Analysis and Research on the Influence of Sonar Dome on Ship's Underwater Electrostatic Field

Qingjie Chen, Runxiang Jiang*

College of Electrical Engineering, Naval University of Engineering, Wuhan, Hubei, 430033, China
*Corresponding author’s e-mail: jiang_runxiang@163.com

Abstract. This paper firstly analyzes the influence of the sonar dome on the ship's underwater electrostatic field in theory, and then uses boundary element software to simulate and analyze this kind of influence. It is found that the sonar dome can be used as a cathode to participate in the electrochemical corrosion of ships, forming a "propeller-hull-sonar dome" corrosion system. In this case, the "dubble compensation anode" method is proposed in order to control the electric field signature, and the effectiveness of this method is verified by the boundary element simulation software.

1. Introduction

When a ship is corroded or switched on anti-corrosion electric current, the static electric field will be generated underwater. This static electric field signal will become the source of the attack signal for underwater weapons. The navies of all countries attach great importance to decreasing the ship's static electric field [1-3], such as "The Каскад-Э" system, the "Advanced ICCP" system, which are used to reduce the static electric field [4], and the Active Shaft Grounding (ASG) is used to reduce the shaft frequency electric field [5]. Domestic research on the electric field of ships began in the 1980s. In order to reduce the electric field of ships, methods of optimized structure for ships, impressed-current compensation and the optimization of cathodic protection have been proposed successively [6-8]. Among them, impressed-current compensation method can reduce the static electric field signal to a greater extent, but it is mainly aimed at the electric field caused by the "hull-propeller" electrochemical system. In fact, when the dome and the hull material are inconsistent and there is an electrical connection, a corrosion-related electric field will also be generated, so the electrochemical corrosion system changes from "hull-propeller" to "dome-hull-propeller" (Dome-Hull —Propeller, DHP). In order to realize electric field stealth to the greatest extent, it is necessary to clarify the influence of the electrochemical corrosion system composed of the dome and the hull on the electric field of the ship, and propose its control method.

2. The mechanism for the generation of "DHP" corrosion electric field

Normally, the hull material is low-alloy steel, the propeller material is aluminum bronze, and the sonar dome material is stainless steel or titanium alloy. When different metals are electrically connected in seawater, they will form an electrochemical corrosion system, so the corrosion current will be formed in seawater. The potential of titanium alloy and stainless steel is greater than that of the hull according to the theory of mixed potential. Compared with the "hull-propeller" electrochemical corrosion system, the "dome-hull-propeller" also contains the current of "hull→dome" in addition to including the current of "hull→propeller". The underwater equivalent current line of the ship is shown in Figure 1.
3. Analysis of the "DHP" corrosion electrostatic field

Since the underwater static electric field of a ship is mainly generated by corrosion and anti-corrosion current, it can be calculated by the finite element method or the boundary element method[9-10]. In this paper, the boundary element method described in literature [9] is used to analyze the characteristics of the corrosion static electric field of the "dome-hull-propeller". The schematic diagram of a typical ship structure is shown in Figure 2, where the length of the ship is $L=130\text{m}$, the width $B=15\text{m}$, and the draught is $4\text{m}$. The dome is made of 316L stainless steel, the hull is made of low-alloy steel, and the propeller is made of aluminum bronze. The polarization curve with a conductivity of $4\text{S/m}$ in seawater is shown in Figure 3.

![Figure 2. Typical ship structure](image)

In order to study the change of the hull potential caused by the dome, the hull is divided into 11 sections from the fore to the stern (named ship0, ship1,..., ship10 in turn). When the materials of the dome are insulation or stainless steel, the hull surface information of the electrochemical corrosion
system of "Hull-Propeller" and "Dome-Hull-Propeller" is shown in Table 1, which is obtained by the simulation calculation. The water depth is 1.0B plane. The electric field signal is shown in Figure 4.

Table 1. Hull-propeller, hull-propeller-dome electrochemical system hull surface information.

| Heading   | Size (m²) | Current (mA) | Maximum potential (mV) |
|-----------|-----------|--------------|------------------------|
|           |           | Hull-propeller | Hull-propeller-dome | Hull-propeller | Hull-propeller-dome |
| Dome      | 56.233    | 0.000         | 4243.208               | -479.459     | -422.968             |
| ship0     | 25.784    | -79.276       | -367.329               | -480.687     | -437.664             |
| ship1     | 141.150   | -372.090      | -1039.819              | -481.474     | -455.701             |
| ship2     | 171.367   | -399.208      | -814.544               | -482.947     | -475.752             |
| ship3     | 211.625   | -457.308      | -854.777               | -483.003     | -477.802             |
| ship4     | 243.208   | -500.026      | -894.782               | -482.976     | -478.872             |
| ship5     | 259.814   | -564.122      | -945.763               | -482.809     | -478.982             |
| ship6     | 261.115   | -616.457      | -964.108               | -482.304     | -478.545             |
| ship7     | 249.835   | -731.820      | -1037.919              | -480.821     | -477.003             |
| ship8     | 227.769   | -951.340      | -1219.597              | -474.765     | -471.267             |
| ship9     | 186.164   | -1864.460     | -2033.569              | -440.300     | -438.547             |
| ship10    | 93.250    | -779.856      | -878.827               | -463.247     | -460.079             |
| Rudder    | 88.257    | -805.997      | -909.872               | -417.493     | -416.013             |
| Propeller hub | 9.439 | 1237.997      | 1185.517                | -392.173     | -391.352             |
| Paddle    | 47.075    | 7189.619      | 6907.734                | -397.597     | -396.596             |

(A) Underwater electric field signal composed of "drain shield-hull-propeller"
From Table 1 and Figure 4, it can be found that due to the intervention of the dome, the current, potential and underwater electric field on the hull surface have changed significantly. Compared with the underwater electric field signal of the "hull-propeller" electrochemical system, there are two positive peaks and one negative peak in the underwater electric field signal of the "dome-hull-propeller" electrochemical system, and the new positive peak appears near the dome. This is because the dome and the propeller serve as cathodes in the conductive seawater, and the middle hull serves as the anode, forming a "dome-hull-propeller" electrochemical system.

4. Research of "DHP" corrosion static electric field stealth method

4.1 Basic principle of impressed current compensation
The impressed current compensation technology proposed in literature[7] is a method to achieve static electric field stealth by applying a current opposite to the natural corrosion current. This method can effectively reduce the electric field of the "ship-propeller" electrochemical corrosion system. The basic principle is to suppress the underwater static electric field of the ship by installing a compensation anode near the cathode to output a compensation current opposite to the natural corrosion current.

Figure 5 is the electric field signal at the depth of 1B plane underwater when the dome is made of insulating material and the output current of the compensation anode is 16A. Comparing Figure 5 and Figure 4(b), it can be found that the underwater static electric field signal can be reduced significantly by applying a certain amount of compensation current to the compensation anode. Before or after current compensation, the peak-to-peak potential of the "hull-propeller" electrochemical corrosion system are 8mV and 2mV, respectively.
5

Figure 5. The electric field value of the plane at a depth of 1B when the deflector is insulated and the compensation current is 16A.

Under the condition that the dome’s material is 316L stainless steel, the relationship curve between the peak-to-peak value of the underwater electric field and the output current of the compensation anode is shown in Figure 6 (the electric field is the smallest when the output current of the compensation anode is 16A). It can be clearly found from figure 6 that due to the intervention of the dome, the ability of the compensation anode to reduce the ship’s electric field has dropped significantly (the potential peak-to-peak value after current compensation is 8.915mV, which is significantly greater than the previous 2mV). This means although the compensating anode can reduce the electric field of the "hull-propeller" electrochemical corrosion system, it cannot reduce the electric field of the "hull-dome" electrochemical system. Therefore, in order to reduce the electric field of the "hull-propeller" electrochemical system while also reducing the electric field of the "hull-dome" electrochemical system, a pair of compensation anodes needs to be installed above the dome.

Figure 6. The peak-to-peak value of the underwater electric field when the anode outputs different compensation currents.

4.2 Double compensation anode electric field control method
In order to better suppress the underwater electric field generated by the electrochemical system of the "dome-hull-propeller", the "duble compensation anode" method is proposed. In addition to installing a pair of compensation anodes above the propeller, a pair of compensation anodes are also installed near the dome (as shown in Figure 7). The compensation anode near the dome is defined as A and the compensation anode near the propeller is defined as B. When the anode B compensation current is 16A and the anode A compensation current is different, the underwater electric field value of the ship is shown in figure 8. It can be found from figure 8 that the peak-to-peak value of the underwater electric
field decreases at first and then increases, which illustrates the correctness of the double-compensation anode method for reducing the electric field of the "dome-hull-propeller" electrochemical corrosion system. Taking the minimum underwater electric field value as the optimized objective function, the optimized output currents of anode A and B are 4.6A and 21.6A, respectively, and the corresponding electric field peak-peak value is shown in Table 2.

![Figure 7](image7.png)

Figure 7. The installation position of the compensation anode near the dome.

![Figure 8](image8.png)

Figure 8. The peak-peak value of underwater potential when anode B=16A and anode A is equal to different currents.

| Condition                        | Ex peak-to-peak value (mV/m) | Ey peak-to-peak value (mV/m) | Ez peak-to-peak value (mV/m) | | peak-to-peak value (mV/m) | U peak-to-peak value (mV) |
|----------------------------------|------------------------------|------------------------------|-------------------------------|--------------------------|--------------------------|
| Natural corrosion                | 0.8254                       | 0.5255                       | 1.0241                        | 0.7155                   | 12.2460                  |
| Tail compensation anode output  | 0.484                        | 0.410                        | 0.6757                        | 0.549                    | 8.915                    |
It can be seen from Table 2 that after the software optimizes the compensation current, the double compensation anode method can greatly reduce the underwater static electric field generated by the "dome-hull-propeller" electrochemical system, and the suppression ratio of the peak-peak value of $|E|$ at the depth of 1B plane underwater increases from 23.27% to 47.53%, an increase of 24.26%. The potential peak-to-peak suppression ratio increases from 27.2% to 76.66%, an increase of 49.46%. The main reason is that the two pairs of compensation anodes can reduce the electric field of the "hull-propeller" and "hull-dome" electrochemical systems respectively, thereby reducing the ship electric field signal to the greatest extent, while one pair of compensation anodes can only reduce the electric field of the "hull-propeller" electrochemical system.

5. Conclusion
The dome will act as a cathode to participate in the electrochemical corrosion of the ship, reducing the ship's electric field stealth performance. The double-compensation anode electric field control method proposed in this paper can greatly improve the electric field stealth performance of ships affected by the dome, and the suppression ratio of the static electric field signal can be increased by 24.26%. In the next step, how to adaptively adjust the anode compensation current according to the temperature, salinity and oxygen content of the seawater and the state of the hull surface is the direction of research.

Acknowledgments
This work was supported in part by the National Natural Science Foundation of China under Grant (51377165).

Reference
[1] Hubbard J C, Brooks S H, Torrance B C.(1996)Practical measures for reduction and management of the electro-magnetic signatures of in-service surface ships and submarines.Underwater Defence Technology Conference, London.
[2] Harrison A S,Hubbard J C.(1994)An underwater electric potential (static electric) signature management toolkit for the non-specialist.Conf Proc UDT,Europe.
[3] Hoitham P,Jeffery I,Brooking B,Richards T.(1999)Electromagnetic signature modeling and reduction.Conf Proc UDT,Europe.
[4] Peng Yu, Runxiang Jiang, Jinfang Cheng.(2017) Research on Stealth Method of Electrostatic Field Related to Ship Corrosion . Journal of Wuhan University of Technology 6: 1017-1021.
[5] Bedard,Joseph R J.(2002)Active shaft grounding system for ELF signature control. Canadian
[6] Chunsheng Lin,Shenguang Gong. (2007)Ship Physics. Weapon Industry Press,Beijing.
[7] XING S H, LI Y,SONG H Q,etc.(2016)Optimizing the quantity,locations and output currents of anodes to improve cathodic protection effect of semi-submersible Crane vessel.Ocean Engineering 1: 144-150.
[8] XING S,WU J,YAN Y.(2009)Optimization of a ship’s ICCP system to minimize electrical and magnetic signature by mathematical simulation.WIT Transactions on Engineering Sciences 1: 69-78.
[9] Adey R A,Niku S M.(1992)Computer modelling of corrosion using the boundary element method.Munn R S.
[10] Adey R A,Pei Y H.(1999)Computer Stimulation as an aid to Corrosion Control and Reduction. Taxas Corrosion.