Predicting corrosion related electrical and magnetic fields using BEM

Robert Adey, John Baynham
Computational Mechanics BEASY Ltd, Ashurst Lodge, Ashurst, Southampton, Hampshire, SO40 7AA, UK Tel: +44 (2380) 293223 Fax: +44 (2380) 292853
www.beasy.com r.adey@beasy.com

Abstract

Computer models have for some years been used to predict the performance of ICCP systems on ships and boats. The objective being to achieve optimum protection of the vessel from corrosion and to predict the associated fields/signatures.

However, in many cases these models have been based on simple dipole approximations. In this paper a new system is described which integrates the electric and magnetic models to provide a tool capable of accurately predicting the impact of any change in the ICCP system, surface conditions or environmental conditions on the electric and magnetic signatures.

The model is based on the boundary element method which enables the exact geometry of the vessel to be described including anodes, reference electrodes, surface conditions and polarisation properties.

The paper not only describes the theoretical background of the model but also it’s application to optimise the ICCP system and it's related electric and magnetic fields.

Introduction

Corrosion damage is a major factor in ship maintenance and availability. Paints and shipboard impressed current cathodic protection (ICCP) systems are important established tools in the reduction of corrosion damage to ships.

ICCP systems are designed to take advantage of the electrochemical corrosion phenomenon. By applying an external source of current to anodes on the ship hull current passes through the surrounding sea water to the parts of the hull to be protected. The ICCP system is designed to ensure that the current flowing from the anodes is sufficient to maintain the potential on the hull below a certain value of potential which inhibits the electrochemical reaction which causes corrosion.

The design of the cathodic protection system is of interest to defence organisations not only to ensure the integrity of the ship but also because of the electric fields generated in the sea water by the ICCP system. These fields are known as the signature of the ship.

Electro magnetic signatures are playing an important role in the detection of naval vessels and in the fusing of intelligent mines. The static electric signature is the electric field associated with the DC corrosion or cathodic protection current which flows through the sea water around a vessel. This is sometimes referred to as the Underwater Electrical Potential or

UEP. The corrosion related magnetic (CRM) field is the coupled magnetic field caused by the corrosion related electric currents flowing in the sea water between the anodes and the ship hull.

It is important to note that UEP and CRM signatures exist even in the absence of a cathodic protection system. They are caused by the galvanic potential differences between the metallic structures in contact with the sea water. For example, the relative position in the electrochemical table of steel and bronze provides a sufficient driving potential to create an electric field.

In order to control the signatures and to preserve the integrity of a vessel it is essential to be able to predict the impact of the design and operation of the ICCP system on the electric fields.

Computational models have been widely used to predict the electromagnetic fields associated with vessels due to on board systems and ferromagnetic aspects. The software BEASY [1] has been widely used to predict the performance of cathodic protection systems by modelling the coupled electric fields and electrochemistry for complete ships and other structures. Other authors have used simple dipole models to make predictions.

In this paper an integrated approach is presented to enable the performance of the ICCP system, the corrosion related electric field and the corrosion related magnetic field to be predicted using one detailed model.

Theoretical Aspects

The boundary element method (BEM) has been proved to provide the optimum solution to problems associated with corrosion simulation [2]. The BEM requires the user to only describe the boundary or surface of the ship to be modelled thus simplifying the modelling process. There are also additional benefits which are described in [2]. Figure 1 shows an example of a BEM model.

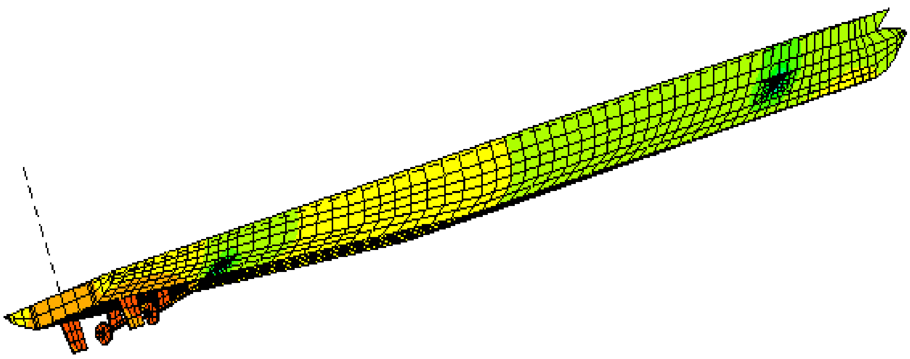

Figure 1 BEM model of a ship
Note: only elements on the wetted surface of the ship

To model a CP problem the computer model must simulate the IR drop through the electrolyte and the electrochemical electrode kinetics on the metallic surfaces. Therefore, a boat in the sea can be considered as a galvanic systems (Figure 2).

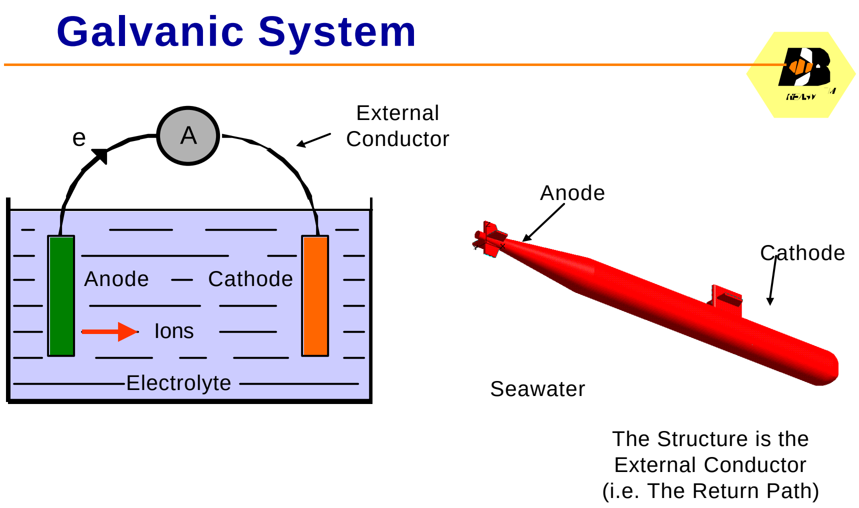

Figure 2 The CP model is a simple galvanic system

BEM solution of the Laplacian in the sea water, combined with representation of the electrode kinetics associated with different surface types, has been shown to provide accurate results for the complex current fields in the sea water and hence the UEP signature

The CRM signature generated by the currents flowing in the sea water can be found by solving the vector potential.

Equation $\nabla^2 \underline{A} = -m\underline{J}$

Where $\underline{A}$ = vector potential
$\underline{J}$ = vector of current density components

The magnetic fields then simply $\underline{B}$ = curl $\underline{A}$. For BEM solutions, the volume integrals involving $\underline{J}$ are converted to surface integrals. This involves subsiding solutions to obtain $\frac{dj_x}{dn}$, $\frac{dj_y}{dn}$ and $\frac{dj_z}{dn}$

Control of the complete sequence of steps is simplified by use of a “wizard” which allows the user to very easily perform all operations. If all steps are to be performed the user actions simply involve selection of the data file and assignment of magnetics properties. The solution sequence is then triggered and proceeds fully automatically

Applications

Example 1 – Base Steel Hull No Anodes

Figure 3 shows the BEM model of a ship hull and propeller in a 50m deep, sea layer. Note: the idealised shape of the propeller. For the UEP analysis the hull and propeller surfaces are assigned appropriate properties; in this case bronze and steel respectively.

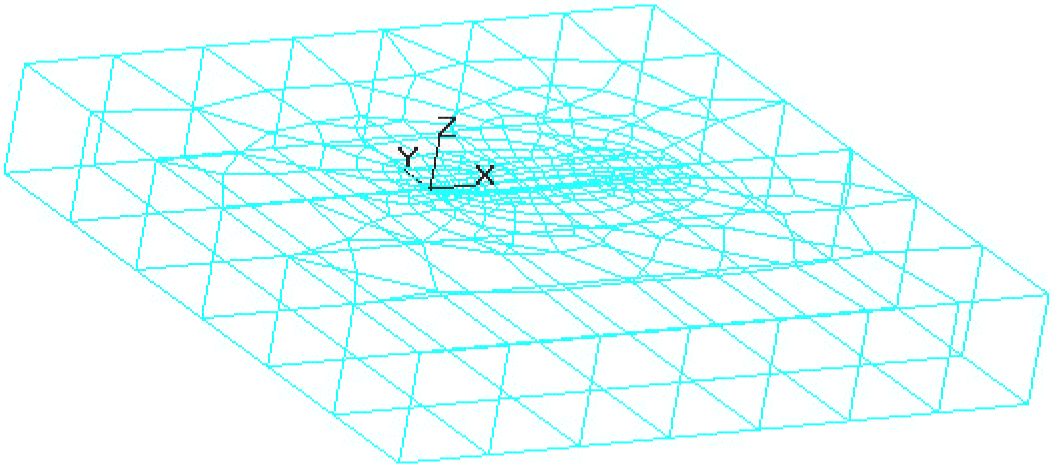

Figure 3 Example 1 BEM Model for combined UEP and CRM analysis

Whereas in a pure UEP analysis the sea surface could be represented using a plane of symmetry, by contrast for combined UEP and CRM analysis the sea surface must be modelled using elements. For combined analysis a "far boundary" must be defined on which components of the magnetics vector potential will be set to zero.

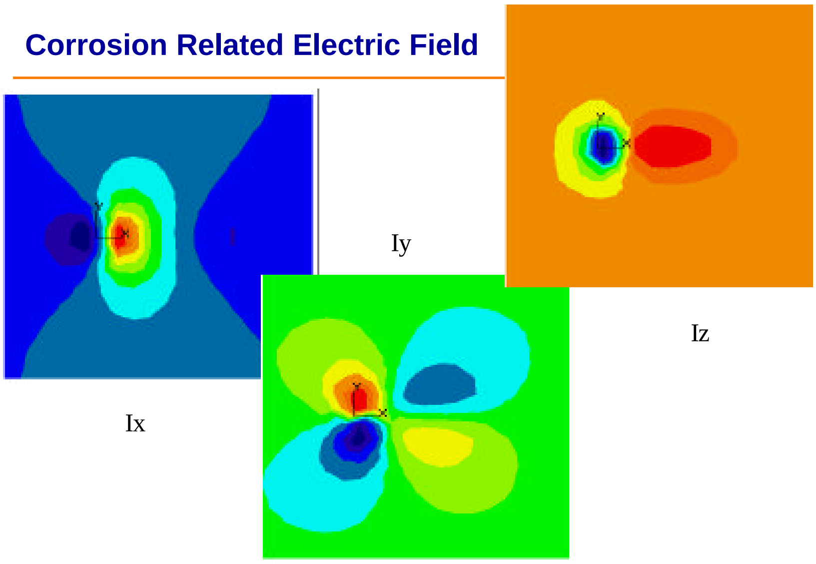

Figure 4 UEP Field at mid depth, no anodes

The mid depth UEP is shown in Figure 4 and the corresponding CRM field is shown in Figure 5.

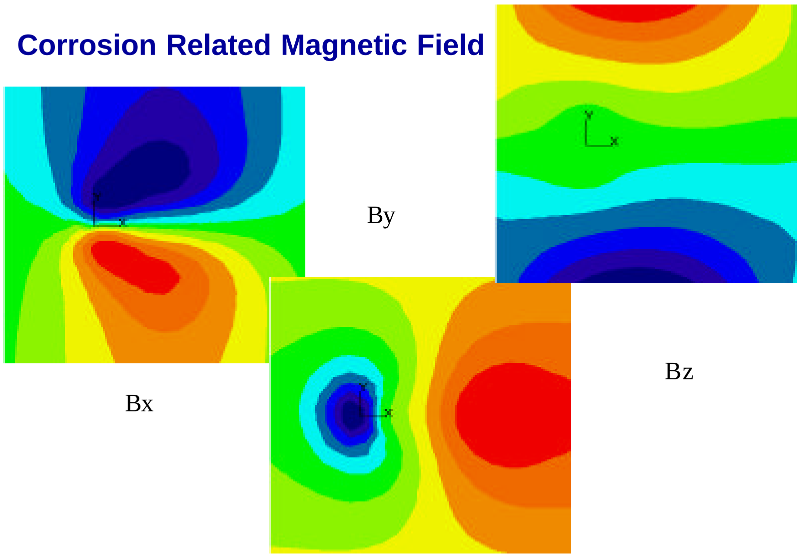

Figure 5 CRM Field at mid depth, no anodes

The distribution of the corrosion related electric and magnetic field can be visualised by plotting a graph of its components on an axis near to and parallel with the centre line of the ship. Fig 6

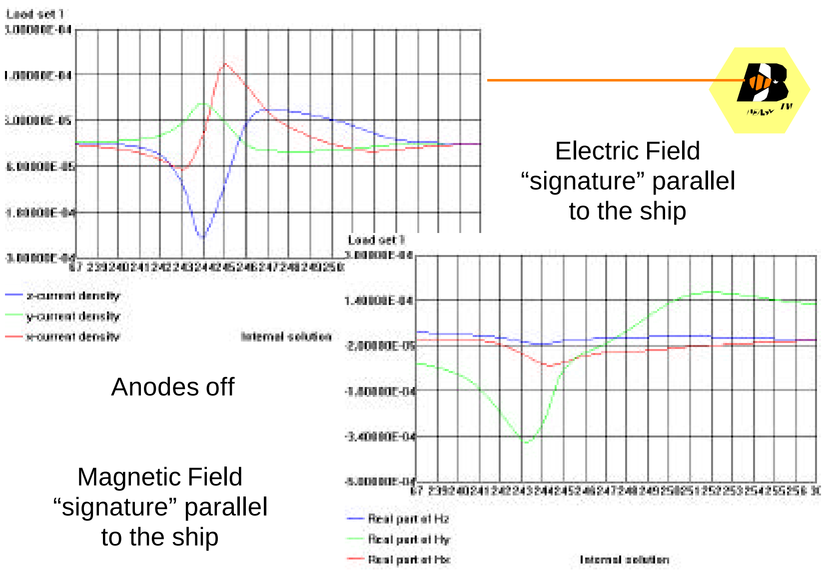

Figure 6 UEP and CRM signatures for the case with the anodes turned off

Example 2

The effect of a CP system on the CRM field can be investigated using parameter studies. Such studies give insight into the effects of different designs and simultaneously provide quantitative data for a specific set of designs. In this study three different “CP systems” have been modelled with alternative anode configurations. The corrosion related electric and magnetic signatures for the case of anodes located above and astern of the propeller are shown in Fig 7

It can be seen from Figures 6 and 7 that both the UEP field and the CRM field are modified significantly by the addition of the anodes. Similar studies can be performed to investigate the impact of ICCP system design and operation on the effectiveness of the protection of the ship against corrosion and the corrosion related signatures.

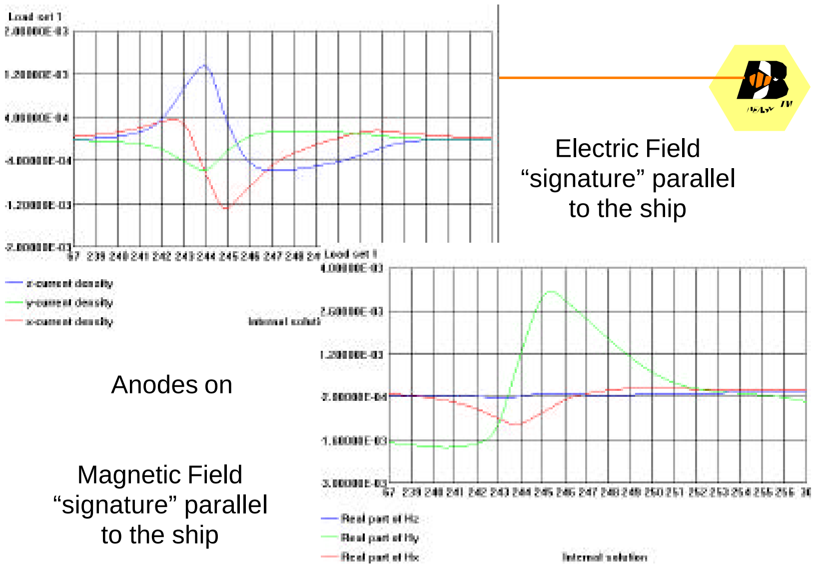

Figure 7 UEP and CRM signatures for the case with the anodes turned on

Conclusions

An integrated approach to the prediction of corrosion related electric and magnetic fields as well as the effectiveness of ICCP systems has been presented.

The software tool provides a mechanism for optimisation of the design and operation of ICCP systems.

The 3D model enables the impact of small changes to the geometric design, coating condition, location of anodes etc to be assessed.

The accuracy of the solution is superior to dipole type models as the three dimensional electric fields are captured, eg, changes to both vertical and horizontal position of the anodes can be assessed.

References

[1] BEASY User Guide, Computational Mechanics BEASY, Southampton, 2000.

[2] Adey R A, Niku S M, “Application of BEM in Corrosion Engineering”, Chapter in Topics in Boundary Element Research Ed, C A Brebbia, Springer Verlag, 1990.

[3] Adey R A, Baynham J M W, “Design and Optimisation of Cathodic Protection Systems Using Computer Simulation”, NACE Corrosion Conference, Orlando USA, 2000.

[4] Adey R A, Pei Yuan Hang, “Computer Simulation as an aid to Corrosion Control and Reduction”, NACE Corrosion Conference, San Antonio Texas USA, 1999.