A Magnetic Distance Measuring System For Drilling Multiple Vertical Wells Simultaneously

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Abstract. With the increasing demand of oil, gas and mineral exploration and development and the development of logging technology, when drilling two or more wells, people need to carry out accurate measurement and positioning. A magnetic distance measurement system diagram for drilling multiple wells simultaneously. This paper presents a magnetic distance measuring system for drilling multiple vertical wells simultaneously. According to the magnetic field data, the geometric relationship between the two BHAS is determined, and the distance and orientation between wells are automatically located to maintain a predetermined geometric relationship, and then simultaneous drilling is realized. The algorithm is simple, the error is within the acceptable range, and it can further improve the efficiency of drilling operation, save time and reduce cost.

1. Introduction

In the field of petroleum exploration, it is a new technology to use weak magnetic field to guide and locate in the 1980s. This method has the characteristics of high data transmission rate, fast measurement and low cost. Because of its good market demand and application prospect, the technology has become a research hotspot of major oil companies at home and abroad, and relevant scholars at home and abroad have also made a lot of research on it. [1]

The application of foreign magnetic field positioning technology in drilling can be traced back to the 1930s and commercialized in the 1980s. As early as 1966, the United States put forward the cable electromagnetic ranging technology, but the cable tools in the casing well need to use the drilling equipment, mud pump, coiled tubing and other tools to push the cable tools forward in the next step of drilling. These driving methods are expensive and need additional equipment, so the efficiency of the technology is very low. [2] With the further research, the measurement methods and algorithms of magnetic field in foreign countries have been improved and developed step by step. In foreign countries, a guiding tool is developed to determine the spatial position of the measurement point and the emission source by using the three-dimensional magnetic field vector measurement of the electromagnetic field / magnetic field source, which has been widely used. [3-7]

In recent years, China has made a preliminary study on magnetic field positioning technology and achieved some results, but due to its late start, it is still in the period of exploration and development. At present, China mainly rents the rotating magnetic field ranging system (RMRS) and the
electromagnetic guidance tool (MGT) to complete the construction of multiple double horizontal wells and connected wells, with remarkable effect. [8-13]

This paper presents a wireless magnetic field positioning technology, which can be used to drill multiple vertical wells simultaneously.

2. Principle model of magnetic distance measuring system

As shown in Fig. 1, a magnetic distance measurement system diagram for drilling multiple wells simultaneously is shown. BHA 10 of well 1 includes bit 11, guide motor 12 and MWD tool 13 to determine well deviation, azimuth and tool face direction. LWD tool 14 provides information for evaluating the formation drilled in the borehole. The system also has an insulation gap 15 located in the drill collar. BHA 20 in well 2 includes bit 21, guide motor 22, MWD tool 23 for telemetry direction and inclination measurement, and triaxial magnetometer in MWD tool 23.

Both well 1 and well 2 have LWD systems, such as periscope15tm, which provide information to evaluate the formation drilled in the borehole. In the process of drilling, the vertical well 1 uses the guide motor to drill according to the position of the geological and geometric structure measured by the while drilling measuring tool, and passes the known current to the insulating gap belt of well 1, generating a magnetic field. The e-pulsetm can be used to generate a 17 amp current with a frequency range from 1 Hz to 50 Hz. The current I (0) of known amplitude, frequency and phase is generated through the insulation gap. The magnetic field measured by the magnetometer of the MWD tool of vertical well 2 is calculated by the algorithm to get the geometric relationship between the two wells. Well 2 is drilled in a specific direction and a specific distance according to the geological and geometric structure measured by the measuring tool while drilling and the geometric relationship between the two wells. During drilling, the triaxial magnetometer of well 2 is near the insulating gap zone of well 1.

When drilling multiple wells, each BHA has an insulating gap and magnetometer, so that each BHA can generate a magnetic field, which can be read by other BHAS. Furthermore, it is not mandatory for one BHA to guide the other. The relative position and direction of the two wells are determined by magnetic ranging.
3. Calculation method of magnetic distance measuring system

When a well is drilled with a conductive water-based mud (WBM), see Figure 2. Current flows from BHA 10 to the bit and radially into the formation along the drill collar. The axial current $I(z)$ decreases approximately linearly with the distance passing through the insulating gap band 15, and is almost zero at bit 11. The current on BHA 10 also decreases with the distance through the insulator gap 15, but usually at a slower rate. The magnetic field $\mathbf{B}(z)$ can be calculated as follows:

$$\mathbf{B}(z) = \frac{\mu_0 [I(z) - I']}{2\pi r} \mathbf{\hat{n}} \times \mathbf{\hat{r}}$$  \hspace{1cm} (1)

Where $I(z)$ represents the distance $Z$ that current flows along the BHA from the insulating gap, $I'$ is the corrected value of current flowing into the formation, $r$ is the distance between the BHA of two wells, $\mathbf{\hat{r}}$ is the unit direction from the BHA of the first well to the BHA of the second well, and $\mathbf{\hat{n}}$ is the unit vector along the axial direction of the BHA of the first well, free space magnetic conductivity $\mu_0 = 4\pi \cdot 10^{-7}$ Henry/m.

When the well is drilled with insulating oil-based mud (OBM), the current of insulating gap zone 15 is basically constant. The magnetic field $\mathbf{B}(z)$ can be calculated as follows:

$$\mathbf{B}(z) = \frac{\mu_0 I(0)}{2\pi r} \mathbf{\hat{n}} \times \mathbf{\hat{r}}$$  \hspace{1cm} (2)

$I(0)$ represents the current passing through the insulating gap, $r$ is the distance between the bottom hole assemblies of two wells, $\mathbf{\hat{r}}$ is the unit vector from the bottom hole assembly of the first well to the bottom hole assembly of the second well, $\mathbf{\hat{n}}$ is the unit vector along the axial direction of the bottom hole assembly of the first well, and the free space permeability $\mu_0 = 4\pi \cdot 10^{-7}$ Henry/m.
As shown in Fig.3(a), it is the relative direction and relative orientation angle of the two wells. The (x, y, z) coordinate system is associated with well 2, where \( \hat{z} \) is a unit vector that aligns with the axis of BHA 20 and points to bit 21. \( \hat{\mathbf{o}} = (0, 0, 0) \) is the coordinate system, located in the magnetometer in MWD tool 23. The unit vector \( \hat{x} \) refers to the horizontal direction to the left. 23 for drilling 2. The unit vector \( \hat{y} \) is along the axis of BHA 10 and points to bit 11. The relative azimuth between the two wells is the angle \( \hat{\varnothing} \), and the angle between the projection of \( \hat{\mathbf{n}} \) in the plane (x, y, 0) and the X axis is \( \theta \).

Place the insulating gap strip 15 in BHA 10 in the plane of magnetometer 23 (z = 0). As shown in Figure 3 (b), the axis of BHA 10 may intersect the plane \( z = 0 \) at the point \( (x_0, y_0, 0) \). For parallel vertical wells, \( y_0 \) should be much smaller than well spacing \( x_0 \). tan \( \gamma = y_0 / x_0 \), so the angle \( \gamma \) is very small.

The radial vector \( \hat{r} \) points from the insulating gap strip 15 to the magnetometer located in MWD tool 23, \( \hat{r} = (-x_0, -y_0, 0, 0) \), \( \hat{r} \) is from 10 to 20. The separation distance between two BHAS is \( r = \sqrt{x_0^2 + y_0^2} \).

The current \( I(0) \) passes through the insulating gap 15 and creates a magnetic field in the magnetometer 23:

\[
\mathbf{B}(\hat{\mathbf{r}}) = \frac{\mu_0 I(0) - r^2}{2\mu_0 r^2} \hat{\mathbf{n}} \times \hat{r}
\]  

(3)

In order to obtain: the distance \( r \) between the two wells, the direction \( \hat{r} \) between 10 and 20, the compensation in the vertical direction \( (y0 \approx y_r) \), the relative orientation between the two wells, \( \theta \) and \( \hat{\varnothing} \). Known parameters: \( I(0) \), \( B_x(\hat{\mathbf{r}}) \), \( B_y(\hat{\mathbf{r}}) \), \( B_z(\hat{\mathbf{r}}) \).

Assuming a small angle, a three-axis magnetometer measures three components, which can be calculated as follows:

\[
B_x = \frac{\mu_0 I(0)}{2\pi r^2} y_0
\]  

(4)

\[
B_y = -\frac{\mu_0 I(0)}{2\pi r^2} x_0
\]  

(5)

\[
B_z = -\frac{\mu_0 I(0)}{2\pi r^2} (x_0 \sin \theta - y_0 \cos \theta) \hat{\varnothing}
\]  

(6)

Calculate the distance \( r \) and relative angle \( \gamma \) between the two wells, and use the above formula to deduce:

\[
x_0 = -\frac{\mu_0 I(0)}{2\pi [1 + (B_x/B_y)^2] B_y}
\]  

(7)

\[
y_0 = -\frac{\mu_0 I(0) B_x}{2\pi [1 + (B_x/B_y)^2] B_y^2}
\]  

(8)

Then the relative distance between the two wells \( r = \sqrt{x_0^2 + y_0^2} \)

(9)

Relative angle \( \gamma = \arctan \left( y_0 / x_0 \right) \)

(10)

Calculate the relative azimuth \( \theta \), \( \hat{\varnothing} \) : firstly, the measured value is measured by magnetometer 23 at \( z = 0 \), so that the relative position of insulating gap band 15 at the point \( (x_0, y_0, 0) \) described above can be obtained; It is assumed that two BHAS are drilling a distance \( \Delta z \) along their path. The measured value of magnetic field is read again at a new position, and then the same calculation is carried out to get the new value of insulating gap band 15 about the X and Y coordinate system of magnetometer 23, i.e. \( (x_1, y_1, \Delta z) \); Two points determine a straight line, \( (x_0, y_0, 0) \) and \( (x_1, y_1, \Delta z) \) can get the relative directions of 10 and 20:

\[
\tan \theta = \frac{y_1 - y_0}{x_1 - x_0}
\]  

(11)

\[
\tan \hat{\varnothing} = \frac{\sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2}}{(x_1 - z_0)^2}
\]  

(12)

Therefore, the information of distance and direction between two BHAS can be obtained.
4. Conclusion

This paper presents a magnetic distance measuring system for drilling parallel horizontal wells simultaneously, which can also be used for drilling multiple horizontal wells at the same time. It can further improve the efficiency of drilling operation, save time and reduce cost; the construction process is simple. In downhole operation, E-PulseTM, a measurement tool while drilling, is used to generate known current, which then generates magnetic field. According to the magnetic field data measured by magnetometer, after a series of calculations, the distance and orientation information between the two wells can be obtained. The algorithm is simple and the result is within the acceptable error range. The magnetic ranging system can be applied to SAGD double horizontal wells and multi wells drilling simultaneously, which has commercial value.

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