Predicting of Ship Magnetic Field Underwater Based on Grey Theory Model

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Abstract: Based on the grey theory DGM (1,1) model, the ship magnetic field at different depths is predicted. COMSOL is used to simulate the ship's magnetic field, and the simulated magnetic field value is applied to the established model. The gray model is used to predict the ship's underwater magnetic field at different depths, which verifies the effectiveness of the gray prediction model.

1. Introduction

Ship is a complex combination. The magnetism of ship hull is produced by different objects, including the magnetism of hull and its equipment, the induced magnetic field caused by permanent magnetism and earth magnetic field of the object itself, leakage magnetic field caused by electric equipment and electronic circuit, and eddy current caused by rotation and swing of metal conductor in ship Eddy current magnetic field, etc. In order to improve the defense ability of ships, it is necessary to deal with the magnetic weapons. Therefore, the magnetic field measurement of ships is a basic content. However, it is difficult to measure the magnetic field of all planes accurately. At present, for the magnetic field analysis of different depths, the ship magnetic field is analyzed through the magnetic field numerical modeling. There are many disadvantageous factors in the calculation of ship magnetic field by using numerical modeling of ship. For example, the numerical modeling of ship magnetic field is an open domain problem and involves complicated boundary treatment. Moreover, the complex physical structure of the ship increases the difficulty of geometric modeling and subdivision [1].

Grey system theory focuses on probability and statistics, which can be used to solve the uncertainty problem of "small sample, poor information" [2]. In this paper, the magnetic field of ships at different depths is studied by grey system theory. When the data of ship magnetic field is not enough, the magnetic field in deep water is predicted by grey system theory.

2. Grey system model

2.1. Grey system theory

Grey theory is a new method to study the uncertain system problem of "part information is known, part information is unknown". Therefore, the quantitative basis of grey system theory is the generating number, which breaks through the limitation of probability and statistics, and makes the result no longer the empirical statistical law based on a large number of data in the past, but a realistic generation law. This process of making the grey system as clear as possible is called whitening [3].

In the application of grey theory, the randomness of the original data is weakened mainly by sequence accumulation generation. Sequence accumulation generation is a method to make the gray process change
from gray to white. It plays an extremely important role in the grey theory. Through the sequence accumulation generation, we can see the development trend of the grey quantity accumulation process, and reveal the integral characteristics or laws contained in the disordered original data\textsuperscript{[4]}. 

2.2. Build grey model

In the construction of grey system model, there are two grey models, GM (1,1) model and DGM (1,1) model. Both of them are common single variable grey prediction models, and their final reduction formula is homogeneous exponential function. The main difference between the two is that GM (1,1) model and DGM (1,1) model are common single variable grey prediction models, 1) The parameters of the model are estimated by difference equation, and the time response formula of the model is deduced by differential equation. Therefore, the model has the properties of partial differential and partial difference. However, due to the "non-uniformity" between the estimation of GM (1,1) model parameters and the source of model expression, even in the face of strictly homogeneous exponential series, there are still simulation errors in GM (1,1) model. The parameter estimation and time response formula of DGM (1,1) come from the difference equation, which ensures the consistency between the model parameter estimation and the source of model time response. Therefore, DGM (1,1) model can realize unbiased simulation of aligned exponential series. The ship magnetic field data are applied to the two models at the same time. By comparing the prediction results of the two models, it is found that the model error of DGM (1,1) prediction is smaller. Therefore, DGM (1,1) model is selected to study \textsuperscript{[5]}. 

The DGM (1,1) model is constructed by using MATLAB. According to the model principle of grey theory, the formula and its calculation method are programmed. At the end of the program, the average relative simulation error of the model is calculated by simulation value and prediction value.

Let $X(0)$ be a nonnegative sequence 

\[ X(0) = (x(0)(1), x(0)(2), \ldots, x(0)(n)) \] 

(1) 

Where $x(0)(k) \geq 0, k = 1, 2, \ldots, n$, The sequence of accumulation is as follows: 

\[ X(1) = (x(1)(1), x(1)(2), \ldots, x(1)(n)) \] 

(2) 

\[ x(1)(k) = \sum_{i=1}^{k} x(0)(i), k = 1, 2, \ldots, n \] 

(3) 

If $\beta$ is a parameter column, and 

\[ \beta = [\beta_1, \beta_2]^T \] 

(4) 

\[ Y = \begin{bmatrix} x(1)(2) \\ x(1)(3) \\ \vdots \\ x(1)(n) \end{bmatrix}, B = \begin{bmatrix} x(1)(1) & 1 \\ x(1)(2) & 1 \\ \vdots & \vdots \\ x(1)(n) & 1 \end{bmatrix} \] 

(5) 

Then the least square estimation parameters of the discrete grey prediction model meet the following requirements: 

\[ \hat{\beta} = (\hat{\beta}_1, \hat{\beta}_2)^T = (B^T B)^{-1} B^T Y \] 

(6) 

Through formula (6), the formula 

\[ \hat{x}(1)(1) = x(0)(1) \] 

is derived and simplified 

\[ \hat{x}(1)(k + 1) = \hat{\beta}_1^k \left( x(0)(1) - \frac{\beta_2}{\hat{\beta}_1 - 1} \right) + \frac{\beta_2}{\hat{\beta}_1 - 1} \] 

(7) 

among $k = 1, 2, \ldots, n - 1$ 

The final reduction formula of DGM (1,1) model is as follows: 

\[ \hat{x}(0)(k + 1) = \hat{x}(1)(k + 1) - \hat{x}(1)(k) = (\hat{\beta}_1 - 1)(x(0)(1) - \frac{\beta_2}{\hat{\beta}_1 - 1}) \times \hat{\beta}_1^k \] 

(8) 

In the formula, make 

\[ B = (\hat{\beta}_1 - 1) \left( x(0)(1) - \frac{\beta_2}{\hat{\beta}_1 - 1} \right) \] 

(9) 

Then equation (8) can be simplified as 

\[ \hat{x}(0)(k + 1) = B \times \hat{\beta}_1^k \] 

(10)
In the expression of $B, \beta_1, \beta_2, x(0)$, $B$ is a constant.

3. Simulation prediction

The grey model is used to predict the magnetic field of ships at different depths. This prediction is to study the magnetic field of ships at different depths from 1.1B to 2.0B.

3.1. Simulation of ship with COMSOL

The generation of ship magnetic field is to use COMSOL simulation software to simulate the ship. In the software, the ship with equal proportion is simulated. In the simulation process, the material, permeability and medium of the ship are set to be the same as the real ship. The simulated ship is shown in Figure 1. The size of the magnetic field generated by the ship under the action of external magnetic field is studied by dividing the simulated ship. Different magnetic field values of different depths under the ship are studied.

In the application of COMSOL to the simulation of ship magnetic field, in order to be as same as the real ship as possible, this paper will set the geomagnetic field close to the value of a certain area in the simulation.

In order to verify the feasibility of the simulation of the ship, the mathematical modeling method is used to simulate the magnetic field of the ship. Finally, the error of the two groups of data is analyzed. The results show that the error of magnetic field after COMSOL simulation is less than 5%. It is proved that this experiment is true.

3.2. Prediction of ship magnetic field by grey model

Firstly, the vertical component of the ship is studied. The study of the vertical component is divided into two parts. Firstly, the maximum value of the vertical component of the ship in different depths is studied. Then, the change of magnetic field in a vertical plane relative to the ship is studied. After normalizing the ship magnetic field, the research results are shown in Fig. 2 and Fig. 3.
It can be seen from the figure that the trend of the ship magnetic field change rate under the two research methods is the same. The gray prediction of the two magnetic fields shows that with the increase of the depth, the error between the predicted value and the measured value is larger, but in the two studies, the error of the predicted value is within the acceptable range.

In the study of fixed magnetic field, induced magnetic field and total magnetic field, as shown in Figure 4, Figure 5 and Figure 6, the magnetic field gradually decreases with the increase of depth. It can be seen from the figure that the change trend of the three kinds of magnetic fields is the same. The measured values of the three magnetic fields are introduced into the grey prediction model, and the error of the predicted values increases with the increase of the measurement depth. The magnetic field predicted by grey model is feasible, and the error is within the acceptable range.
Figure 4 Comparison of predicted and measured total magnetic field at different depths

Figure 5 Comparison of predicted and measured values of induced magnetic field at different depths
4. Conclusion and discussion

With the increase of depth, the error between the predicted value and the simulation value is increasing. The minimum error is 4.5% and the maximum is 16.2%. In this experiment, the amount of data is too small. After increasing the amount of data in the later stage, the error can be further reduced. Therefore, the grey model can be applied to the study of ship magnetic field.

The research object of this paper is the research on the increase of depth. Later, we can study the changes of different magnetic fields with the extension of horizontal plane. Through the extension of the plane, the magnetic field data of the ship's large plane can be obtained, which can ultimately improve the numerical algorithm of the ship.

References

[1] Xiao,C.H., Zhou, G.H. (2010) overview of numerical modeling technology of magnetic field in warship magnetic stealth.In:2011 National Academic Conference on electrical theory and new technology. Tianjin. 265-270.

[2] Ding,M., Liu,Z., Bi,R., (2015) Photovoltaic power prediction based on grey system correction wavelet neural network [J]. Power grid technology, 39 (9): 2438-2443.

[3] Wang,C., (2016) Research on power load forecasting based on Grey Theory[D]. Jinan: Shandong University, 16-36.

[4] Liu,S.F., Dang,Y.G., Fang,Z.G., Xie,N.M., 2010 grey system theory and its application. Version 5. Beijing: Science Press.

[5] Zeng,B., Yin,X.Y., Meng,W., (2018) Practical grey prediction modeling method and its matlab program implementation. Science Press, Beijing.