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Influence of anode location and quantity for the reduction of underwater electric fields under cathodic protection

Y.-S. Kim[a], S.K. Lee[b], J.-G. Kim[a,*]

[a] School of Advanced Materials Engineering, Sungkyunkwan University, 2066, Seobu-Ro, Jangan-Gu, Suwon-Si, Gyonggi-Do, 16419, Republic of Korea
[b] The 6th Research and Development Institute, Agency for Defense Development, 18th, Jinhae P.O.Box, Jinhae-Gu, Changwon-Si, Gyeongsangnam-Do, 51678, Republic of Korea

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ABSTRACT

To investigate the effect of anode location and quantities on underwater electric fields, numerical simulations were performed using the boundary element method. Simulations were performed for the cases of 3, 4, and 5 pairs and the installation locations of the anodes were set at 10 different hull regions. Although the potential difference was nearly unchanged with changes in the anode locations, the electric field was effectively diminished when the anodes were uniformly distributed through prevention of the current concentration at the specific region. Additionally, increasing the number of anodes decreased the underwater electric field, although the decrease rate of the electric field reduced. Thus, the locations of anodes should be uniformly distributed and an adequate number of anodes should be applied to effectively reduce the underwater electric fields.

1. Introduction

Electric fields form around ship due to current flow from cathodic protection (CP) systems, such as impressed current cathodic protection (ICCP) and sacrificial anode cathodic protection (SACP) (Xing et al., 2009). Also, underwater electrical potentials (UEP), which can generate underwater electric signatures, may form even in the absence of CP systems due to galvanic corrosion between the hull (steel) and propeller (nickel aluminum bronze, NAB). A steady current flow around the hull of a ship can create an underwater electric field. Modern underwater mines are attuned to these electric field signatures and use them to detect and classify passing vessels. Thus, diminishing underwater electric fields is required to increase survivability (Mathiazhagan, 2010; DeGiorgi et al., 2005).

One of the main sources for current flow is the cathodic protection current from ICCP. According to the Evan's diagram in Fig. 1, the applied current for CP can be theoretically determined by the polarization curve (Abootalebi et al., 2010; Kim et al., 2016). As seen in Fig. 1, the anodic current density is under activation control (activation polarization) and the cathodic current density is limited at a higher current density (concentration polarization). As the applied current for CP is increased, the potential of the ship material is reduced and the corrosion current density is reduced accordingly (Roberge, 1999). Additionally, the amount of applied current is generally proportional to the intensity of the underwater electric field, indicating that the applied current should be minimized for electric field silencing.

Prior to the 1980s, the quantity and location of the ICCP anodes were determined primarily based on empirical equations and the experience of engineers. However, ICCP designed with these methods can often lead to under or overprotection, easily inducing insufficient cathodic protection or hydrogen induced cracking and the cathodic stripping of coatings. To solve this problem, it is important to consider the relationship between the cathodic protection efficiency and the location or number of anodes. Recently, the prediction or design of CP and underwater electric fields has been performed via numerical simulation, especially the boundary element method (BEM) (Kim et al., 2017a,b; Zamani et al., 1987; Xing et al., 2016; Z. Lan et al., 2012). Although cathodic protection optimization studies investigating the location or quantity of anodes have been performed previously (Diaz and Adey, 2005), these methods possess some challenges due to their complex structure, presence of a sacrificial anode, and polarization curves under various conditions. Therefore, detailed studies are therefore needed under a variety of conditions and structures. Also, prediction methods for underwater electric fields are needed to decrease the time-consuming processes used during the design of vessels.

The latest researches included simulation of underwater electric field caused by cathodic protection, influence of deep sea condition on the electric field of an underwater vehicle (Kim et al., 2018a,b), investigation of underwater electric field of ship protected by cathodic current using computer simulation under the different conductivity

* Corresponding author.
E-mail addresses: kimjg@skku.edu, kimjg@skku.ac.kr (J.-G. Kim).

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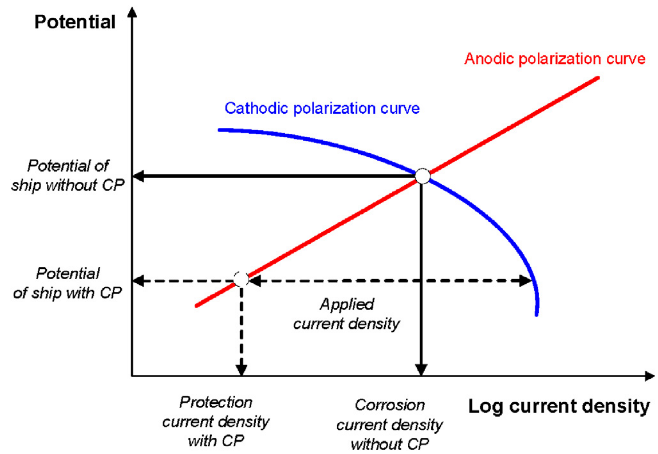

Fig. 1. Evan's diagram, indicating the relationship between the applied current and protection potential.

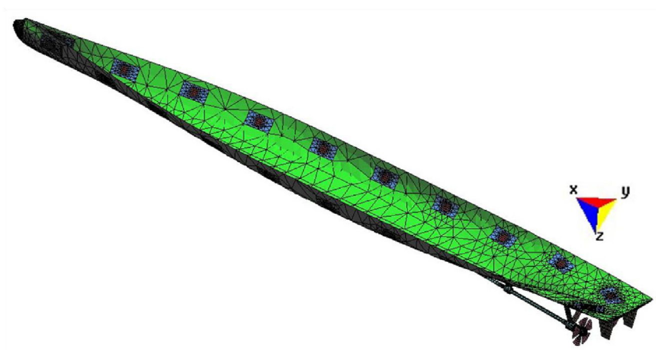

Fig. 2. Numerical model of the ship used in the simulation.

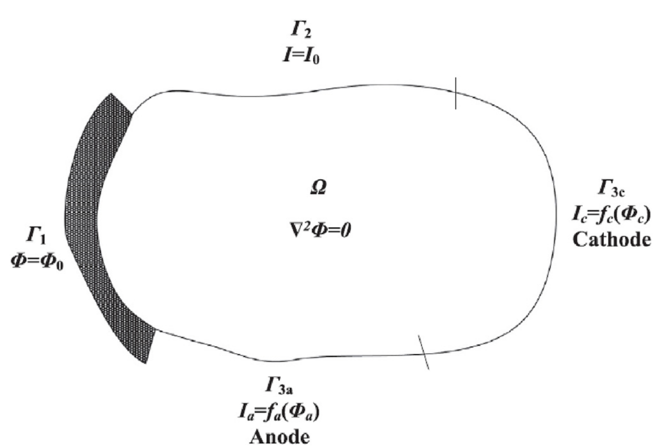

Fig. 3. Boundary conditions with regard to cathodic protection.

Table 1
Results of the anode positions with the sum of the installed number and normalized maximum electric field for the case of 3 pairs. Anode positions are numbered from 1 to 10 according to the uniformly sectioned 10 regions from bow to stern.

Anode position	Sum of anodes installed position number	Normalized maximum electric field
(1, 2, 3)	6	0.757
(1, 2, 6)	9	0.445
(1, 3, 7)	11	0.464
(2, 4, 7)	13	0.309
(2, 5, 7)	14	0.401
(3, 5, 8)	16	0.318
(4, 6, 9)	19	0.359
(5, 7, 9)	21	0.432
(7, 8, 9)	24	0.631
(8, 9, 10)	27	0.967

Table 2
Results of the anode positions with the sum of the installed number and normalized maximum electric field for the case of 4 pairs. Anode positions are numbered from 1 to 10 according to the sectioning 10 region from bow to stern.

Anode position	Sum of anodes installed position number	Normalized maximum electric field
(1, 2, 3, 4)	10	0.643
(1, 2, 4, 8)	15	0.551
(1, 3, 5, 8)	17	0.325
(1, 4, 6, 8)	19	0.257
(2, 4, 6, 10)	22	0.501
(2, 5, 7, 9)	23	0.294
(4, 5, 7, 10)	26	0.345
(3, 6, 9, 10)	28	0.342
(6, 7, 8, 9)	30	0.547
(7, 8, 9, 10)	34	0.635

Table 3
Results of the anode positions with the sum of the installed number and normalized maximum electric field for the case of 5 pairs. Anode positions are numbered from 1 to 10 according to the sectioning 10 region from bow to stern.

Anode position	Sum of anodes installed position number	Normalized maximum electric field
(1, 2, 3, 4, 5)	15	0.576
(1, 2, 3, 4, 9)	19	0.631
(1, 2, 4, 6, 10)	23	0.526
(1, 3, 5, 7, 9)	25	0.225
(2, 3, 5, 7, 9)	26	0.246
(2, 4, 6, 7, 9)	28	0.232
(3, 4, 6, 8, 9)	30	0.275
(2, 5, 7, 8, 10)	32	0.252
(5, 6, 7, 8, 9)	35	0.438
(6, 7, 8, 9, 10)	40	0.539

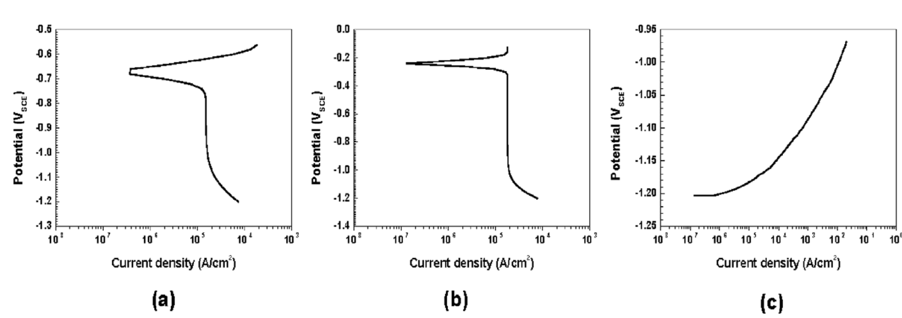

Fig. 4. Polarization curves of (a) HY80, (b) NAB and (c) Zn.