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RESEARCH PAPER

A true three-dimensional wellbore positioning method based on the earth ellipsoid

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Abstract: In view of the problems existing in the current wellbore positioning method, a true three-dimensional wellbore positioning method was presented, and an example for analysis was given. The current positioning method uses the grid north as the reference datum to the north, positions in the horizontal plane based on the map projection coordinates, and positions in the vertical direction based on the elevation coordinates. It has inherent defects and errors, as the two positioning methods above are independent of each other, and only use the constant meridian convergence and constant magnetic declination at the wellhead to calculate the borehole trajectory for the whole well. Based on the earth ellipsoid and its calculating principle, the transformation relationship between the wellhead coordinate system, geodetic coordinate system and elevation coordinate system was revealed, and the true three-dimensional wellbore positioning method using the true north as the reference datum to the north was presented. Analysis results of an example show that the current positioning method yields a smaller vertical depth and a larger horizontal displacement for the target, and produces larger errors compared with the true three-dimensional positioning method. The true three-dimensional positioning method has fundamentally solved the problems existing in the current positioning method, accurately positioning the relative location between the target and the wellhead, and significantly improves the accuracy and reliability of borehole trajectory design.

Key words: drilling theory; directional drilling; wellbore trajectory; wellbore positioning

Introduction

The core technology of directional drilling including wellbore trajectory design, monitoring and control. During the design process of borehole trajectory, the position of the wellhead and the target should be determined first, and then the parameters of the target relative to the wellhead, such as true vertical depth and horizontal displacement, et al. can be calculated[1–3]. In the process of borehole trajectory monitoring and control, the coordinates of borehole trajectory in space also need to be calculated at any time to reach the expected target. These are all wellbore positioning issues.

To meet the needs of borehole trajectory design, monitoring and control, drilling engineers usually build a three-dimensional Cartesian coordinate system considering the wellbore to be the origin with due north, due east and vertical axes, known as the wellhead coordinate system. At present, the borehole positioning by a method combining horizontal plane positioning and vertical direction positioning is commonly used both in China and oversea. In the wellhead coordinate system, the target north and east coordinates equal to the difference values of ordinate coordinates and abscissa coordinates by map projection between the target and the wellhead respectively, and the target vertical depth equal to the elevation difference between the wellhead and the target [1–3].

However, the current wellbore positioning method has some obvious flaws. For example, there is projection distortion when the earth ellipsoid is projected onto a plane, so the map projection coordinates inevitably have errors; positioning on the horizontal plane and the vertical direction are unrelated, different vertical wells remain parallel to each other forever in vertical direction, but in fact they should be more and more close and intersect in the vicinity of the earth center.

At present, the research on wellbore positioning mainly focuses on the uncertainty of wellbore trajectory[4–9], and the target positioning relative to the wellhead has been studied little. Williamson et al.[10] used the variable scale factor to calculate the map projection coordinates to reduce the error caused by distortions of map projection, but did not include the improvement method of other defects. Based on the earth ellipsoid and calculating principle, a true three-dimension wellbore positioning method is presented in this paper, which can avoid the distortion caused by map projection and maintain the coordination between vertical positioning and hori-

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zontal plane positioning. The presented method can fundamentally eliminate the defects of the current positioning method, and accurately position the relative position between the target and the wellhead.

1. Current positioning method

1.1. North reference

The wellhead coordinate system is the basis for design and monitoring of wellbore trajectory, its primary task is to determine the north reference. Directional drilling involves three references of north, the true north, map projection coordinate north and magnetic north. The true north points to the geographic North Pole, the map projection coordinate north (also referred to as grid north) points to the positive direction of the longitudinal axis on the map projection plane, such as Gauss projection, UTM (Universal Transverse Mercator) projection, and the magnetic north points to the magnetic North Pole. In the wellhead coordinate system, the vertical depth axis along the direction of gravity line points to the center of the earth, so the selected north reference will determine the direction of the north and east axes. In addition, the north reference also is the calculation datum of azimuth angle, the azimuth angles corresponding to the three north references are called the true azimuth angle, coordinate azimuth angle (also known as the grid azimuth angle) and magnetic azimuth angle respectively[11–13]. The relationship between the three azimuth angles is shown in Fig. 1.

Since the magnetic North Pole changes over time, the magnetic north is not a suitable north reference, otherwise it will cause inconvenience to wellbore anti-collision, old-well sidetrack drilling and oilfield development[11–13]. In theory, both the true north and the coordinate north (grid north) can be used as the north reference. As the target north and east coordinates are easily determined at the wellhead coordinate system according to the map projection coordinates, which can be used directly to design wellbore trajectory, so the grid north is commonly used as the north reference nowadays.

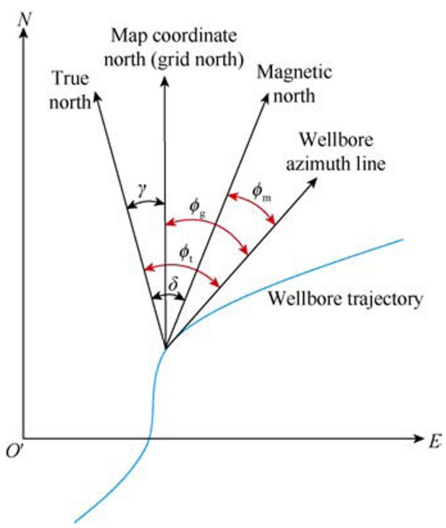

Fig. 1. North reference and azimuth angle.

1.2. Target positioning method

During the design of wellbore trajectory, the target position relative to the wellhead should be determined first. The current positioning method determines the target space coordinates in the wellhead coordinate system by the horizontal plane and vertical direction positioning respectively[1–3]. Positioning in the vertical direction is used to determine the target vertical depth, which is the elevation difference between the wellhead and the target. Positioning on the horizontal plane is used to determine the target coordinate parameters, such as north and east coordinates. The positioning method and steps are as follows: (1) project the wellhead and the target onto the earth ellipsoid surface along the normal line of the earth ellipsoid respectively, and get the geodetic coordinates (L, B); (2) according to the map projection principle and method, project the wellhead and the target onto the map projection plane respectively, and get their coordinates on the projection plane(x, y)[14–16]; (3) the north and east coordinates of the target relative to the wellhead are the differences of ordinate x and abscissa y between target and wellhead respectively on the map projection plane; (4) calculate the parameters like horizontal displacement and closure azimuth et, al. of the target with the target north and east coordinates.

The borehole trajectory can be designed after the target space coordinates in the wellhead coordinate system are determined. It is important to note that the north reference is the grid north at this point.

2. Problems existing in the current positioning method

2.1. Positioning in the horizontal plane and vertical direction

In the wellhead coordinate system, the plane constituted by the north and east axes is regarded as a horizontal plane. However, the geoid is the sea surface assuming the oceans are in perfectly still and balanced state, and it is a closed surface extending to the continent interior and surrounding the entire earth. The modeling earth ellipsoid requires the ellipsoid size and shape to best match the geoid in the studied area[14]. That is to say, the geoid is close to ellipsoid, not flat. In a small area, the geoid can approximate to a horizontal plane, but the absolutely horizontal plane does not exist.

As shown in Fig. 2, assuming that the geodetic elevation of two points A and C are all zero (on the earth ellipsoid), and they are in the same meridian plane. If two vertical wells at points A and C are drilled respectively, the two wells will be drilled down in parallel according to the current positioning method, but in fact the two wells will become closer and meet in the center of the earth. In particular, if the two points A and C located in the equator and the North Pole respectively, then these two wells should be perpendicular with each other rather than parallel. Obviously, for cluster wells, the current positioning method cannot accurately position the relative positions of the wells.