Journal of Natural Gas Science and Engineering 22 (2015) 656–660

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse

A new orientation design model and numerical solution for coiled tubing drilling

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ARTICLE INFO

Article history:
Received 16 July 2014
Received in revised form
10 December 2014
Accepted 1 January 2015
Available online 14 January 2015

Keywords:
Coiled tubing drilling
Orienter
Tool face adjustment
Constraint equation
Numerical solution

ABSTRACT

Coiled tubing cannot be rotated in the wellbore from the surface, thus, an orienter is used to steer it in the proper direction. Due to the limits of rotation mode, bottom hole assembly (BHA) can only be rotated in increments in one direction at a fixed angle. As a result, the actual tool face angle is not equal to the design angle in most cases. The difference in the angle will affect the coincidence rate of the drilling trajectory, potentially causing orientation failure. The traditional method for adjusting the weight on the bit (WOB) is to eliminate the angle deviation. However, the change in the WOB is completely dependent on the expertise of the directional engineer and the formation parameters. This dependence limits the applicability of this adjustment method and increases the uncertainty and construction risks during the drilling process. To solve this problem, a new two-arc orientation design model is proposed that meets the orientation requirements and is easy to operate on site. Compared with the traditional experience-based method, this new method avoids uncertainty from human factors and can be programmed for automated drilling.

1. Introduction

Conventional directional drilling with a drill string of jointed pipes occasionally requires the drill string to be turned at the surface to generate torque at the bottom. Thus, it is necessary to orient the bent sub to control the tool face angle and guide the wellbore trajectory in the desired direction. The high rigidity of the conventional drill string allows the torque to be transmitted. An attractive alternative to drill string is coiled tubing (Crouse and Lunan, 2000). Coiled tubing has a relatively small size 1–1/4 to 4–1/2 inches in diameter (Sarvesh et al., 2011), and a thin wall cross section of approximately 5/32 inches, which makes it flexible enough for many thousands of feet to be wound on a reel that is only 9–10 feet in diameter. Coiled tubing is advantageous over conventional drill string in that it can be run into and out of a well rapidly because there are no threaded joint connections to link up or break down. In addition, the absence of threaded connections allows coiled tubing to be run while under pressure and while fluids are being pumped through it. However, the reel cannot be rotated in the surface. Thus, when drilling with coiled tubing, neither rotary drilling nor the rotational orientation of the BHA can be accomplished without the use of a special rotating device to orient the BHA. This device, called an orienter (Ronald and Pringle, 1994), allows the directional driller to position the directional assembly in the desired tool face orientation, allowing the wellbore to be drilled in a selected direction.

The BHA used in coiled tubing drilling is controllable, enabling the formation of wellbores along the design trajectory. A typical BHA (Maehs et al., 2005; Pai et al., 2013) includes a drill bit positioned at one end of the coiled tubing to form the wellbore, a bent sub with typically one-half to three degrees for drilling a curved wellbore section, a hydraulic motor that rotates based on the flow of the drilling mud, a measurement while drilling (MWD) device for taking directional measurements and transmitting signals to the surface, and an orienter for changing the tool face angle to direct the bit to drill at a certain heading.

The orienter is operated by pulsing the drilling fluid by cycling the pumps on and off. Each cycle causes the orienter to rotate by an incremental amount to orient the bent sub relative to the direction of the coiled tubing to achieve the desired tool face angle (Bingham, 2000). Different orienter models have different fixed angular increment values. The fixed angle is 20° in the orienter from Sperry-Sun (Gleitman et al., 1996), 25.7° in United States patent 5450914 (Coram, 1995) and 30° in United States patent 7946361

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http://dx.doi.org/10.1016/j.jngse.2015.01.001

(Gurjar et al., 2011).

The angle can be adjusted in multiples of the fixed angle, producing discontinuous changes in the tool face angle jumping (Meek et al., 2002). Thus, coiled tubing drilling and conventional drilling differ dramatically, and the actual adjusted tool face angle is rarely exactly equal to the design angle. For example, if the design tool face angle is 70°, the current angle is 20° and the fixed angle of the orienter is 20°, then the actual angle can be adjusted to 60° (two rotations) or 80° (three rotations). The difference between the adjusted and design angles will affect the coincidence rate of the drilling trajectory, potentially causing orientation failure.

Until now, there is no theoretical method for solving this problem. In construction site, the directional engineer has to control the varying WOB to control the reactive torque (Eddison et al., 1994), which applies lateral forces to the BHA, and thereby changes the borehole direction to eliminate the angle deviation. However, the change in the WOB is completely dependent on the expertise of the directional engineer and the formation parameters. Such experience-based methods are not widely applicable and increase the uncertainty factors and construction risks during the drilling process.

This paper proposes a new two-arc orientation design model. It fully considers the adjustment characteristics of orienter in the design process. The design results can meet not only the angle orientation requirement, but also the practical engineering requirement. The problem of angle deviation is solved theoretically in the orientation process.

2. Two-arc orientation design model

2.1. Assumptions of the model

1. The sliding drilling mode is used to drill and correct the well trajectory in this model. The well trajectory is approximated by the space arc due to its stable deflecting capacity. Thus, the design well trajectory is based on the assumption of the space arc (Liu, 2006)
2. Only one set of BHA is used during orientation. Thus, the build-up rates of the two arcs are equal and known.
3. The well trajectory is continuous.
4. The effects of reactive torque and bit walk are not considered.
5. The value of build-up rate is equal to the value of dogleg severity without considering the formation effect.

2.2. Model foundation

The two basic angle constraint equations for space arc (Han, 2007) are

$$\cos\gamma = \cos\alpha_1\cos\alpha_2 + \sin\alpha_1\sin\alpha_2\cos(\varphi_2-\varphi_1) \tag{1}$$

$$\cos\alpha_2 = \cos\alpha_1\cos\gamma - \sin\alpha_1\sin\gamma\cos\omega \tag{2}$$

where subscripts 1 and 2 are the initial and final points for orientation, respectively. The parameters of the two points are represented by the corresponding subscripts, where α_1 and α_2 indicate the deviation angles of 1 and 2, and φ_1 and φ_2 indicate azimuth angles of 1 and 2, respectively. In the equations, γ is the dogleg and ω is the tool face angle between 1 and 2.

The parameter ω is unknown in the conventional design process and can be solved using Eqs. (1) and (2). Because of the special rotation mode of the orienter in coiled tubing drilling, it is difficult to adjust the actual tool face angle to be exactly equal to the ideal design value ω. As a result, the actual trajectory often cannot achieve α_2 and φ_2. Thus, a new model is needed to design a well trajectory according to the orientation requirement.

The well trajectory of a two-arc orientation design is shown in Fig. 1.

In this design, 0 is the intersection point of the two arcs; the deviation angle α_0 and azimuth angle φ_0 are the angle parameters of 0; γ_1 and ω_1 are the dogleg and tool face angle in the first arc, respectively; γ_2 and ω_2 are the dogleg and tool face angle in the second arc, respectively; and θ is the fixed angle of the orienter.

The well trajectory constraint equations of the model can be obtained from Eqs. (1) and (2) as follows:

$$\cos\gamma_1 = \cos\alpha_1\cos\alpha_0 + \sin\alpha_1\sin\alpha_0\cos(\varphi_0-\varphi_1) \tag{3}$$

$$\cos\alpha_0 = \cos\alpha_1\cos\gamma_1 - \sin\alpha_1\sin\gamma_1\cos\omega_1 \tag{4}$$

$$\cos\gamma_2 = \cos\alpha_0\cos\alpha_2 + \sin\alpha_0\sin\alpha_2\cos(\varphi_2-\varphi_0) \tag{5}$$

$$\cos\alpha_2 = \cos\alpha_0\cos\gamma_2 - \sin\alpha_0\sin\gamma_2\cos\omega_2 \tag{6}$$

2.3. Model solution

2.3.1. Solving for two tool face angles

It is important to define reasonable values for ω_1 and ω_2 based on the special rotation mode of the orienter and the actual drilling situation. The defined formulas are

$$n = [(\omega-\omega_a)/\theta] \tag{7}$$

$$\omega_1 = \omega_a + \theta{*}n \tag{8}$$

$$\omega_2 = \omega_1 + \theta \tag{9}$$

where, ω_a is the actual tool face angle before orientation, and n is an integer by rounding down of Eq. (7), representing the rotation number of the orienter.

For example, when $\omega = 50°$, $\omega_a = 20°$, and $\theta = 20°$, then $\omega_1 = 40°$ and $\omega_2 = 60°$.

2.3.2. Solving for the angle parameters of 0 and two doglegs

Parameters α_1, α_2, φ_1 and φ_2 are known, whereas ω_1 and ω_2 are solved in 2.3.1. There are four unknown parameters in Eqs. (3)–(6): $\alpha_0\varphi_0$,γ_1 and γ_2. The constraint equations are typical nonlinear transcendental equations. Because specific expressions for the unknown parameters cannot be derived to obtain an analytical

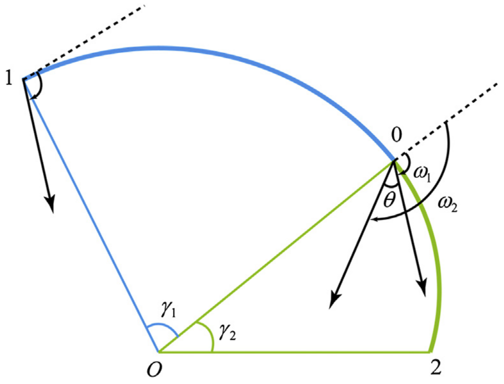

Fig. 1. Well trajectory of a two-arc orientation design.