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THE METHOD OF LOCATION AND IDENTIFICATION OF WEAK ELECTRIC FIELD SOURCE IN SEAWATER

There are electrochemical processes occurring on a metal object surface in seawater. As the result of these processes, one can observe an electric field in the object vicinity. The paper presents the method and measurement system that allows to locate the detected object and to identify parameters of its simplified model in form of a current dipole. The identify method is based on the matrix norm minimization. The matrix contains results of measurements and parameters of the object in request taken as the current dipole. The results of simulation and experimental detection of sea mines are given. The research results confirmed the effectiveness of the developed method.

1. INTRODUCTION

On the surface of a metal object placed in seawater, regardless of the coverage type, after some time the electrochemical processes occur. These processes are the source of an electric field in the vicinity of the object. Among many objects in the sea there are naval mines. The naval mines placed at the bottom are the most difficult to detect by a sonar. The mine produces the electric field, which can be detected by a sensors system. In the paper, the method and the sensors system to locate and identify the object in request are presented. The simple model of the object in request was taken as the current dipole [1, 2]. The measuring system consists of electric field sensors arranged on the circle circumference. The location and identification method is based on the matrix norm minimization. The matrix contains the results of measurements and parameters of the dipole current, which represents the object in request [2]. The matrix norm minimum was calculated by the Lavenberg-Marquardt's optimization method [4]. The results of simulation and experimental detection of a model of sea mine were presented in the paper. The experimental studies were carried out in a seawater pool with a dummy mine. The research results confirmed the effectiveness of the developed method.

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2. MEASURING SYSTEM

Based on the analysis of the electric field distribution in the mine vicinity, the electric field sensors structure was chosen. Electric potential sensors were arranged on circle circumference parallel to the seabed (Fig.1), what allowed to detect an object regardless of the search direction [3]. The measuring system is moved along the selected trajectory in the search region. The signal from each sensor positioned on the circle circumference and from the reference sensor (S1) is gathered by a microprocessor system and then sent by a fiber optic cable to the computer. The system records the potential values relative to the reference sensor (S1). On the basis of the measured signals, the computer calculates the field source localization and performs its identification.

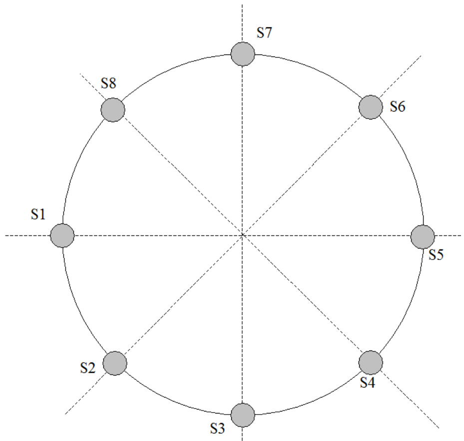

Fig. 1. The electric field sensors system, where Si – i-th electric field sensor

3. THE OBJECT LOCATION AND IDENTIFICATION

Electric potential values near the mine are small and, what is worse, can be different for the same mine type. The detection distance range of such objects using the electric field sensor is small in range of a few meters. In the case of relatively signal values to noise (the order of mV) in addition to the signal detection one can carry out the object location and its identification. In the analyzed method of location and identification, a general object model with some selected parameters should be taken into account. The number of the model parameters in request should be as small as possible, because too large number of parameters extends the calculation needed to minimize the norm. With this in mind, a simple electric field model as a current dipole was adopted. The current dipole consists of two current sources with the same current capacity spaced at a distance L (Fig.2). The dipole current potential placed in the conductive medium with the electrical conductivity σ is given by the relationship:

$$\varphi=\frac{I}{4\pi\sigma}\left(\left(\frac{1}{(x-x_o+0.5L\sin\theta\cos\alpha)^2+(y-y_o+0.5L\sin\theta\sin\alpha)^2+(z-z_o+0.5L\cos\theta)^2}\right)^{0.5}+\\-\left(\frac{1}{(x-x_o-0.5L\sin\theta\cos\alpha)^2+(y-y_o-0.5L\sin\theta\sin\alpha)^2+(z-z_o-0.5L\cos\theta)^2}\right)^{0.5}\right) \tag{1}$$

where: I – current source intensity, L – distance between the current sources, θ – angle between the dipole axis and the z axis, α – angle between the x axis and the dipole axis projection on the xy plane, x_0,y_0,z_0 – the object coordinates (Fig.2).

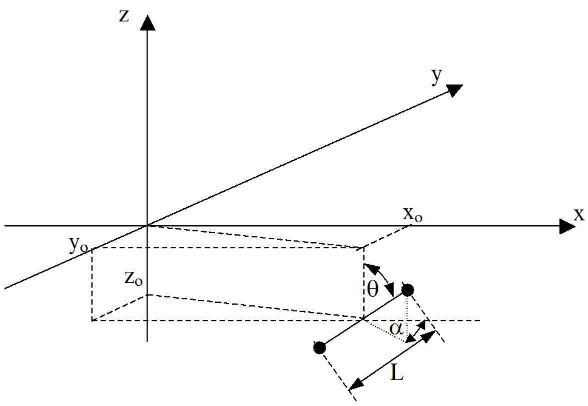

Fig. 2. The current dipol model and the system of coordinates

The object location and identification was carried out minimizing the norm:

$$\sum_{i=1}^{lp}\sum_{j=1}^{lc}\left(Sp_{j,i}-Sm_{j,i}\right)^2 \tag{2}$$

where: $Sp_{j,i}$ – the measured potential difference between the j-th sensors pair in the i-th system position, $Sm_{j,i}$ – the potential difference between the j-th sensors pair in the i-th position calculated from the analytical model (1), lp – the number of measurement points and lc – the number of sensor pairs.

The number of unknown parameters in the problem under consideration is eight, i.e. I, σ, L, θ, α, x_0, y_0, z_0. It is assumed that the line between the sensors No. 1 and No. 5 (Fig.1) is consistent with the x axis of the rectangular coordinate system for which y=0. Because the seawater electrical conductivity σ can be measured, the number of unknown parameters is limited to seven. In order to minimize the norm (2) the Levenberg-Marquardt's algorithm [4] has been used. The minimizing procedure was chosen to minimize the potential differences for the following sensors pairs (Fig.2): {S1,S3}, {S1,S5}, {S1,S7}, {S2,S4}, {S2,S6}, {S2,S8}, {S3,S5}, {S3,S7}, {S4,S6}, {S4,S8}, {S5,S7}, {S6,S8}. Figure 3 shows examples of potential differences calculated for the following parameters: x_0=10m, y_0=1.8m, z_0=2m, I=0.1A, α=30°, θ=90° and L=0.6m. The software was made in the MathLab environment. To verify the proposed method the calculated results were taken as the measured results and using described above algorithm the object parameters were identified.

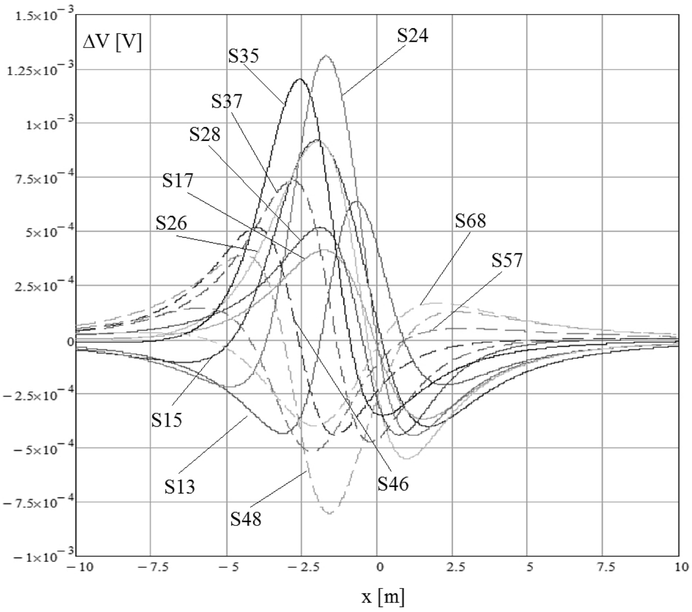

Fig. 3. Distributions of the potential differences for the following object parameters: x_o = 10 m, y_o = 1.8 m, z_o = 2 m, I=0.1A, α = 30°, θ = 90°, L=0.6m

As the result of the norm minimum calculation the following estimated object parameters were obtained: x_e = 9.6 m, y_e = 1.64 m, z_e = 1.98 m, I=0.03A, α = 0°, θ = 92°, L_e = 0.88m. These results show that the proposed method with satisfactory precision specifies the object location, but with some, quite significant errors, determined the object identification. However, such errors are acceptable for practical applications.

4. EXPERIMENTAL RESEARCH

The developed method to locate and identify the electric field source was verified for the experimental results also. Figure 4 shows the capsule containing six sensors measuring the electric field. The mine was placed on the pool bottom and the measuring capsule has been moved on the surface of water in the pool (Fig.5). On the Figure 6 some examples of electric potential differences between the probes $S_{1,3}$, $S_{1,4}$, $S_{1,6}$, $S_{2,4}$, $S_{2,6}$, $S_{3,5}$, $S_{4,6}$ are presented. The capsule was moved over the mine on the position $x_o = 3$ m, $y_o = 0$ m, $z_o = -0.5$m, L=0.50m and angles $\alpha = 0°$, $\theta = 90°$.

Fig. 4. Photo of the measuring capsule containing six electric field sensors

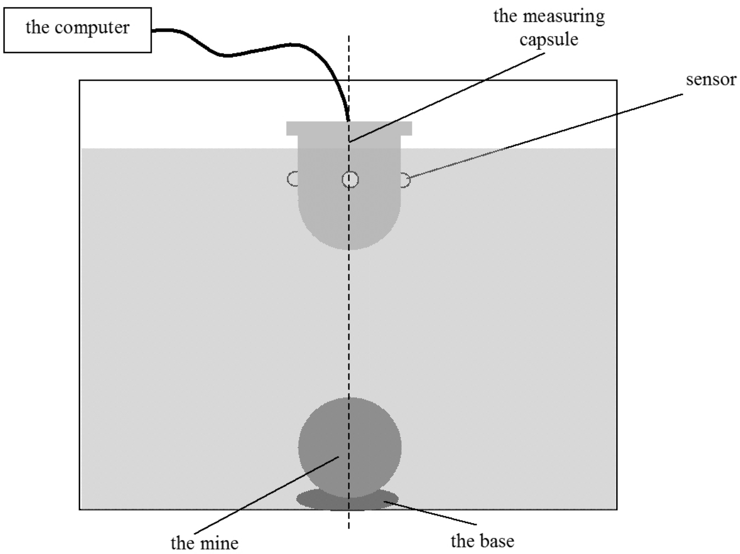

Fig. 5. Location of the mine and the measuring capsule in the pool

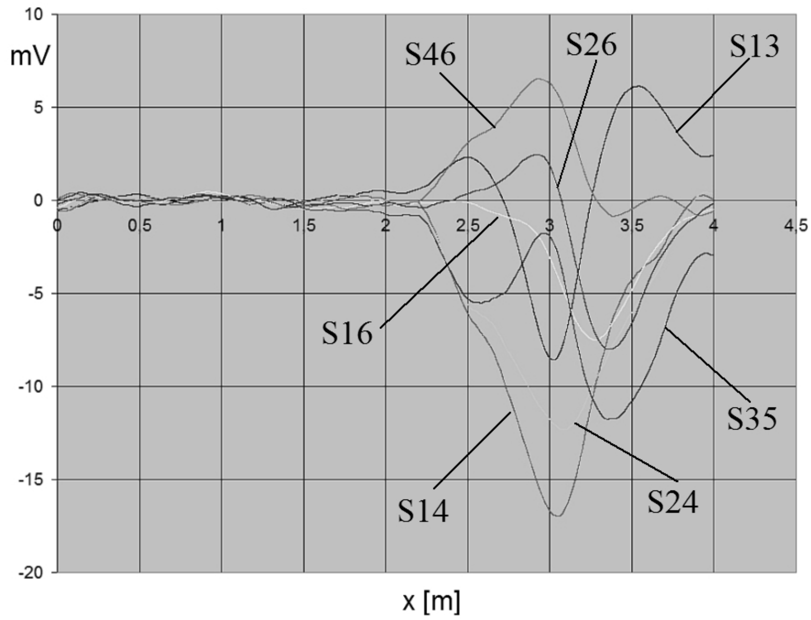

Fig. 6. Electrical potential differences distributions between probes $S_{1,3}$, $S_{1,4}$, $S_{1,6}$, $S_{2,4}$, $S_{2,6}$, $S_{3,5}$, $S_{4,6}$

As the result of optimization calculations the following location parameters of the electric source were obtained: x_e = 2.97 m, y_e = -0.18 m, z_e = –0.58 m, $\alpha = 0°$, $\theta = 43°$, L_e = 0.28m, I = 0.035 A. The results of the source location could be regarded as satisfactory, while the identification is fraught with some errors. It should be noted that especially the distance between the current source can not be identified with the length of the object in request. The electric field distribution depends on where the damages of non- conducting coating on the mine surface are located. The location of these damages influences the electric field distribution outside the object. The location of these damages on the mine surface also influences angles α and θ. Errors, due to these conditions, occur, and thus the approximate nature of the object identification.

5. SUMMARY

From the conducted research of the method for localizing and identifying small object at sea the following conclusions result:

- the Levenberg-Marquardt's optimization algorithm can be used to locate and identify objects placed in the sea, using the measuring results obtained from the measuring system moving relative to the test object;

- the results of the numerical tests and the results of measurements in the laboratory pool confirm the satisfactory performance of the presented method of location and identification of objects. The developed algorithm to locate and identify objects shows sufficient accuracy in the object localization and is less accurate in the object identification. However, the algorithm should be improved in further work.

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REFERENCES

[1] Chave A.D., Booker J.R.: Electromagnetic Induction Studies. Rev. of Geophysics. Vol. 25, No 5, pp. 989-1003, 1987.

[2] Martyshko P.S.: Three-Dimensional Electromagnetics. Society of Exploration Geophysicists. 1999.

[3] Sensor pola elektrycznego do identyfikacji bojowej platform morskich, min morskich oraz improwizowanych ładunków wybuchowych. Raport końcowy z projektu rozwojowego *MNiSzW nr OR00007009. Gdańsk 2011.*

[4] Charalambous C.: Conjugate gradient algorithm for efficient training of artificial neutral networks. IEE Proceedings, vol.139, no.3, pp.301-310, 1992.