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Comparison of the directional survey calculation methods applied on real well data

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ABSTRACT

Directional surveys have been around since the beginning of drilling in the oil and gas industry. The tools have constantly been changing during the years, which cannot be said for the calculation methods. The most common directional survey calculation methods were compared in this paper. The methods were compared with the introduction of relative differences, where each or every second, every third, or every fifth survey station is taken into consideration. The results were plotted graphically over the length of the wellbore. They were also visualized. The tangential method was found to be inappropriate for its use in any circumstances. The average angle method or balance tangential method should be used for field application whereas the helical arc method is recommended for computer calculations.

1. Introduction

Since the first commercial wells were drilled, directional surveys have been used in the oil and gas industry. In the beginning, mostly vertical wells were drilled but after the improvement of technology and increase in knowledge took place, more deviated wells were drilled. Due to the complexity of the reservoirs and geological challenges, wells are nowadays rarely drilled vertically but are rather in a deviated, horizontal, "S" shape or any shape which is needed to maximize the drilling efficiency and reservoir recovery. The wells have become very complex and, therefore, good directional survey tools and methods are needed.

At first, magnetic survey instruments were used. Those were mostly used to ensure that the well is not deviated from the planned vertical trajectory. After that, gyroscopes were used, and other advanced instruments have come into use in the last few decades. The tools work on different principles, but they provide the same two major pieces of information: the azimuth and the inclination. With the measured depth known at any time, the number of measurements is sufficient to determine each of the survey station's coordinates with the help of a directional survey calculation method.

Choosing the right method to calculate the well trajectory is an important issue concerning not only directional drillers, but the industry and companies as well. The use of a wrong directional survey method may result in higher costs, not hitting the pay zone or hitting the offset well. Therefore, an appropriate method should be used.

The directional survey methods used in this paper are the most common methods which can be found in literature. Wilson [1] proposed the radius of curvature method and compared it with tangential methods. The balanced tangential method was published a few years later [2]. The minimum curvature method was improved and became convenient for use [3]. An improved angle average method was proposed by Ruqjang [4]. Lastly, the helical arc method, which was proposed by Callas, is also used [5].

One of the motivations to write this paper was the lack of proper comparisons between the methods. There is often a confusion regarding which method to use for field application and which one for computer calculations. Therefore, the purpose of this paper is to help with the decision making process. The tangential, balanced tangential, average angle, minimum curvature, radius of curvature, and helical arc method are compared in the paper.

If measurements are taken close enough, the choice of the method is not as crucial. However, surveys are rarely taken very closely because of high costs. The paper represents the comparisons of four scenarios: if each or every second, every third or every fifth survey station is used.

2. Material and methods

Six methods were used and their equations will be provided in this chapter.

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2.1. Tangential method

This is the simplest method which was used in the industry for many years. The method assumes that the wellbore course of the segment has a constant inclination and azimuth, as they are at the lower survey station. The inclination and azimuth from the upper survey is not considered [6].

If the section length is considered as $\Delta MD = MD_i - MD_{i-1}$ then the equations can be written as follows [6]:

$$\Delta TVD = \Delta MD_i \cos I_i \tag{1}$$

$$\Delta North = \Delta MD_i \cos A_i \tag{2}$$

$$\Delta East = \Delta MD_i \sin I_i \sin A_i \tag{3}$$

where I_i and A_i are the inclination and the azimuth at the survey station of interest, respectively.

2.2. Average angle method

The average angle method has been used worldwide and it was developed as an alternative for the tangential method. The method simply averages the angles of inclination and the azimuth at both survey stations. This is then a well path with a length equal to the actual course length between the two stations. The coordinates can be determined as follows [6]:

$$\Delta North = \Delta MD_i \cdot \sin \frac{I_{i-1} + I_i}{2} \cdot \cos \frac{A_{i-1} + A_i}{2} \tag{4}$$

$$\Delta East = \Delta MD_i \cdot \sin \frac{I_{i-1} + I_i}{2} \cdot \sin \frac{A_{i-1} + A_i}{2} \tag{5}$$

$$\Delta TVD = \Delta MD_i \cdot \cos \frac{I_{i-1} + I_i}{2} \tag{6}$$

2.3. Balanced tangential method

The balanced tangential method is a modified tangential method and it takes the direction of the upper station for the first half of the course length, then the one of the lower station for the second half. It can substantially reduce the errors in that method. Because of this modification, the method is known as the balanced tangential method. The method is very simple and therefore has been widely used in the fields. The change in departure components is defined by following equations [7]:

$$\Delta TVD = \Delta MD_i (\cos I_{i-1} + \cos I_i) \frac{1}{2} \tag{7}$$

$$\Delta North = \Delta MD_i (\sin I_{i-1} \cos A_{i-1} + \sin I_i \cos A_i) \frac{1}{2} \tag{8}$$

$$\Delta East = \Delta MD_i (\sin I_{i-1} \sin A_{i-1} + \sin I_i \sin A_i) \frac{1}{2} \tag{9}$$

2.4. Radius of curvature method

In this method, the wellbore is assumed to be a smooth curve in either or both the vertical and horizontal projections. Each segment of the measured depth is defined by data obtained at both ends of the segment [1].

Full derivation of the method can be seen in Appendix A. The final equations yield:

$$\Delta TVD = \Delta MD_i \mathrm{sn}I_- \cos I_+ \tag{10}$$

$$\Delta North = \Delta MD_i \mathrm{sn}I_- \sin I_+ \mathrm{sn}A_- \cos A_+ \tag{11}$$

$$\Delta East = \Delta MD_i \mathrm{sn}I_- \sin I_+ \mathrm{sn}A_- \sin A_+ \tag{12}$$

2.5. Minimum curvature method

The method assumes a curved wellbore over the course length by fitting a spherical arc between two points by calculating the dogleg curvature from the 3D vectors and scaling it by a ratio factor [8].

The ratio factor can be defined as [6]:

$$FC = \frac{2}{D_2 + (D_2 = 0)} \tan\left(\frac{D_2}{2}\right) \tag{13}$$

And the change in departure components can be determined as follows:

$$\Delta TVD = \frac{\Delta MD_i}{2} FC_i (\cos I_{i-1} + \cos I_i) \tag{14}$$

$$\Delta North = \frac{\Delta MD_i}{2} FC_i (\sin I_i \cos A_i + \sin I_{i-1} \cos A_{i-1}) \tag{15}$$

$$\Delta East = \frac{\Delta MD_i}{2} FC_i (\sin I_i \sin A_i + \sin I_{i-1} \sin A_{i-1}) \tag{16}$$

2.6. Helical arc method

The helical arc method assumes that the actual borehole segments are closely approximated by the right helical arcs that are an exact fit to the end points of segments. To fit a helical arc connecting k and $(k+1)$ points of a borehole, directional data at three successive points must be taken. Therefore, the method can be considered as a three-point integration method [5].

The desired iteration equation for computing successive helical departures is defined as [5]:

$$P_{k+1} = P_k + S(D_x, D_y, D_z), \quad k = 1, 2, \ldots, n-1 \tag{17}$$

If the vector $\overrightarrow{W} = (V_x, V_y, V_z)$ is a corresponding cylinder of k-th helical arc and S is the inverse transformation of T, then the final departure components are as follows:

$$S(D_x) = \left(V_x V_z D_x + V_y D_y + V_x D_z \sqrt{(1 - V_z^2)}\right) \Big/ \sqrt{(1 - V_z)^2} \tag{18}$$

$$S(D_y) = \left(V_y V_z D_x + V_x D_y + V_y D_z \sqrt{(1 - V_z^2)}\right) \Big/ \sqrt{(1 - V_z)^2} \tag{19}$$

$$S(D_z) = -D_x \sqrt{(1 - V_z)^2} + V_z D_z \tag{20}$$

X – axis is defined as north, Y – axis as east and Z – axis as the depth of a wellbore.

Please notice, that when the inclination is constant, $U_{3,i}$ will be constant, which means that $D_{3,k}$ is going to be zero. Furthermore, values u and v, which are needed to calculate vector $\overrightarrow{W}$, will equal zero as well. Because of that, the vector $\overrightarrow{W}$ will be (0, 0, 1) at any given point. Consequently, the transformation vectors $T(\overrightarrow{U}_k)$ and $T(\overrightarrow{U}_{k+1})$ cannot be calculated because division with zero occurs.

The problem is easily solvable, since a transformation of any arbitrary vector with the vector (0, 0, 1) yields the same arbitrary vector. In this case, $T(\overrightarrow{U}_k) = \overrightarrow{U}_k$ and $T(\overrightarrow{U}_{k+1}) = \overrightarrow{U}_{k+1}$. To avoid this problem the "IF" function was used in the calculations. It was set up in a way that if u and v yield zero, the transformation of the directional vector yields the directional vector.

2.7. Relative differences between the methods

The main goal of the paper is to compare the methods between each other. There are many possible solutions to do so, but in this paper relative differences were used. First, the difference between each method coordinates (North, East, TVD) were calculated. The six methods are compared and therefore fifteen possible combinations exist.

The above differences yield a vector of differences between two methods. From this vector, the length of it can be calculated as: