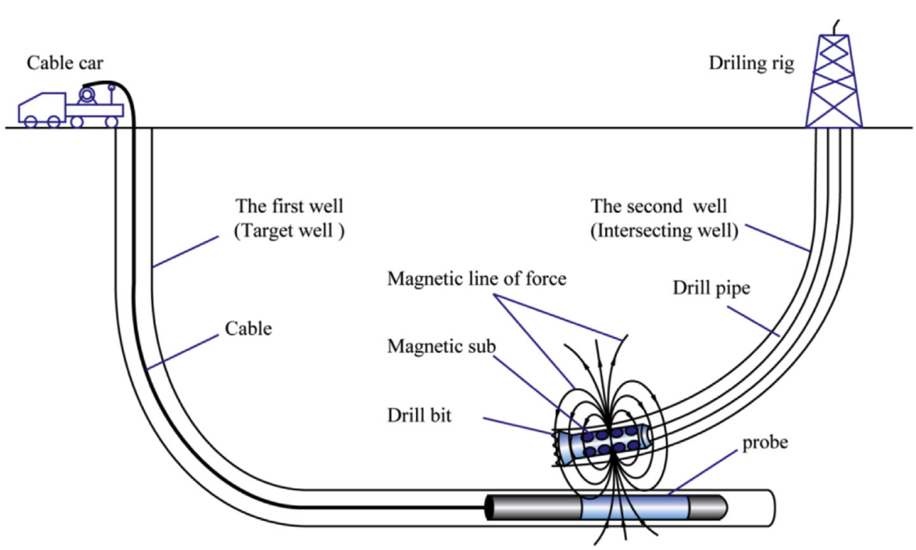

Fig. 1. Operational view of RMRS for Intersection between two horizontal wells.