

Research Article

Detect Adjacent Well by Analyzing Geomagnetic Anomalies

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Abstract: This study describes a method of determining the position of adjacent well by analyzing geomagnetic anomalies in the drilling. In the experiment, put a casing in the geomagnetic field respectively to simulate 3 conditions, which are vertical well, deviated well and horizontal well. Study the interference of regional geomagnetic caused by casing, summary the law of the regional geomagnetic field anomalies caused by the adjacent casing. Experimental results show that: magnetic intensity distortion caused by deviated well is similar to that caused by horizontal well, but the distortion is different from vertical well. The scope and amplitude of N and E component magnetic intensity distortion will increase with the increase of casing inclination, meanwhile the scope and amplitude of V component distortion will decrease and the distortion value changes from negative to positive to the southwest of adjacent well. Through the analysis of geomagnetic anomalies, the position of the adjacent wells could be determined.

Keywords: Adjacent well, anti-collision, earth magnetic field, geomagnetic anomaly, relief well, well casing

INTRODUCTION

In the drilling process, the intensive well pattern lead to well collision, so we have to location the adjoining well and make anti-collision. When relief well is drilled and wellbore anti-collision is under construction, scanning is a common method to determine the relative position of oil well and operating well, such as minimum distance scanning, horizontal distance scanning and normal plane scanning (Xiushan and Zhangzhi, 1999; Xiushan, 2007; Jiahua *et al.*, 2004; Xiushan and Yinao, 2000; Binbin *et al.*, 2011; Zhiyong, 2007; Zidian and Xiu, 2004; Liejuan *et al.*, 2006; Guoping and Lin, 2010). But these scanning methods are based on accurate well track, which is calculated by the well track parameters. If there is any calculation error, the calculated wellbore trajectory will deviate from the real well trajectory and then the error ellipsoid will appear (Wilson and Brooks, 2001; John, 1990; Brooks and Wilson, 1996; Wolff and De Wardt, 1980; Walstrom *et al.*, 1969), so it is very difficult to judge the location of adjacent well by using the method of scanning, which brings great difficulties to drilling relief well and working on wellbore anti-collision.

In order to calculate well trajectory, it is necessary to use the inclinometer to survey some parameters, such as tool face angle, inclination and azimuth. Commonly used measuring device is magnetic inclinometer. To survey the borehole continuously while drilling, it is

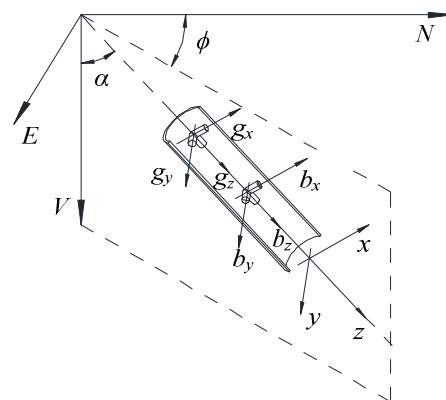


Fig. 1: Wellbore geometry parameter measurement schematic diagram

required to use both of rugged, solid-state triaxial accelerometer and magnetometer. Figure 1 sketches these relationships. Accelerometers measure component of the Earth's gravitational field, while magnetometers measure component of the Earth's magnetic field. In each case the fields are acting in a specific direction and by measuring the orientation of the surveying tool with respect to that direction, the inclination, azimuth and tool-face angle can be determined and the wellbore trajectory can be described by these data (Inglis, 1987). When the operating well is near the oil well, adjacent borehole ferromagnetic casing in the geomagnetic field

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will be magnetized (Aharoni, 2000; Ruigao and Qingzhong, 2003; Zhong and Zhengqin, 2003), which will cause local geomagnetic field anomalies, result in the magnetic measurement parameters abnormal, cause the azimuth distortion and lead to directional operation error and therefore the relative position of adjacent well can be determined by analysis of geomagnetic anomalies. This provides an alternative method to drilling relief well and working on wellbore anti-collision.

Ferromagnetic cylinder magnetized by the geomagnetic produces magnetizing field, which radiates magnetic field. It will be superimposed on geomagnetic in the region, thus cause an obvious distortion of the gentle geomagnetic field around it, The magnetic field produced by the ferromagnetic string is looked on as the interference sources of the geomagnetic field, through the analysis of geomagnetic distortion caused by ferromagnetic string, to determine its distance and azimuth angle and then achieve magnetic field detection.

Study of the magnetic field detection is divided into two parts: the magnetic field distribution of the magnetic interference source, that is, magnetic source is known, find the magnetic field, which is the forward problem of magnetic field. Secondly, according to the distribution characteristics of different magnetic field to eliminate interference and isolate the target body magnetic anomaly data processing. On this basis, explore the way that different magnetic source distribution is determined according to different magnetic anomaly, which is the inverse problem of magnetic anomaly. According to the forward and inversion problems of magnetic anomaly, magnetic interference source distribution model is identified, which is used in magnetic detection.

Analysis of magnetic ranging interference is mainly based on the measured magnetic anomaly to determine the geometric parameters of magnetic body (the position, shape and size) and magnetic parameters (size, direction of magnetization) which causes the magnetic anomaly (Zhining, 2005). According to the theory of static magnetic field, the distribution of the magnetic field is calculated out from the known magnetic substance by using the mathematical tools. Conversely, the magnetic parameters and geometric parameters of magnetic substance are calculated out according to the magnetic anomaly. Only when the magnetic field distribution of different magnetic substances is calculated out and the inherent law between magnetic field characteristics and the magnetic parameters and geometric parameters of magnetic substance is summed up, can these rules be used to make the interpretation on magnetic anomaly. Especially, solving the inverse problem of magnetic and geometric parameters of the magnetic anomaly must be on the basis that forward problem is given, so forward problem is the base of inverse problem.

In order to judge the direction of adjacent well accurately by studying the interference of regional

geomagnetic caused by casing, the experiment simulates vertical, horizontal and deviated well, measures the magnetic field intensity around the casing and summaries the law of the regional geomagnetic field anomalies near the adjacent casing. It is meant to provide theory and guidance for wellbore trajectory control when relief well and wellbore anti-collision are drilled.

MATERIALS AND METHODS

In order to describe the relationship between the geometric parameters of borehole trajectory and the parameters, which is surveyed by accelerometers and magnetometers, what should be done is to establish earth coordinate system and instrument coordinate system respectively. As is shown in the figure, the earth coordinate system is O-NEV and N, E, V axis respectively point north, east and the center of the earth. The inclinometer coordinate system is o-xyz. The borehole axis direction is z axis of instrument; the x axis is perpendicular to the Z axis and points to the direction of bending tool. Then the y axis direction is determined according to the right-hand rule. Accelerometers and magnetometers are respectively installed along the three axes direction of instrument coordinate. Figure 1 shows the schematic diagram of the coordinate:

$$T_{\phi} = \begin{bmatrix} \cos \phi & \sin \phi & 0 \\ -\sin \phi & \cos \phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$T_{\alpha} = \begin{bmatrix} \cos \alpha & 0 & -\sin \alpha \\ 0 & 1 & 0 \\ \sin \alpha & 0 & \cos \alpha \end{bmatrix} \quad (2)$$

$$T_{\omega} = \begin{bmatrix} \cos \omega & \sin \omega & 0 \\ -\sin \omega & \cos \omega & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

$$B_1 = [0, 0, B_0]^T \quad (4)$$

$$B_{NEV} = [B_N, B_E, B_V]^T \quad (5)$$

$$b_{xyz} = [b_x, b_y, b_z]^T \quad (6)$$

$$T_I = \begin{bmatrix} \sin I & 0 & \cos I \\ 0 & 1 & 0 \\ -\cos I & 0 & \sin I \end{bmatrix} \quad (7)$$

$$T_\delta = \begin{bmatrix} \cos \delta & -\sin \delta & 0 \\ \sin \delta & \cos \delta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (8)$$

$$B_{NEV} = T_\delta T_I B_1 \quad (9)$$

$$b_{xyz} = T_\omega T_\alpha T_\phi B_{NEV} \quad (10)$$

Eq. (11) is derived by Eq. (1) to (10):

$$B_{NEV} = \begin{bmatrix} B_N \\ B_E \\ B_V \end{bmatrix} = \begin{bmatrix} b_x (\cos \omega \cos \alpha \cos \phi - \sin \omega \sin \phi) + b_y (-\sin \omega \cos \alpha \cos \phi - \cos \omega \sin \phi) + b_z (\sin \alpha \cos \phi) \\ b_x (\cos \omega \cos \alpha \sin \phi + \sin \omega \cos \phi) + b_y (-\sin \omega \cos \alpha \sin \phi + \cos \omega \cos \phi) + b_z (\sin \alpha \sin \phi) \\ b_x (-\cos \omega \sin \alpha) + b_y (\sin \omega \sin \alpha) + b_z (\cos \alpha) \end{bmatrix} \quad (11)$$

where,

- ϕ = Wellbore azimuth angle, degrees
- α = Wellbore angle of inclination, degrees
- ω = Tool-face angle, degrees
- δ = Magnetic declination, degrees
- I = Magnetic inclination, degrees
- T_ϕ = Matrix of ϕ
- T_α = Matrix of α
- T_ω = Matrix of ω
- T_δ = Matrix of δ
- T_I = Matrix of I
- B_N = North component of the earth's induction field
- B_E = East component of the earth's induction field
- B_V = Vertical component of the earth's induction field
- b_x = x component of magneto static induction field measured by inclinometer
- b_y = y component of magneto static induction field measured by inclinometer
- b_z = Axial component of magneto static induction field measured by inclinometer
- B_0 = Geomagnetic field intensity
- B_1 = Magnetic matrix measured by inclinometer while clinometer axis collinear with geomagnetic direction

Experimental program: The experiment study focuses on the influence of casing on the earth's magnetic field, with inclinometer measuring the geomagnetic field parameters around casing pipe. The inclinometer is fixed on a wooden structure inclinometer bracket and casing moves centering on inclinometer, with the wooden structure turntable clamping the casing pipe. Casing is perpendicular to the radius of circle with in clinometer as the center. The Angle, which forms

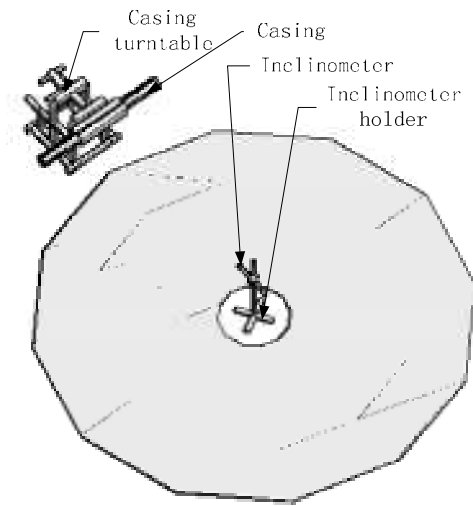


Fig. 2: The experimental apparatus schematic 1

between casing and the inclinometer, is called the relative azimuth Angle. The angle between the axis of the casing axis and the gravity is called casing inclination angle. In the experiment casing inclination is taken as 0° 30° 45° 60° 75° 90°.

The experimental device consists of four parts, as shown in Fig. 2:

- Wooden structure turntable, used to grip and control the casing inclination angle
- Wooden structure holder, clamping inclinometer, maintaining a fixed posture
- Casing as geomagnetic disturbance sources in the experiment, experiment selecting 2 m 7 inch N80 casing pipe
- Measuring instrument using YSS-32 type electronic multi-shot, it is utilized to store relevant data

RESULTS AND DISCUSSION

The data analysis: The measurement of the magnetic field intensity consists of two parts (Zhining, 2005; Ge, 2002), which are geomagnetic and interference magnetic field intensity and interference magnetic field is caused by casing in the geomagnetic. The earth's magnetic field is looked as a benchmark magnetic field and the interference magnetic intensity is regarded as measure geomagnetic intensity reducing geomagnetic intensity. The calculation formula is shown in Eq. (12). The following analysis is based on the above content:

$$\begin{bmatrix} B_{Nd} \\ B_{Ed} \\ B_{Vd} \end{bmatrix} = \begin{bmatrix} B_{Nm} \\ B_{Em} \\ B_{Vm} \end{bmatrix} - \begin{bmatrix} B_{Nr} \\ B_{Er} \\ B_{Vr} \end{bmatrix} = \begin{bmatrix} B_{Nm} - B_{Nr} \\ B_{Em} - B_{Er} \\ B_{Vm} - B_{Vr} \end{bmatrix} \quad (12)$$

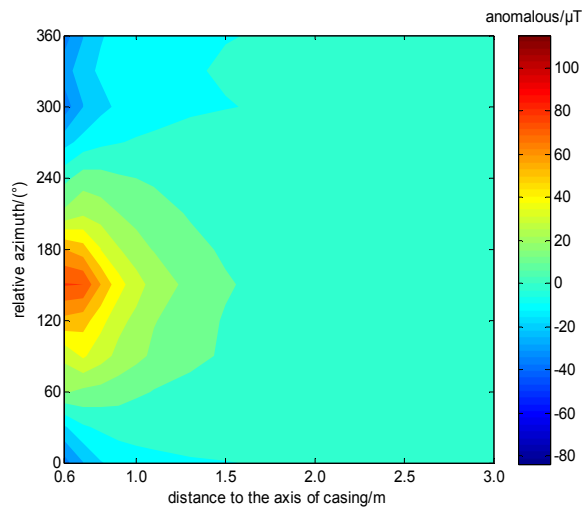


Fig. 3: N component of magnetic field intensity anomalies distribution while casing inclination is 0°

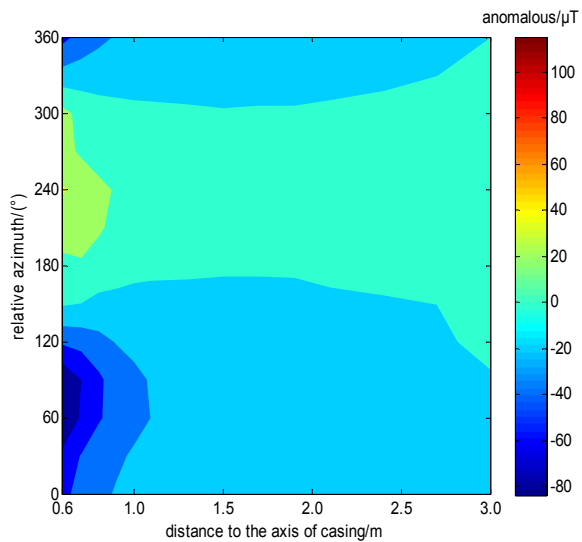


Fig. 4: E component of magnetic field intensity anomalies distribution while casing inclination is 0°

- B_{Nm}, B_{Em}, B_{Vm} = Magnetic intensity measured value of north, east, vertical component
- B_{Nr}, B_{Er}, B_{Vr} = Magnetic intensity real value of north, east, vertical component
- B_{Nd}, B_{Ed}, B_{Vd} = Magnetic intensity distortion value of north, east, vertical component

While the casing pipe angle of inclination is 0°:

Analysis of North component of magnetic intensity distortion, as shown in Fig. 3: When the relative azimuth Angle is 0°~180° and 300° ~360, B_{Nd} is negative, which shows the measured value is less than the true value. When the relative azimuth Angle is a definite value, if the azimuth belongs to 0°~120°, B_{Nd}

value will increase with distance increasing. If the azimuth belongs to 120°~180° and 300°~360°, B_{Nd} do not have a significant change. When the relative azimuth Angle is 180°~300°, B_{Nd} is positive. B_{Nd} value will decrease with distance increasing, but the amplitude variation range is small.

When the distance is a definite value, with azimuth increasing, there is a trend that B_{Nd} increases first and then decreases and the peak and valley value are respectively at relative azimuth Angle 240° and 60°. If the distance is between 0.6~1 m, B_{Nd} has larger amplitude and if the distance belongs to 1~3 m, there will be a small amplitude variation range.

Because azimuth 0° points north, when the casing is to the southwest of inclinometer, the value of B_{Nd} is positive. If the casing is to the northeast of inclinometer, the value of B_{Nd} is negative. When the casing is to the northwest or southeast of inclinometer, B_{Nd} has small amplitude.

Analysis of East component of magnetic intensity distortion, as shown in Fig. 4:

When the azimuth is within the range of 0°~30° and 270°~360°, there are a few negative B_{Ed} values, most of which are positive. In the range B_{Ed} will increase with the relative distance increasing, but the amplitude is small. When the azimuth is within the range of 30°~270°, the B_{Ed} value is positive and the value will decrease with the relative distance increasing.

When the distance is definite value, with azimuth increasing, there is a trend that B_{Ed} increases first and then decreases. The peak and valley value are respectively at relative azimuth Angle 150° and 30°, but the valley value is small. While the distance is between 0.6~1.5 m, B_{Ed} has larger amplitude. While the distance is between 1.5~3 m, there is not a significant change.

While the casing is to the southeast of inclinometer, the value of B_{Ed} is positive. When the casing is to the northwest of inclinometer, the value of B_{Ed} is negative. When the casing is to the northeast or southwest of inclinometer, B_{Ed} has small amplitude.

Analysis of vertical component of magnetic intensity distortion, as shown in Fig. 5:

While the relative azimuth is a definite value, B_{Vd} will increase with the distance increasing. While the distance is a definite value, there is not obvious change about B_{Vd} . It shows that B_{Vd} is negative in the whole area of the experiment and if the distance is between 0.6~1.2 m, B_{Vd} is large. While the distance is between 1.2~3 m, B_{Vd} is small.

Section brief: As for vertical well, while it is to the northeast of oil well, N component of magnetic field intensity will be less than the true value. If to the southwest, N component will be Larger than the actual

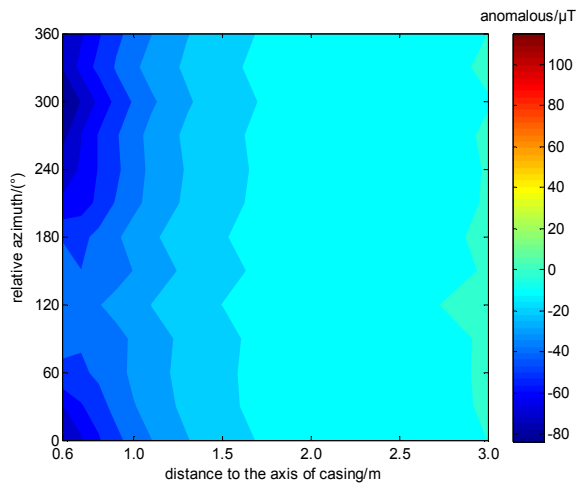


Fig. 5: V component of magnetic field intensity anomalies distribution while casing inclination is 0°

value. In the northwest and southeast, the distortion of N component is not obvious. While to the northwest of oil well, E component of magnetic field intensity will be larger than the actual value. If to the southeast, E component will be less than the actual value. To the northeast or southwest, the distortion of E component is not obvious. V component of magnetic field intensity is less than the real value around oil well.

While the casing pipe angle of inclination is 30°, 45°, 60°, 75°, 90°:

Analysis of North component of magnetic intensity distortion, as shown in Fig. 6 to 10: When the relative azimuth Angle is 0°~120° or 270°~360°, B_{Nd} is negative. While the azimuth is 0°~90° or 300°~360°, B_{Nd} value will increase with the distance increasing. If the azimuth is 90°~120° or 270°~300°, B_{Nd} doesn't have a significant change. When the relative azimuth Angle is 120°~270°, B_{Nd} is positive and B_{Nd} value will decrease with the distance increasing, but the amplitude variation range is small.

When the distance is a definite value, with azimuth increasing, there is a trend that B_{Nd} increases first and then decreases. The peak and valley value are respectively at relative azimuth Angle 210° and 30°. While the casing pipe angle of inclination is small, within the distance ranging from 0.6~1.4 m, the amplitude of B_{Nd} is large. Within the distance ranging from 1.4~3 m, B_{Nd} changes less. The scope of large distortion of N component of magnetic field intensity will be larger with the casing inclination increasing.

While the casing is to the south by west 30° of inclinometer, the value of B_{Nd} is positive. When the casing is to the north by east 30° of inclinometer, the value of B_{Nd} is negative. When the casing is to the east or west of inclinometer, B_{Nd} has a small change.

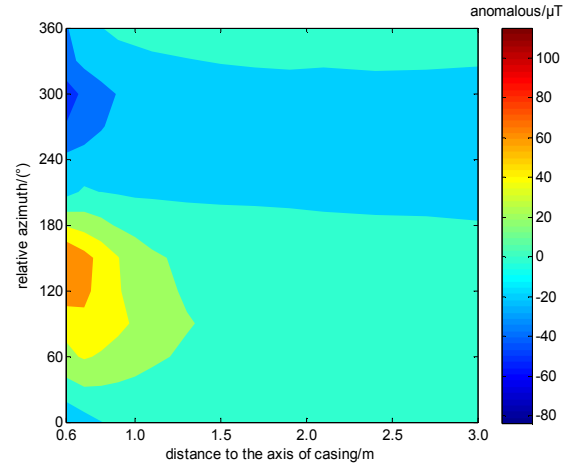


Fig. 6: N component of magnetic field intensity anomalies distribution while casing inclination is 30°

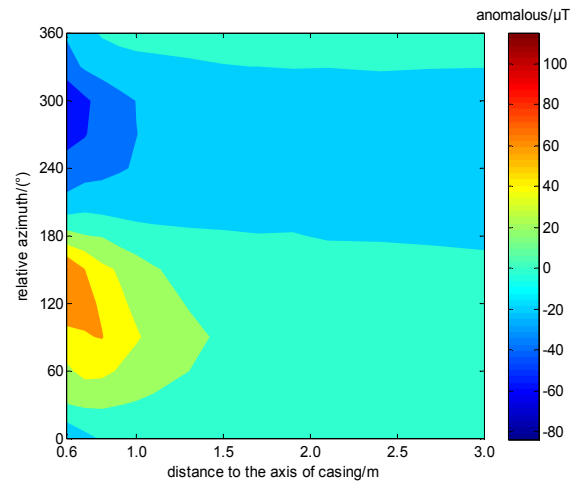


Fig. 7: N component of magnetic field intensity anomalies distribution while casing inclination is 45°

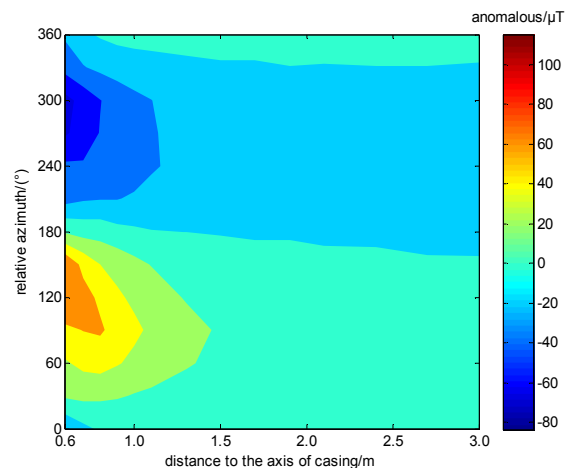


Fig. 8: N component of magnetic field intensity anomalies distribution while casing inclination is 60°

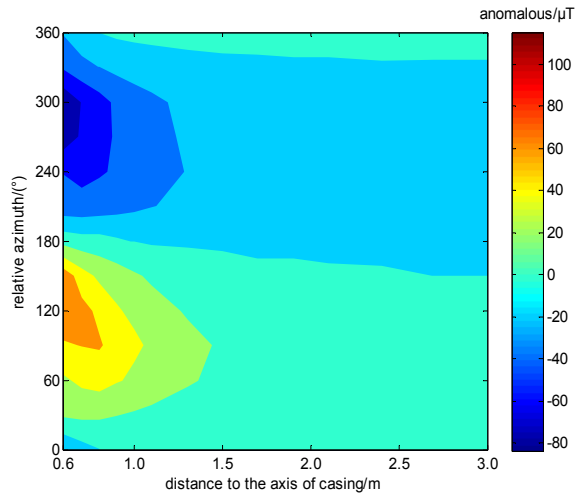


Fig. 9: N component of magnetic field intensity anomalies distribution while casing inclination is 75°

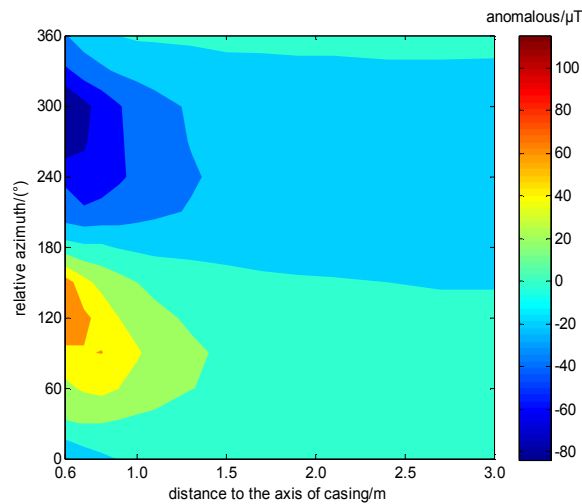


Fig. 10: N component of magnetic field intensity anomalies distribution while casing inclination is 90°

Analysis of East component of magnetic intensity distortion, as shown in Fig. 11to 15: While the relative azimuth Angle is 0°~30° or 210°~360°, B_{Ed} is mainly negative. While the azimuth is between 240°~360°, B_{Ed} value will increase with the distance increasing. If the azimuth is between 0°~30° or 210°~240°, with the distance changing, B_{Ed} doesn't change significantly. When the relative azimuth Angle is 30°~210°, B_{Ed} is positive and B_{Ed} value will decrease with the distance increasing, but the amplitude variation range is small.

If the distance is a definite value, with azimuth increasing, there is a trend that B_{Ed} increases first and then decreases and the peak and valley value are respectively at relative azimuth Angle 120° and

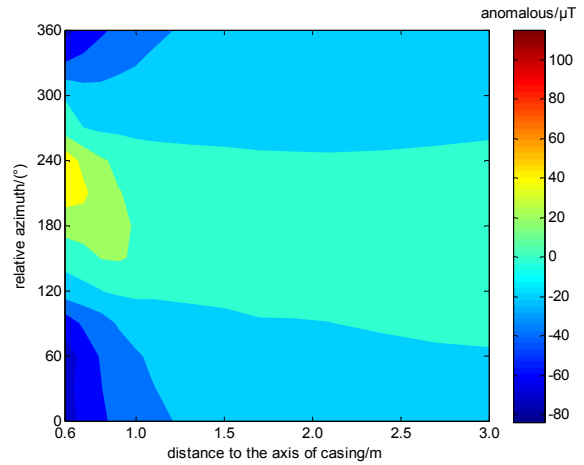


Fig. 11: E component of magnetic field intensity anomalies distribution while casing inclination is 30°

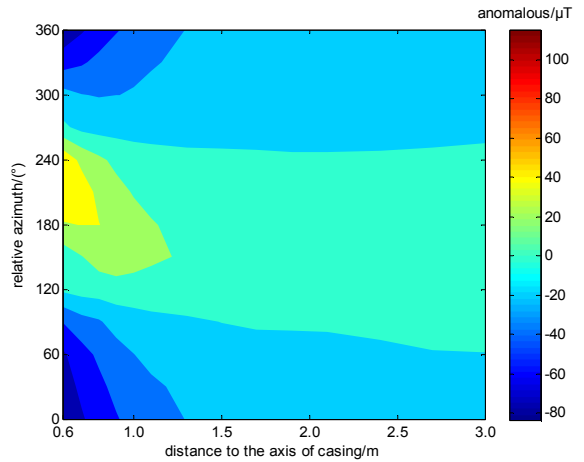


Fig. 12: E component of magnetic field intensity anomalies distribution while casing inclination is 45°

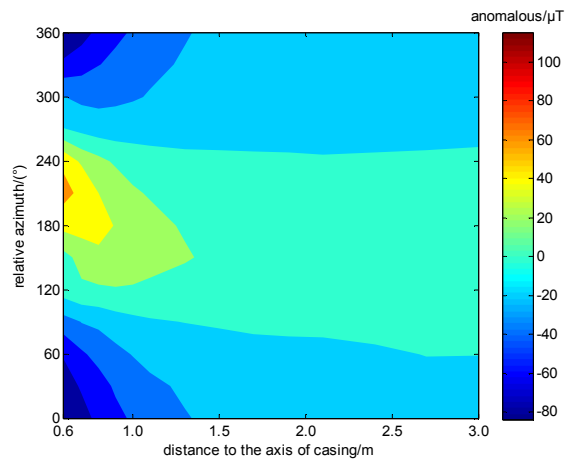


Fig. 13: E component of magnetic field intensity anomalies distribution while casing inclination is 60°

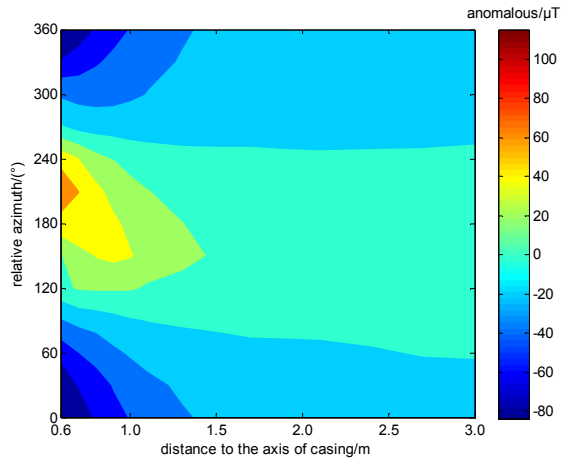


Fig. 14: E component of magnetic field intensity anomalies distribution while casing inclination is 75°

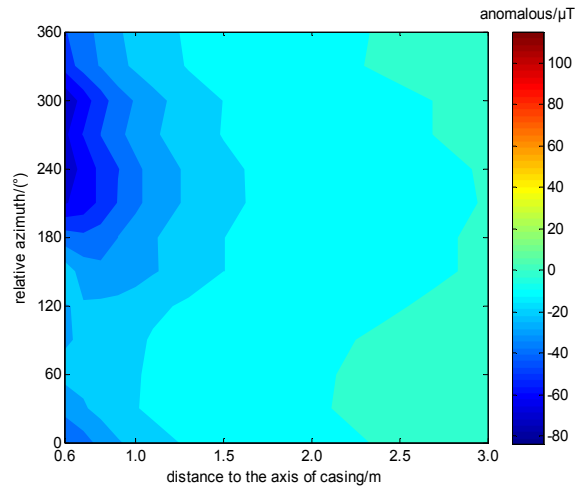


Fig. 17: V component of magnetic field intensity anomalies distribution while casing inclination is 45°

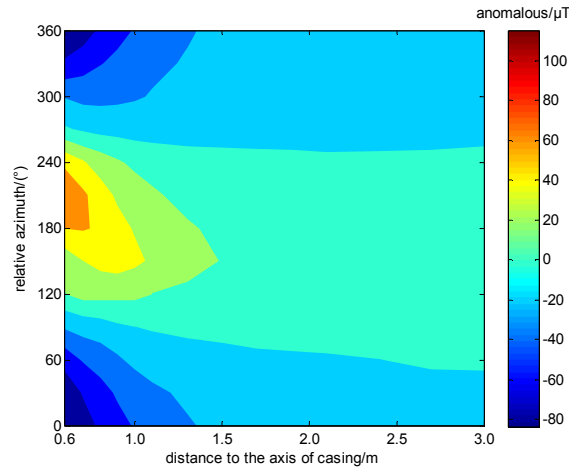


Fig. 15: E component of magnetic field intensity anomalies distribution while casing inclination is 90°

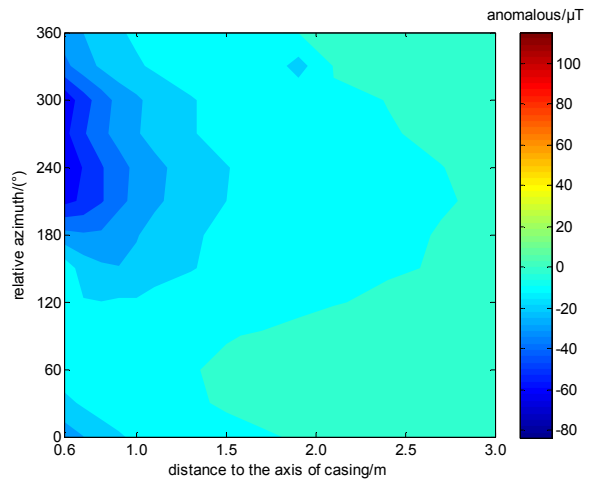


Fig. 18: V component of magnetic field intensity anomalies distribution while casing inclination is 60°

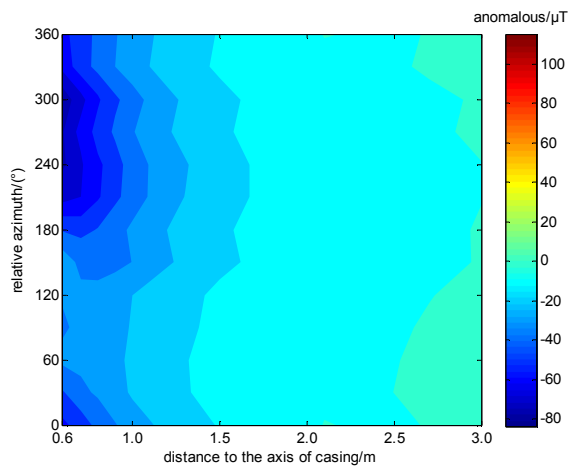


Fig. 16: V component of magnetic field intensity anomalies distribution while casing inclination is 30°

300°. While the distance is between 0.6~1.5 m, B_{Ed} change amplitude will be larger more than other scopes. With the casing inclination increasing, the scope of large distortion of E component of magnetic field intensity will be larger.

While the casing is to the east of inclinometer, the value of B_{Ed} is positive. If it is to the west of inclinometer, B_{Ed} is negative. When the casing is to the south or north of inclinometer, B_{Ed} has a small change to the true value.

Analysis of vertical component of magnetic intensity distortion, as shown in Fig. 16 to 20: With the relative azimuth Angle is 150°~330°, B_{Vd} value will increase with distance increasing. With the casing inclination increasing, the amplitude of B_{Vd} will decrease. When

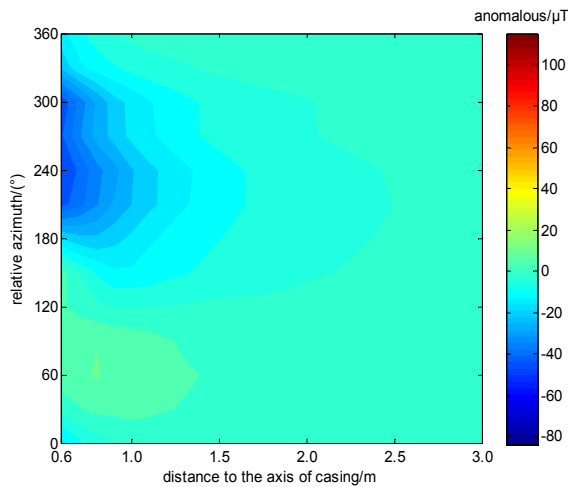


Fig. 19: V component of magnetic field intensity anomalies distribution while casing inclination is 75°

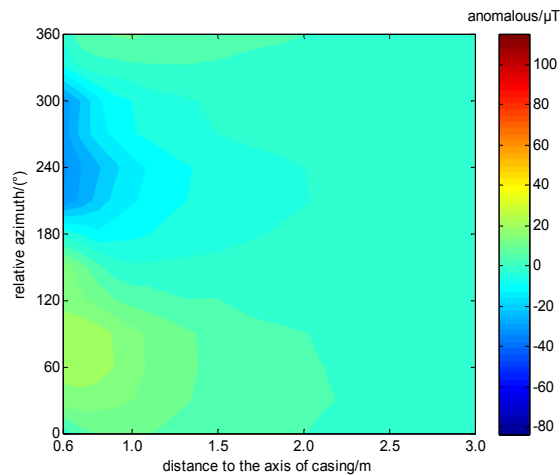


Fig. 20: V component of magnetic field intensity anomalies distribution while casing inclination is 90°

the casing is to the northeast of inclinometer, B_{Vd} is positive, while in other scopes it is negative.

When the relative azimuth Angle is 330°~360° and 0°~150°, with the relative distance increasing B_{Vd} increases first and then decreases progressively. When the casing is to the northwest of inclinometer, B_{Vd} is still negative, but the amplitude becomes smaller. There the distance of B_{Vd} changes from 0.6~1.5 m to 0.6~1 m.

Section brief: When the adjacent well is deviated or horizontal well, if the casing is to the north of inclinometer, N component of magnetic field intensity will be larger than true value. If it is to the south of inclinometer, the component intensity will be less than true value. If the casing is to the east or west of inclinometer, the distortion of N component is not obvious. If the casing is to the west of inclinometer, E

component of magnetic field intensity will be larger than true value. If it is to the east of inclinometer, the component intensity will be less than true value. If the casing is to the south or north of inclinometer, the distortion of E component is not obvious and V component of magnetic field intensity is less than the real value in experimental plot. But in the southwest the component of magnetic intensity is less than in the northeast.

CONCLUSION

Magnetic intensity distortion caused by deviated well has similar characteristics to horizontal well, but the distortion is different from vertical well. With the casing inclination increasing, the scope and amplitude of N and E component magnetic intensity distortion will increase, meanwhile the scope and amplitude of V component distortion will decrease. Through analysis of magnetic distortion, the relative position of the adjacent wells could be determined.

In drilling operation, if the adjacent well is vertical well and the relative distance of operating well and adjacent well is reduced, the following characteristics and situations will appear: if the N component of magnetic intensity increases, the drilling well should be to the northeast of adjacent well. If the intensity decreases, the well should be in the southwest. If the E component of magnetic intensity decreases, the drilling well should be to the northwest of adjacent well. If the intensity decreases, the well should be in the southeast; and the V component of magnetic intensity decreases.

In drilling operation, if the adjacent well is deviated or horizontal well and the relative distance of operating well and adjacent well is reduced, the following characteristics and situations will appear: if the N component of magnetic intensity increases, the drilling well should be to the north of adjacent well. If the intensity decreases, the adjacent well should be in the south. If the E component of magnetic intensity decreases, the drilling well should be to the east of adjacent well. If the intensity increases, the well should be in the west. If the amplitude of V component magnetic intensity decreases, the adjacent well should be to the northeast, otherwise the well is in the southwest.

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