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Research on Ocean Magnetic Exploration Technology Based on Acoustics

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Abstract. In this paper, based on the analysis of the principle of the ocean magnetic measurement and the underwater acoustic localization, a kind of ocean magnetic measurement method combined with acoustics is proposed. The ocean magnetic survey method overcomes the defect of the positioning of the marine magnetometer probe. Through a two exploration for a submarine pipeline, marine magnetic prospecting technology with improved and no improvement is adopted respectively. After comparison test, it can be seen that the exploration results of the ocean magnetic survey method combined with acoustics are about 33% better than that before the improvement. This method is more practical for the exploration of submarine pipelines.

1. Introduction

At present, the most commonly used method for submarine pipeline exploration is the magnetic force detection method \cite{1-4}. Magnetic measurement is completely free from the buried depth of submarine pipelines, and can be used to rapidly explore the sea-level location of submarine pipelines\cite{5}. However, when measuring the magnetic anomaly value, there is a problem of accurate underwater positioning of the marine magnetometer, which can only be used to determine the distance from the probe to the surface of the water. Finally, there will be larger positioning errors in the survey.

In this paper, an accurate positioning method of underwater buried objects which combines the ultra-short baseline and the marine magnetometer is proposed, which overcomes the defect of the magnetometer probe positioning and realizes the accurate positioning of the underwater buried objects.

2. Marine Magnetic Measurement Combined with Acoustic Positioning

In order to solve the problem of underwater precise positioning of marine magnetometer at the present stage, this paper proposes an accurate positioning method for underwater burial objects based on acoustic-based underwater positioning that is a marine magnetic survey method combined with acoustics. This method uses GPS, ultra-short baseline positioning systems, marine magnetometer probe and other equipment. The system diagram is shown in Figure 1. The ultra-short baseline positioning system is mainly composed of three parts: a transponder, a transmitting transducer and a receiving array. Among them, the transmitting transducer and the receiving array are fixed on the ship, and the transponder is mounted on the underwater mechanism.
2.1. Coordinate Definition and Conversion of Underwater Buried Object Location Method

The positioning method of underwater buried objects consists of three coordinate systems: (1) geodetic coordinates; (2) ultra-short baseline coordinates (the position of the transponder relative to the ultra-short baseline transmitting transducer); and (3) the coordinates of the magnetometer probe relative to the ultra-short baseline transponder. The map of the geodetic coordinates is shown in Figure 2.

The $O_A(X_AO, Y_AO, Z_AO)$ (the geodetic coordinates based on the $O$ point) indicates the location of the receiving array and the transmitter at the $A$ point on the vessel in the geodetic coordinates. The $B_A(X_{BA}, Y_{BA}, Z_{BA})$ indicates the position of the transponder at the $B$ point relative to the transmitting transducer. The $C_B(X_CB, Y_CB, Z_CB)$ indicates the position of the magnetometer probe at the $C$ point relative to the transponder. The $O_C(X_CO, Y_CO, Z_CO)$ represents the position of the ocean magnetometer probe in the geodetic coordinates and its coordinates are obtained from the following formula:

$$ (X_{CO}, Y_{CO}, Z_{CO}) = (X_{AO} + X_{BA}, Y_{AO} + Y_{BA}, Z_{AO} + Z_{BA}) $$

The ultra-short baseline coordinates are based on the $A$ point as the original point and translates the geodetic coordinate system. As shown in Figure 3, five of the receive primitives are located at points of $D_A(X_{DA}, Y_{DA}, Z_{DA}), E_A(X_{EA}, Y_{EA}, Z_{EA}), F_A(X_{FA}, Y_{FA}, Z_{FA}), G_A(X_{GA}, Y_{GA}, Z_{GA})$ and $A$ respectively. Their specific location parameters are set to $D_A(d/2,0,0), E_A(-d/2,0,0), F_A(0,d/2,0)$ and $G_A(0,-d/2,0)$, and $d$ is the distance between the two receiving transducers of $D_A$ and $E_A$ or $F_A$ and $G_A$. The distances from $B$ to $D_A$, $E_A$, $F_A$, $G_A$ and $A$ are $S_{DA}$, $S_{EA}$, $S_{FA}$, $S_{GA}$, $S_A$, respectively. $\theta_x$, $\theta_y$, $\theta_z$ are the angles of $AB$ and $X$, $Y$ and $Z$ respectively.
2.2. Application of Underwater Acoustic Positioning in Ocean Magnetic Survey

Figure 4 is a sound propagation model between two primitive and transponder in the $X$-axis direction. The $c\Delta t$ is the difference of sound path in the chart. The formula is expressed as:

$$c\Delta t = \frac{c\Delta \phi_x}{2\pi f}$$

Figure 4. Sound propagation model

$\Delta \phi_x$ indicates that the phase difference between the received signals of the two primitives $D_A$ and $E_A$ in the $X$-axis direction and can be measured; $f$ represents the frequency of sound waves; $\Delta t$ indicates the time difference between signals received by two primitives $D_A$ and $E_A$ in the $X$-axis direction;

Since $B$ is far away from the receiving array, $\theta_x$ can be approximately equal to the angle between $E_A B$ and the $X$-axis, then:

$$\cos \theta_x = \frac{c\Delta t}{d} = \frac{c}{2\pi f d} \Delta \phi_x$$

Among them, $c$ shows the velocity of sound wave propagation in water;

Due to $d \ll S_{AB}$, it can be approximated that $S_{EA} = S_d = \frac{1}{2} c t$, $t$ represents the time from when the signal is sent to the receiving array to receive the response signal. According to formula (3) available:

$$X_{BA} = \cos \theta_x \cdot S_d = \frac{c^2 t}{4\pi f d} \Delta \phi_x$$

In the same way, we can get the following:

$$Y_{BA} = \cos \theta_y \cdot S_d = \frac{c^2 t}{4\pi f d} \Delta \phi_y$$

$$Z_{BA} = (S_d^2 - X_{BA}^2 - Y_{BA}^2)^\frac{1}{2} = \frac{1}{2} c t (1 - \frac{c^2 \Delta \phi_x^2}{4\pi^2 f^2 d^2} - \frac{c^2 \Delta \phi_y^2}{4\pi^2 f^2 d^2})^\frac{1}{2}$$

Among them, $\Delta \phi_y$ indicates that the phase difference between the received signals of the two primitives $F_A$ and $G_A$ in the $X$-axis direction can be measured;
2.3. The Position Calculation of The Probe of The Marine Magnetometer

The transponder $B$ dragged on the measuring vessel and moved along the measuring line. The towing cable was about 3 times as long as the captain. The probe $C$ of marine magnetometer moves with the movement of the transponder $B$, so the position of the probe can be calculated according to the movement trend of the transponder.

By underwater acoustic positioning, the position of the transponder $B$ relative to the transmitting transducer $A$ can be obtained. The coordinates of the transponder in a certain time period are taken, and the trajectory equation $z = f(x, y)$ of the transponder in the water can be obtained through the fitting curve. Fig. 5 is a schematic diagram for solving the position principle of the marine magnetometer probe $C$ relative to the transponder $B$. $B_A$ and $B_A'$ represent the position of the transponder at the current moment and the previous moment, and $C_A$ represents a current position of the ocean magnetometer probe $C$. The ray $l$ in the diagram is a direction determined by the projection point on the horizontal plane by $B_A$ and $B_A'$. $\delta$ is the angle between the tangent line of the $B_A$ point along the direction of $l$ and the ray $l$, $\varphi$ is the angle between the ray $l$ and the positive direction of the $X$-axis, and $S$ is the distance between the transponder and the probe on the underwater mechanism.

\[ Z = f(x, y) \]

\[ \delta = \arctan(\frac{\alpha f}{\alpha l}) \]

\[ |B_A'C_A| = S \]

At present, the position $B_A'C_A$ of the marine magnetometer probe relative to the transponder can be determined by the angle $\delta$ and the modulus $|B_A'C_A|$, as shown in Fig. 5. The included angle $\delta$ can be calculated by formula (7), and the modulus $|B_A'C_A|$ can be obtained by formula (8).

\[ X_{CB} = S \cos \delta \cos \varphi \]

\[ Y_{CB} = S \cos \delta \sin \varphi \]

\[ Z_{CB} = S \sin \delta \]

2.4. Marine Magnetic Prospecting

The marine magnetometer probe is dragged to the measuring vessel and measured along the measuring line to obtain the total magnetic field at each point $C_0(X_{CO}, Y_{CO}, Z_{CO})$ along the measurement line. After the measurement is completed, whether the daily variation data and the actual measurement data
are observed is within the allowable range of error, if there is no existing, the daily variation is corrected, and then the already selected basic field is subtracted from the corrected data, the magnetic anomaly $\Delta T$ can be calculated.

According to the magnetic anomaly value $\Delta T$ obtained at each point $C_0(X_{CO}, Y_{CO}, Z_{CO})$, the magnetic anomaly profile is drawn. Finally, the position of the sea level of the submarine pipeline is located by the interpretation of the magnetic anomaly.

### 2.5. Underwater Buried Object Positioning Implementation Process

1) determine the position of the ultra-short baseline transmitting transducer and the receiving array on the survey ship, which is recorded as $A_0(X_{AO}, Y_{AO}, Z_{AO})$ and measured by the GPS global positioning system.

2) determine the position $B_4(X_{B4}, Y_{B4}, Z_{B4})$ of the transponder relative to the transmitting transducer, calculated by formula (4) ~ (6).

3) determine the position $C_5(X_{CB}, Y_{CB}, Z_{CB})$ of the marine magnetometer probe relative to the transponder, calculated by formula (9) ~ (11) and (1).

4) determine the sea-level position of the submarine pipeline, which can be obtained by marine magnetometer probe using marine magnetic prospecting.

### 3. Experimental Analysis and Case

In order to verify the effectiveness and feasibility of the proposed acoustic based marine magnetic exploration technology, two methods are used to carry out the test. First, marine magnetometer probe is used to drag directly to the ship's tail [3], and the second method uses ocean magnetic exploration technology based on acoustics. The body flow is as follows:

1) geomagnetic daily variation observation
2) ocean magnetic measurement combined with acoustic localization

The experiment takes 5 measuring lines, which are $L_1$, $L_2$, $L_3$, $L_4$ and $L_5$. Each measuring line is perpendicular to the submarine pipeline. The distance between them is 100m, and the length of each measuring line is 1500m. The specific schematic diagram is shown in Fig. 6. Method 1 and method 2 take 5 lines for the exploration of a submarine pipeline in the ocean the same speed. The result of the experiment is shown in table (1). Among them, $x$ and $y$ are the actual coordinates of submarine pipelines. $X_1$ and $Y_1$ are the coordinates of submarine pipelines obtained by method 1. $X_2$ and $Y_2$ are the coordinates of submarine pipelines obtained by method two. The actual coordinates of submarine pipelines are obtained by artificial diving.

The distance difference between Method 1 and Method 2 and the actual pipeline is obtained by Formula (12). The results are shown in Table (2). Among them, $\Delta S_1$ and $\Delta S_2$ are the distance difference of Method 1 and Method 2 respectively. It can be clearly seen in Table (2) that there is a big improvement in the error of method 2 over method 1 in locating the position of the sea level of the submarine pipeline. Further, the formula (13) can be used to calculate the error-optimized size $P$ of the two methods on the five lines. As shown in Table (2), it can be seen that Method 2 optimizes the error of about 33% over Method 1.

$$\Delta S = \sqrt{(X - x)^2 + (Y - y)^2}$$  \hspace{1cm} (12)

$$P = \frac{\Delta S_1 - \Delta S_2}{\Delta S_1}$$  \hspace{1cm} (13)
Figure 6. Line planning map

Table 1. Experimental results

| line | x / m  | y / m  | X1 / m | Y1 / m | X2 / m | Y2 / m |
|------|--------|--------|--------|--------|--------|--------|
| L1   | 790738.31 | 2499815.87 | 790737.58 | 2499818.66 | 790737.81 | 2499817.75 |
| L2   | 790653.30 | 2499763.21 | 790652.58 | 2499765.98 | 790652.81 | 2499765.07 |
| L3   | 790568.28 | 2499710.56 | 790567.58 | 2499713.31 | 790567.81 | 2499712.40 |
| L4   | 790483.27 | 2499657.90 | 790482.58 | 2499660.63 | 790482.81 | 2499659.72 |
| L5   | 790398.25 | 2499605.25 | 790397.58 | 2499607.95 | 790397.81 | 2499607.05 |

Table 2. Error optimization

| line | ΔS1 / m | ΔS2 / m | P     |
|------|---------|---------|-------|
| L1   | 2.88    | 1.95    | 32%   |
| L2   | 2.86    | 1.92    | 33%   |
| L3   | 2.84    | 1.90    | 33%   |
| L4   | 2.82    | 1.88    | 33%   |
| L5   | 2.78    | 1.85    | 33%   |

4. Conclusion
A marine magnetic survey method combined with acoustics is proposed in this paper, which accurately locates the probe of the marine magnetometer, and has more accurate positioning results for the exploration of the submarine pipeline. It was verified by experiment.

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