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Investigation of Design Methodology for Impressed Current Cathodic Protection Optimum System

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In this paper, physical scale modeling was employed to identify the configurations of ICCP system and the electric field signatures. Computational boundary element modeling technique has been used to simulate the performance of the CP system and to predict the associated electric fields signatures. The optimization methods combined with the computer models and physical scale modeling will be presented here, which enable the optimum system design to be achieved both in terms of the location and current output of the anode but also in the location of reference electrodes for impressed current cathodic protection(ICCP) systems. The combined methodology was utilized to determine optimal placement of ICCP components (anodes and reference electrodes) and to evaluate performance of ICCP system for the 2%, 10% and 14% wetted hull coatings loss. The objective is to design the system to minimise the electric field while at the same time provide adequate protection for the ship. The results show that experimental scale modeling and computational modeling techniques can be used in concert to design an optimum ICCP system and to provide information for quickly analysis of the system and its surrounding environment.

Keywords *: impressed current cathodic protection (ICCP), electric field signature, Boundary Elements Methods (BEM), physical scale modeling (PSM)*

1. Introduction

Corrosion damage is a major reason in ship maintenance. Impressed current cathodic protection system (ICCP) with coating is an effective method of controlling the corrosion. ICCP system has been widely used for protecting ships from corrosion. ICCP system is designed to provide adequate cathodic current to anodes on the ship hull to be protected, in the meanwhile the cathodic protection current passing seawater also generates electric signature and induces magnetic field.[1] Because an ICCP system involves impressing current onto the hull of the ship current flow will into the sea giving rise to both an electric and magnetic signature, the operation for today's vessel is composed of a large number of treats that use electromagnetic signature as a means of detection.[2] For this reason the ICCP system must not only be designed so that they perform adequate corrosion protection but they must be also be design so as to maintain stealth. The purpose of optimization design of cathodic protection systems is not only to protect the integrity of the ship but also to minimize the electric fields signatures generated in the sea water by the impressed current cathodic protection system (ICCP) system.[3] In this paper we present the research results of two methodologies for designing optimal ICCP systems. The first is physical scale modeling which is experimentally based. The second is computational boundary element modeling analysis techniques which relies on computational analyses.

2. Material and methods

A methodology for ICCP system design based on experimental physical scale modeling and computational boundary element modeling analysis techniques has been studied.

Computational numerical modeling reliability depends on polarization curves and acquiring of coating condition and PSM is time-consumed and must be fitted with complicated equipments and measurement system.[4]

2.1 Computational boundary element modeling

The use of boundary element methods to model corrosion systems which are governed by Lap lace's equation is well established. The computational analyses method relies heavily on validation using experimental results.[5]

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In this paper, optimization methods combine with the computer models will be presented which enable the optimum system design to be achieved both in terms of the location and current output of the anode but also in the location of reference electrodes for ICCP systems. Examples will be presented the same ship that used by the physical modeling. Numerical modeling software has been programmed and was used to calculated potential profile on the hull surface and in seawater surrounding the hull. Steady electric field could be predicted by providing boundary condition such as material polarization characteristics, dimension limitation and medium properties. The steady electromagnetic signature due to ICCP can be predicted with numerical modeling based on boundary element method.

Computational modeling is used to evaluate multiple candidate ICCP system designs. Changes in anode number and placement, reference cell number and placement and power zone definitions can be readily evaluated. The final design as determined by computational analysis is then evaluated by physical scale modeling. In this study, coating damages of assured wetted hull surface and rudder surface has the 2%, 10% and 14% coatings loss, respectively. Four different systems have been computationally analyzed: one control point (single-zone) system with four and six anodes, and two dual control point (two-zone) systems with either four or six anodes, respectively.

2.2 Physical scale modeling

Physical scale modeling is a experimental technique in which the linear dimension of the structure and the Conductivity of the electrolyte is scaled by the same factor.[4)]

A 1/100 physical scaling model representing of a typical ship was established and used to study optimization of the impressed current cathodic protection (ICCP) system in this study. The model ship was manufactured from 1 mm thick mild steel, with two high manganese aluminium-bronze propellers and high strength steel shafts. The hull was painted with an epoxy coating with areas of bare steel to represent damaged paint. The measured hull potential profiles along the centre line of a 1:100 scale model with 2%, 10% and 14% paint damage were illustrated, which the abscissa represent the frame number of model hull, the coordinate represent the surface potential of the hull. Frame numbers 0 and 250 correlate with bow and stern at the waterline. The model ship is shown in Fig. 1. The model was fitted with the scale size ICCP system, which consists of anodes connected to power supplies, reference electrodes to monitor hull potential state, and a controller to adjust the current output of the anodes. The platinum- niobium thread scale anodes on the shields were fitted to the hull. Impressed current cathodic protection was provided by a potentiostatic instrument (Solartron SI1287 Electrochemical Interface) employing a miniature Ag/AgCl reference electrode to control the dc current output. A set potential of -0.85 V (vs. Ag/AgCl) was maintained at the reference electrode .The model was immersed and tested in a tank containing sea water diluted to a conductivity of 35 mSm^{-1}(i.e. one -hundredth that of standard sea water). The distribution of potential over the hull was measured by an array of 16 miniature Ag/AgCl reference electrodes. The virtual instrumentation NI PXI 1042 was employed to sample, process and obtain the potential profile of the ship hull.

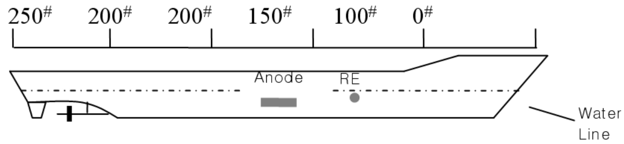

Fig. 1. Diagram of physical model of ship hull

Tests were carried out under four ICCP configuration systems. The configurations were as flows:

1) Four anodes single zone.
2) Six anodes single zone.
3) Four anodes double zone.
4) Six anodes double zone.

The effects of reference electrode and anode on distribution of the potential profile over the hull were examined by using single factor method. Based on these experiments, optimum single-zone and double-zones impressed current cathodic protection design was considered by using uniform design method. Fig. 1 show the diagram of model hull fitted with ICCP system.

3. Results and discussion

3.1 Computational software (BEM)

Computational software based boundary element computational methods have been programmed as predictive tools for on-hull potential profiles and corrosion related electric field signature in seawater surrounding the hull. The software enables to calculate surface potential and current density distribution of hull, propeller and anode; determine potential target valve of reference cell; model the parameters of ICCP system such as anode location, reference electrode location and number of anodes to achieve protection potential that be set previous; predict the electric field flowing through the sea water surrounding a ship by providing boundary condition such as material polar-

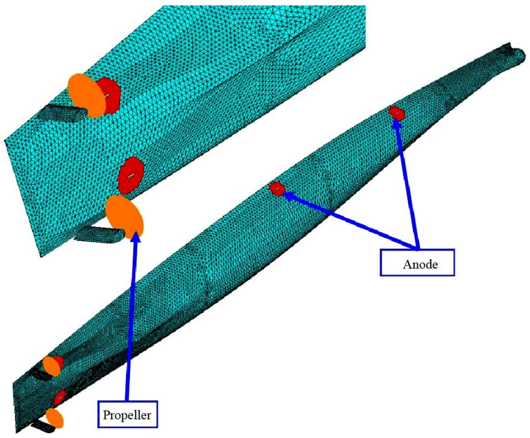

Fig. 2. Boundary element model of ship hull including propellers and rudders(Six anodes double zone ICCP system, 2% coatings loss)

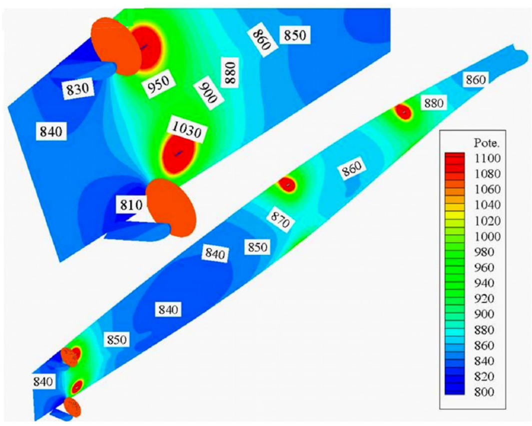

Fig. 3. Potential contours on the ship hull including propellers and rudders (mV.Ag/AgCl)(Six anodes double zone ICCP system, 2% coatings loss)

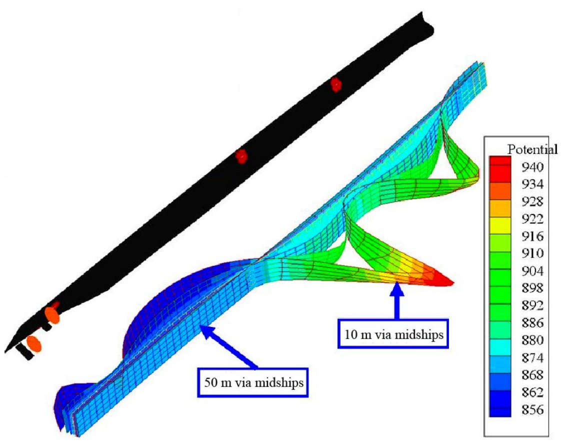

Fig. 4. Ship underwater steady electric field signature prediction(at a depth of 5 m from waterline)

ization characteristics, dimension limitation and medium properties. The computation results based on multiple ICCP configuration of a typical ship are available. Some results of optimal design are illustrated in Figs. 2-4.

Fig. 2, 3 shows that Boundary element model and potential contours of ship hull including propellers and rudders. Fig. 4 shows that steady electric field surrounding ship at a depth of 5 meters from waterline that be predicted by Boundary element model techniques. The steady electromagnetic signature due to ICCP can be predicted with numerical modeling based on boundary element method. The steady electric signature around hull can be greatly lessened by optimizing electrode's locations and multi-zone ICCP in software numerical modeling based on the boundary element method.

3.2 Experimental results (PSM)

A 1/100 physical scaling model of a typical ship was established and used to study optimization of the impressed current catholic protection (ICCP) system. The physical scale modeling is used to evaluate the optimal design of ICCP as determined by computational analysis.

Results show that the relative location and number of anodes, reference electrodes markedly affects the overall shape and magnitude of the potential profile over the hull. As given anode position, fig. 5 shows that the fluctuation of potential profile is reduced by increasing the amount of anode. As also shown in fig. 5, compared with single-zone ICCP system, the double-zones system can optimize the potential profile and remain more stable with minimum variation. Under the optimization configuration of ICCP system, the potential range along the surface of the hull was between -0.80 V and -1.0 V (Ag/ACL), which provide adequate corrosion protection to the hull of the

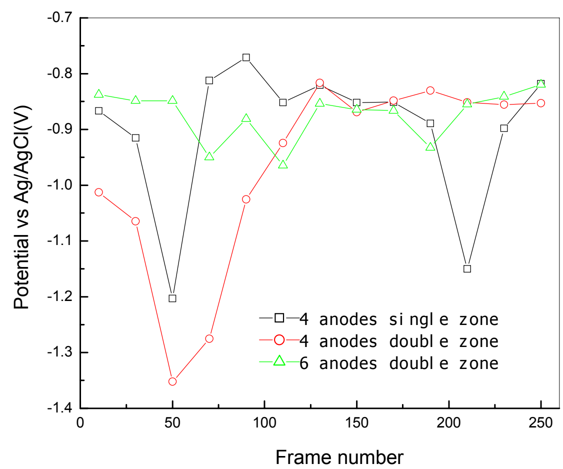

Fig. 5. Comparisons of single zone and double zone ICCP system of model ship

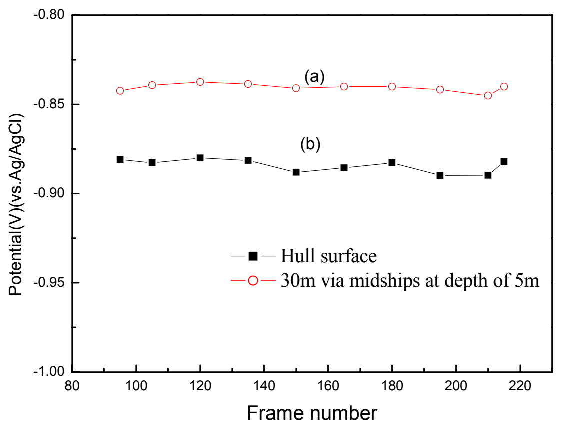

Fig. 6. Ship underwater steady electric field signature of model ship(Six anodes double zone ICCP system)

vessel. Under water potential profiles (steady electric field) at a depth of 5 m from the waterline are shown in Fig. 6. It was clear that a six anodes double-zone ICCP system is more likely to produce the most even potential distribution, which provided adequate corrosion protection to the hull of the ship and avoided under- and over- protection for the hull. The optimization design of ICCP system can minimize the electric fields signatures generated in the sea water by the impressed current catholic protection system (ICCP) system. The potential profiles of hull under same ICCP configuration system show very good agreement between experimental and computational results.

The use of physical scale modelling is an experimental technique which does not depend on the electrochemical polarization data and uses the actual materials of a ship hull which are protected in a real electrolyte. Thus, different ICCP configuration can be evaluated in the laboratory under various operational conditions. Scale model testing could determine the optimum placement of anodes and reference cells to produce uniform potential on the entire hull surface.

4. Summary

1) The work that has been presented here is part of an on-going research project that closely links computational with experimental validation.

2) The potential profiles of hull under same ICCP configuration system show very good agreement between experimental and computational results.

3) The steady electromagnetic signature due to ICCP can be predicted with numerical modeling based on boundary element method. The steady electric signature around hull can be greatly lessened by optimizing electrode's locations and multi-zone ICCP in software numerical modeling based on the boundary element method and physical scale model (PSM).

4) The results show that experimental scale modeling and computational modeling techniques can be used in concert to design an optimum ICCP system and to provide information for quickly analysis of the system and its surrounding environment.

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