Magnetic Detection Method for Seabed Cable in Marine Engineering Surveying

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Abstract  The detection and identification of the seabed cable is becoming an important task in the marine engineering. The features of the magnetic anomaly can be used to detect the existence of the seabed cable. The magnetic field model is presented, and the consistency of the magnetic anomaly distribution between the simulation of the model and the observed data is verified. The comparison shows that the seabed cable can be effectively detected and identified with reasonable method.

Keywords  seabed cable; magnetic filed model; detection and identification

Introduction

With the development of marine resources investigation and exploitation, the detection and identification of underwater pipeline is becoming an important task in the marine engineering. It is very difficult to detect underwater pipeline by conventional method, such as echo sounding method and side scan sonar method[1]. Furthermore, the conventional acoustic methods cannot effectively detect seabed cable because the seabed cable is thin in size and often buried by sediments. On the contrary, the electromagnetic characteristics of seabed cable provide the possibility of detection by magnetism methods. The ferromagnetic substance of seabed cable and the electrical current can produce an external magnetic field, its magnetic anomaly intensity (ΔT) is about 0.5-150 nT. Because the sensitivity of high resolution cesium vapor magnetometer can reach 0.005 nT(sampling rates at 1 Hz), the tiny change of magnetic anomaly produced by seabed cable can be effectively detected. Based on the characteristics of the magnetic field, the feature of the magnetic anomaly can be applied to analyze and identify seabed cable. The magnetism detection method has more advantages over the traditional methods, because the air, water and seabed have little influence on it. Since the advent of marine magnetometer, it has been attempted to detect seabed target, such as seabed cable. Extensive studies have been made in developed countries. In the past decades, the result of the magnetism detection was used for reference only, not for the exact identification of the seabed target. No further research in this field has been made for a long time. With the development of technology of high-precision magnetometer, the capability of the magnetism detection has been greatly improved. So the detection theory and method should be analyzed and researched. It is the...
aim of the paper to study the magnetism detection model and method in detection and identification of seabed cables.

1 Magnetic field modeling of seabed cable and its characteristics

Seabed cable is made of ferromagnetic substance which can produce magnetic field, and the electric current of seabed cable can also produce additional magnetic field in the same time. Therefore, the magnetic field of seabed cable ($T$) is composed of the magnetic field ($T_1$) induced by ferromagnetic substance and ($T_2$) induced by the current:

$$T = T_1 + T_2$$

where $T$ is the magnetic field of seabed cable; $T_1$ is the magnetic field induced by ferromagnetic substance; $T_2$ is the magnetic field induced by the current.

1.1 Magnetic field modeling of ferromagnetic substance

Coordinate system is established for the study of magnetic field modeling of seabed cable shown in Fig.1 $XOY$ is the horizontal observation plane, $Y$ axis is the heading of cable, $Z$ axis is vertical downward, $XYZ$ is a right-hand coordinate system. The origin is the intersection points of survey line and cable, $I$ is the inclination, $A'$ is declination, $H_0$ is projection of $T_0$ in $XOY$ plane, $H_x, H_y, H_z$ are the components of $T_0$ in $X, Y, Z$ coordinate axis respectively.

Fig.1 Coordinator of seabed cable

If the cross section area of seabed cable is $S$, depth is $D$, valid magnetization strength is $M_s$, valid magnetization inclination is $i_s$, the distribution of the magnetic field in observation profile is\[^{[2,3]}\]:

$$T_i = \mu_0 M_s S \left[ 2\pi (x^2 + D^2)^{3/2} \cdot \left( (D^2 - x^2) \cdot (\sin I \sin i_s \cos I \cos A - 2Dx) \cdot (\cos I \sin I + \cos I \sin i_s \cos A)\right) \right]$$

where $A$ stands for magnetic azimuth of observation profile.

The Eq.(2) is the cylinder magnetic field model of seabed cable. Shown as Eq.(2), for the same inclination, the magnetic field intensity of seabed cable depends on heading of cable.

1) If the heading of seabed cable is south-north ($A=90^\circ, i_s = 90^\circ$), Eq.(2) becomes to:

$$T_i = \mu_0 M_s S \left[ 2\pi (x^2 + D^2)^{3/2} \cdot (D^2 - x^2) \cdot \sin I \right]$$

2) If the heading of seabed cable is east-west ($A=0^\circ, i_s = I$), Eq.(2) will be:

$$T_i = \mu_0 M_s S \left[ 2\pi (x^2 + D^2)^{3/2} \cdot \left( (x^2 - D^2) \cos 2I - 2Dx \sin 2I \right) \right]$$

The range of valid magnetization inclination is $I \approx i_s \leq 90^\circ$. Magnetic anomaly induced by cylinder magnetic field model of seabed cable depends on the direction, the valid magnetization intensity and the cross section area of seabed cable.

1.2 Additional magnetic field modeling induced by the electrical current

The seabed cable is taken as an idealized infinite length. As we know in electromagnetism\[^{[4]}\], the electrical current of the seabed cable can produce a magnetic field ($H$) as follows:

$$H = \frac{1}{2\pi \nu}$$

The intensity of magnetic field is observed by marine magnetometer, which is the component along the direction $T_0$. The relations between magnetic field and electrical current are spiral in right-hand, therefore, the magnetic field $T_2$ will be given by:

$$T_2 = H \cdot \cos(\alpha + I) \cdot \left[ \pm i/2\pi (x^2 + D^2)^{1/2} \cdot \cos(\arctan(x/D) + I) \right]$$

where $T_2$ is the component of electrical current magnetic field intensity in the direction $T_0$ (units:
nT); \( i \) is electrical current intensity (units: A); \( \alpha \) is the angle between the electrical current magnetic intensity \( H \) and the horizontal plane (units: rad); \( I \) is the magnetic inclination (units: rad).

In Eq.(6), the magnetic field induced by additional electrical current of seabed cable depends on the intensity of electrical current.

### 1.3 Magnetic modeling of seabed cable

In Eq.(2), \( T_1 \) is the component of magnetization intensity \( M \) in the direction \( T_0 \). In Eq.(6), \( T_2 \) is the component of magnetic fields intensity induced by the electrical current \( H \) in the direction \( T_0 \).

Therefore, the magnetic field model of the seabed cable will be given by:

\[
T = \mu_0 M_S \sqrt{\frac{2\pi}{x^2 + D^2}} \left[ (D^2 - x^2) \cdot (\sin I \sin i_s - \cos I \cos i_s \cos A) - 2Dx \cdot (\cos I \sin i_s \sin A) \right] \pm \frac{I}{2\pi(x^2 + D^2)^{1/2}} \cos(\arctan(x/D) + I) \tag{7}
\]

### 1.4 Spatial distribution of magnetic field of seabed cable

The spatial distribution of magnetic field of seabed cable can be computed and analyzed by the model established above. Commonly, it is assumed that the magnetization intensity of seabed cable \( M = 1500 \) A/m, the magnetic inclination \( I = 40^\circ \). In general, the range of magnetic inclination is 30°-60° in China sea. The distance from the center of the cable is 30m-30m. The magnetic anomaly curve of given instance is shown as Fig.3. The heading of seabed cable is east-west. In Fig.3(a), the strength of electrical current is \( i = 2000 \) A, the radius of cable is \( R = 5 \) cm, the simulated magnetic anomaly curve varies with \( D \); in Fig.3(b), the strength of electrical current is \( i = 0 \), the radius of cable is \( R = 5 \) cm, the simulated magnetic anomaly curve varies with \( D \).

It can be seen from Fig.3 that if the intensity of electrical current is \( i = 0 \), the magnetic field is only induced by cylinder model. The strength of induced magnetic field will reduce with the increase of the distance. In Fig.3(a), when the depth \( D = 1 \) m, the maximal magnetic field intensity induced by cable is about 300 nT. When the depth \( D = 7 \) m, the maximal is about 15 nT, when \( D = 7 \) m, the magnetic field intensity will be 0.

It can be concluded that the magnetic field induced by electrical current is the dominant component of the seabed cable. The intensity of magnetic field will rapidly reduce with the increase of depth. Therefore, theoretically speaking, the maximum distance between the sensors (tow-fish) and the seabed cable...
must be less than 5 cm in the detection process. The optimal distance between fish and seabed cable is between 1-2 m in practice.

Due to the difference of the assumed value, the variable amplitude of the curve is shown in Fig. 3. It can be also seen that the different change trend of the model varies with the distance between the fish and the center of seabed. In addition, when the seabed cable is used as the case study, the magnetic field induced by eclectic current is dominant. When the minus signal in Eq.(7) is selected, the change trend of magnetic anomaly simulated curves will be reverse.

2 Detection and identification of seabed cable

2.1 Magnetic field detection of area seabed

For further discussion, an example is adopted to validate the method of detection and identification of the seabed cable.

The background earth magnetic field of the detection area is smooth and it has no obvious magnetic anomaly. The direction of seabed cable is east to west. The magnetic inclination of the area is about 40°, the depths range from 20 m to 50 m. G-881 marine magnetometer is used during the detection process. The sensitivity of the instrument is 0.005 nT and the sampling rate is 1 Hz. Also the NGE-60 DGPS, SDH-13D echo sounder are used during the detection process.

To eliminate the magnetic effect of the survey boat, the magnetometer sensor is towed behind the boat at a sufficient distance about 3-5 times of boat length. The designed direction of the survey line is south-north, the length of survey line is about 300 m, 33 survey lines have been designed in survey area of 300 m south-north by 5.4 km east-west.

To keep the position’s stability of the fish, the reading of echo sounder has been adopted to compare with the reading of the depth sensor of magnetometer. The distance between the sensor and the sea bottom is kept to about 1.5 m. For better result, a plumb is added to the tow cable at the distance of 8 m from the fish, the length of the cable is 90 m (about 3 times of the boat length)

During the detection process, the geomagnetic diurnal variation has been ignored for the time span of the detection process which is no longer than 2 h. In addition, the influence of the boat magnetic is all the same in the same line direction, so the test for the influence of the boat magnetic is neglected also. The length of the tow cable is about 3 times of the boat length. Because the distance between of the seabed and cable is about 0.8-1 m, the buried depth is no need to be determined.

2.2 Discrimination of magnetic field of seabed cable

After analyzing the detection data, it is found that 25 lines have obvious magnetic anomaly, the percentage is 76 to the total lines. Among these obvious magnetic anomalies, the maximal value is 118 nT, the minimal value is 2 nT. And the line 14, 20, 26, 28, 29, 31, 32, 33 have no obvious magnetic anomaly. The magnetic field intensity of No.14 survey line is shown in Fig.4. There is no obvious magnetic anomaly in No.14 survey line. The reason is the influence of the wave, ocean current, and the speed of the ship.

Those detected obvious magnetic anomaly curves are shown in Fig.5. There are obvious and regular magnetic anomalies along the survey lines, which indicate that there exists the ferromagnetic substance under the water. The magnetic anomaly curve obtained by detection has the same trend as the emulated magnetic abnormal curve in Fig.3. The validity of the magnetic model of the cable is proved to be correct through the example.

Fig.4  Magnetic field intensity change of surveying line without abnormal magnetism point
After analysis of the detected data, it can be concluded that the line among the obvious and regular magnetic anomaly points is the heading of the seabed cable. The contours of partial detected area and the distribution of the survey lines are shown in Fig.6. The general heading of the cable is obtained. Because of the positioning error during the detection process and the impact of the sea water etc., the position of the cable has not been reduced to its real position. After fitting, the heading of the seabed cable is not a straight line. The calculated position of the seabed cable and the magnetic anomaly are shown in Table 1.

Through the analyzing, the magnetic anomaly of seabed cable is obvious, the maximal magnetic variation is 118 nT, the minimal magnetic variation is 2 nT. Therefore, the magnetic anomaly caused by seabed cable can be detected effectively by G-881 marine magnetometer. The heading of the seabed cable can be obtained by connecting the detected magnetic anomaly points.

Table 1  Lists of coordinates, magnetic field intensity and magnetic anomaly of seabed cable

| Number | Longitude/(') | Latitude/(') | Magnetic anomaly/nT |
|--------|---------------|---------------|---------------------|
| 1      | 57.903 21     | 51.600 39     | +10                 |
| 2      | 57.933 64     | 51.596 98     | +42                 |
| 3      | 57.963 85     | 51.590 55     | +15                 |
| 4      | 58.002 08     | 51.589 38     | +9                  |
| 5      | 58.049 56     | 51.587 96     | +12                 |
| 6      | 58.083 55     | 51.587 59     | +20                 |
| 7      | 58.120 72     | 51.586 97     | +15                 |
| ...... | ......         | ......         | ......               |
| 25     | 59.154 18     | 51.543 02     | +9                  |

Fig.6  Contour map of magnetic anomaly detection area and positions of seabed cable

It should be noted that the magnetic anomaly caused by seabed cable is hard to be distinguished, when the background magnetic field is complicated enough. Therefore, in order to detect and identify the magnetic anomaly caused by seabed cable, the background magnetic field must be investigated in the whole area. Meanwhile, the depth of the water and the seabed bottom characteristics has to be collected. Only through the above analyzing, the strong disturb of the background can be discriminated.

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