Combining boundary element and discrete source methods for the modelling of corrosion related magnetic fields

M.D. Pocock[1] & V.G. DeGiorgi[2]
[1]*Frazer-Nash Consultancy Ltd, UK*
[2]*Naval Research Laboratory, USA*

Abstract

This paper presents a pragmatic modelling approach for solving the Corrosion Related Magnetic (CRM) field that is particularly effective for medium and far-field predictions. Possible techniques for solving the CRM include, Finite Element (FE), Boundary Element (BE) and Discrete Source Methods. The strengths and weaknesses of each of these approaches are discussed. The proposed approach combines a BE model of the static electric field from which a discrete source model of the CRM field is derived. The advantages of this method are that an accurate solution to the CRM field is rapidly obtained without meshing throughout the sea volume. Results obtained with the BE and discrete source solvers within the FN*REMUS* software are used to illustrate the process.

1 Introduction

Electromagnetic fields are increasingly used to detect naval vessels. When corrosion occurs an electric field is generated in the surrounding conducting medium, and this is referred to as the Static Electric (SE) field or the Underwater Electric Potential (UEP). A related field, the Corrosion Related Magnetic (CRM) field, arises due to the corrosion current flowing in the conducting medium.

These fields will be present whether corrosion protection systems are in place or not, however with careful design of the corrosion protection system the effects of the fields can be minimised, while simultaneously controlling corrosion. It should be noted that although the CRM field has a magnetic influence it cannot be countered by a degaussing system as its source is not ferromagnetic.

The SE and CRM fields differ in terms of their source:

- The SE is due to surface fields on the vessel.
- The CRM is due to the currents flowing throughout the seawater; it is due to a distributed source.

This difference in source leads to differences in behaviour, for instance the SEfield will obey a decay law approximately r^{-3} whereas the CRM field will follow an approximate r^{-2} decay. The difference also affects the modelling, as the SE field is ideally suited to integral approaches and the CRM less so, as described below.

1.1 Volume and Integral Methods

The reason that integral (or boundary) techniques are favoured over volume techniques for SE field modelling is that the problem domain is very large, consisting of the seawater surrounding the vessel. The solution domain should be terminated at considerable distance beyond the location at which the sensors are located. This can still represent a very large volume especially when far-field effects are being assessed. A volume technique, such as the Finite Element (FE) Method will require a large mesh throughout the seawater.

In contrast, an integral method, such as the Boundary Element (BE) method, will require only the surface of the solution domain to be meshed. If the solution domain is assumed to be infinite the outer boundary is not meshed and symmetry can be used to model a semi-infinite domain containing a sea-surface without meshing the surface.

For an integral method to be applied a Greens function is required. As the SE field within a homogeneous sea follows Laplace's equation a Greens function is readily available. For a sea where the properties vary with depth a layered Greens function may be used, alternatively the sea may be modelled as discrete homogeneous volumes each of which will require a surface mesh. As the amount of inhomogenality increases a volume or hybrid volume-integral approach may be more suited.

Boundary element (BE) methods have been successfully used to model the SE field for many years, and several solution codes exist [1, 2].

As described above, the Corrosion Related Magnetic (CRM) field arises due to a dispersed source. Volume methods are ideally suited to solving such fields, because the mesh will extend throughout the region containing the dispersed source. However as with the SE field, a very large volume mesh would be required to assess the far-field CRM.

For an integral method to be applied to solving the CRM field a method of evaluating the volume integrals of current density throughout the solution domain is required. Such a Boundary Element (BE) method has been proposed [3]. This however requires an outer mesh around the region containing the dispersed source that generates the CRM field. Unlike the BE solution of the SE field, the CRM field solution cannot be infinite (or semi-infinite) in extent, and

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to determine the far-field CRM a large outer surface mesh is required. This integral solution is more computationally efficient than a volume one, but still requires an arbitrary boundary to the dispersed source.

1.2 Discrete Source Methods

Within a discrete source (DS) method, the model is reduced to a series of sources (monopoles) whose effects are summed at the desired solution locations. It is the number, location and strength of these monopoles that need to be determined.

For a corrosion problem, the monpoles are current sources or sinks, and their number, location and strength can be determined from the vessel's physical properties. Any number of monopoles can be used to represent a vessel but typically 5 to 10 monopoles are sufficient, with 2 of these representing anodes of a 2-zone ICCP system. The strength of the monopoles representing the anodes can be determined from the likely ICCP output. The monopoles representing the hull are equally spaced along the length of the vessel, and their (current sink) strength determined from apportioning the average surface current density between them, with a larger sink at the aft end to account for propellers. The total current of all monopoles must sum to zero.

Once the DS model is set-up as described, the monopole strengths can be adjusted and solutions to different scenarios obtained very rapidly (typical run times are ten's of seconds). Often a DS method is initially set-up to match known results (either measured or modelled) and used to perform 'what-if' analysis.

The DS method employed here [4] includes the effects of surface and conducting seabed, so the 'what-if' can include extrapolating measured littoral fields to deep water or vice-versa.

The DS method [4] can calculate both SE and CRM fields from the same set of monopoles. To determine the CRM, a method of images is employed to determine the magnetic field at the solution location due to the sources and sinks within the conducting medium.

The volume of seawater displaced by the vessel is not accounted for in a DS model, so these methods can provide very good results from the far-field to within a few 10's of metres of the vessel surface. In the very near-field the DS result will not be accurate as the individual contributions of each source/sink will be seen as a 'ripple' in the solution field. This is not a concern for CRM modelling where the far-field effects are more important than the near-field ones.

It can be seen that employing a DS analogy to the problem removes the need to mesh the solution domain. This will enable far-field CRM to be calculated.

2 Method

This previous section described how the DS method might be used to calculate the SE field using the vessel and environmental properties to determine the source strengths. The alternative method presented here uses a boundary element

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solution of the SE field to set-up the discrete source model from which the CRM is determined.

The advantages of this combined method are:

1. The BE method can supply a accurate SE field, from which the monopole strengths can be determined
2. The CRM can be calculated without any meshing of the sea volume

2.1 Boundary Element Solution of the SE Field

To obtain an accurate SE field the boundary element model of vessel the should include the following features

- A suitably detailed 3-dimensional geometry of the vessel. Surface areas should be correct however some detailed geometry may be omitted or re-shaped.
- Full representation of the electrochemical surface properties of each wetted material
- A model of the corrosion protection system. If this is an ICCP system then the anodes, reference electrodes and the control algorithms need to be included.
- The sea surface

The boundary element mesh required to provide a SE field solution for the above model will only cover the wetted surface of the vessel.

If a littoral scenario is to be analysed the seabed may need to be modelled and therefore meshed. This will be computationally expensive. The method described below is able to use an SE field calculated from a deep-water BE model (i.e. without seabed mesh) to predict littoral CRM (and SE) fields. This is because the presence of the seabed will affect the fields to a greater extent than the surface current distribution, and it is these surface currents that are incorporated from the BE model into the DS one.

To provide data suitable for incorporating into the DS model, the SE field is calculated from the BE model at a specified set of points. For a surface vessel, these are typically in rows running fore-aft at a few tens of metres below the keel and extending tens of metres fore and aft of the vessel. Several rows of points with one under the keel and the others spaced athwartships are used. Figures 1 and 2 show typical components of electric field obtained from a hypothetical surface vessel.

2.2 Discrete Source Solution of the CRM Field

This calculated SE field is used to derive the DS model. In effect the source and sink strengths are modified until its SE field matches that of the BE solution.

The DS software used here, the FN*REMUS* Characterisation Suite [4], automates this process, making use of both the fields and the surface currents predicted by BE. Originally developed to enable models to be rapidly derived from range data this capability within the Characterisation Suite uses inversematrix solution techniques to determine the optimum sources/sink strength at a given set of locations to match the given near/medium field SE data. The strengths are then modified to ensure that the far-field representation is also correct.

Figure 3 shows the beginning state of the DS model. The sea depth (30m), sea conductivity and seabed conductivity are set to match the BE model and sources/sinks (shown as white dots) are equally spaced to represent the hull.

The SE field data from the BE model is imported into the DS model and the optimum source/sink strengths determined. The resulting DS model is shown in Figure 4. Here a '+' above a monopole indicates a source, a '-' represents a sink, and the size is proportional to the source/sink magnitude. The correspondence between the BE and DS components of SE field is shown in Figure 5.

Once a good representation of the SE field has been obtained from the DS model, the CRM can be calculated. A 200m by 200m grid of solution points has been defined at a depth of 20m. The vertical component of the CRM field over this grid is shown in Figure 6.

To demonstrate the far-field capability of the proposed method, Figure 7 shows the magnitude of the CRM field at athwartships distances of 30m and 1km. These last results also demonstrate the ability to extrapolate to different environments; here the sea depth has been increased to 1km.

To reiterate, no surface or volume meshes were required to calculate the CRM, once the SE field has been determined. Furthermore, the set-up and run times for the CRM calculations are only a minute or two.

The method presented here can be modified as follows

1. The CRM field (and indeed the SE field) can be calculated for other sea-depths and sea or seabed properties from the original BE model
2. Instead of deriving the monopole strengths from a BE prediction of the SE field, measured range data could be used.

3 Validation

The method presented for the prediction of CRM fields has been compared against measured data however these results cannot be presented here. This paper has therefore concentrated on describing this method, and uses a hypothetical vessel developed specially for the paper.

During the development of the combined approach comparisons were made between CRM fields from FE and DS methods for various scenarios. It was found that FE gave better results near to the vessel, and the DS was better in the medium to far field, and also when a sea-surface or seabed was included.

4 Conclusions

It has been shown that the Boundary Element (BE) and Discrete Source (DS) methods may be combined to provide a far-field Corrosion Related Magnetic (CRM) field modelling capability. Results obtained with the FN*REMUS* BE and DS software have been presented.

The advantages of this combined method over BE and FE solutions are

- Very quick model set-up and run times
- No requirement for a mesh within the solution domain
- Accurate prediction of the medium and far-field CRM

The main disadvantage of DS methods is the lack of accuracy in very near-field solutions. This however is not a concern for CRM modelling where the far-field is the primary interest.

The method presented here can also be used to determine the CRM field from a measured SE field.

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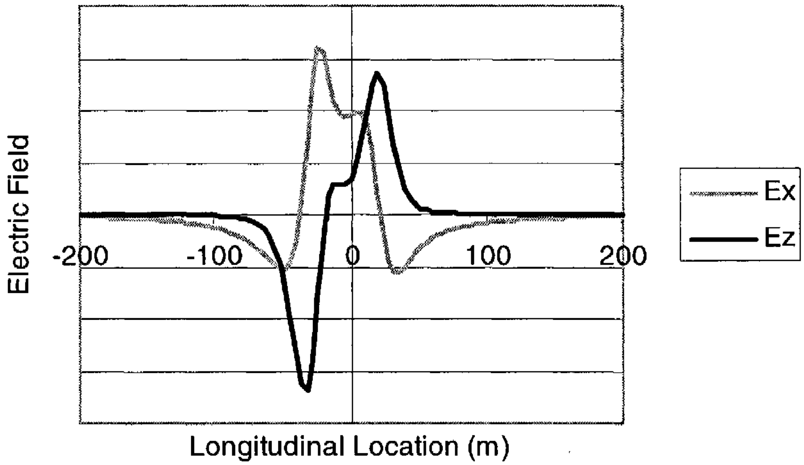

Figure 1: Electric field under keel. (Z-axis is vertical and X is longitudinal.)

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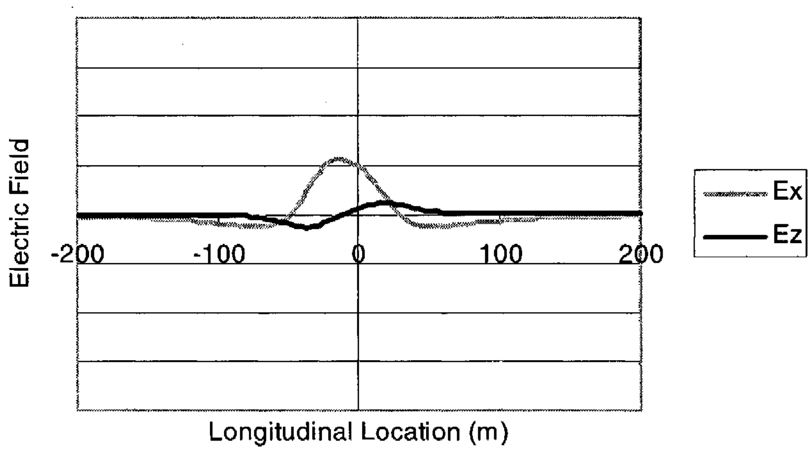
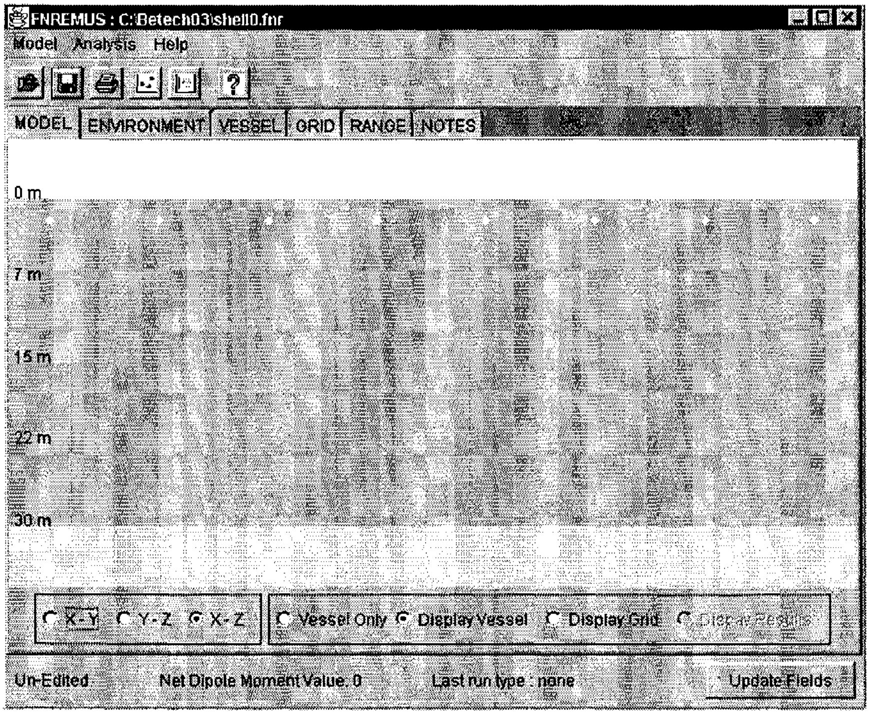


Figure 2 Electric field at 30m athwartships



○ X-Y ○ Y-Z ● X-Z

○ Vessel Only ● Display Vessel ○ Display Grid ○ Display Results

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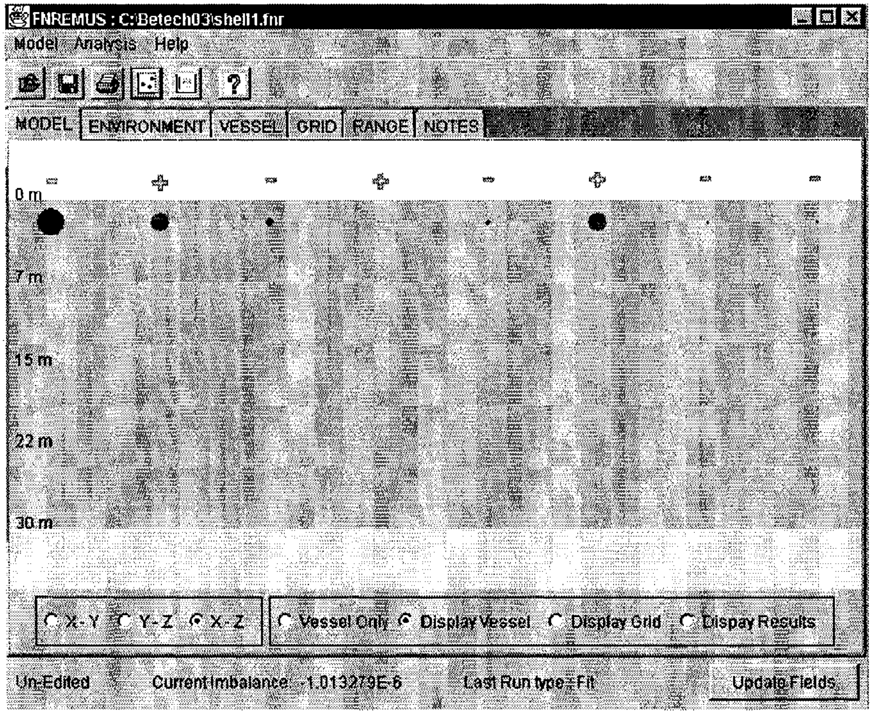
Figure 3: Initial discrete source model, with zero monopole strengths



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○ Vessel Only ● Display Vessel ○ Display Grid ○ Dispay Results

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Figure 4: Discrete source model showing source '+', and sink '-' strengths

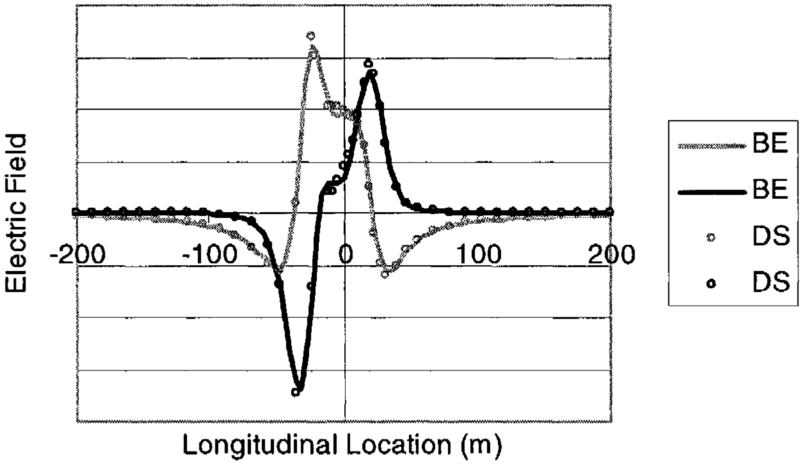

Figure 5: The SE fields calculated by the boundary element (BE) and discrete source (DS) methods under the keel. (Ex shown grey and Ez black).

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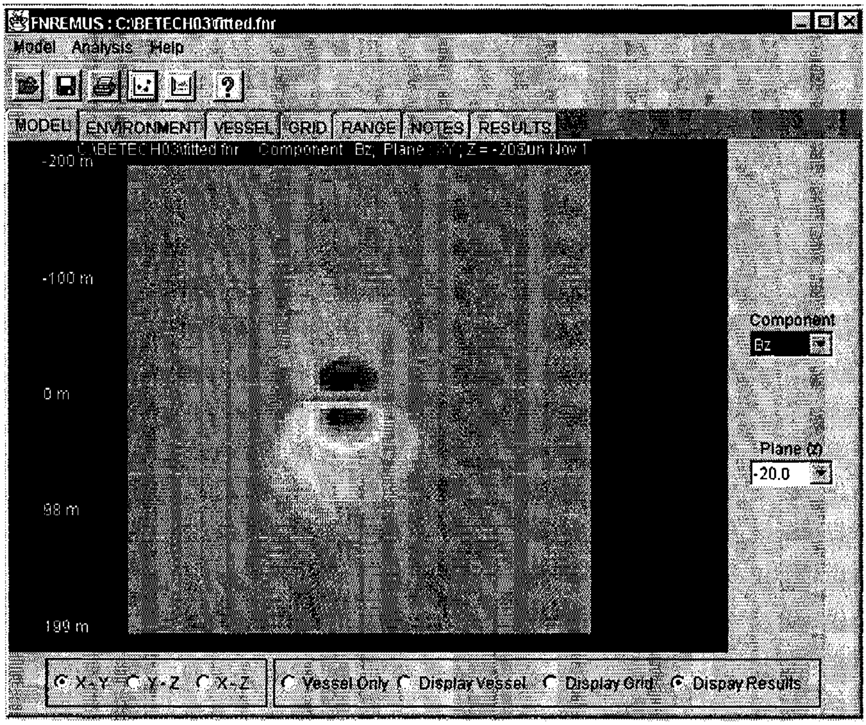

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Figure 6: Vertical component of CRM field at a depth of 20m.

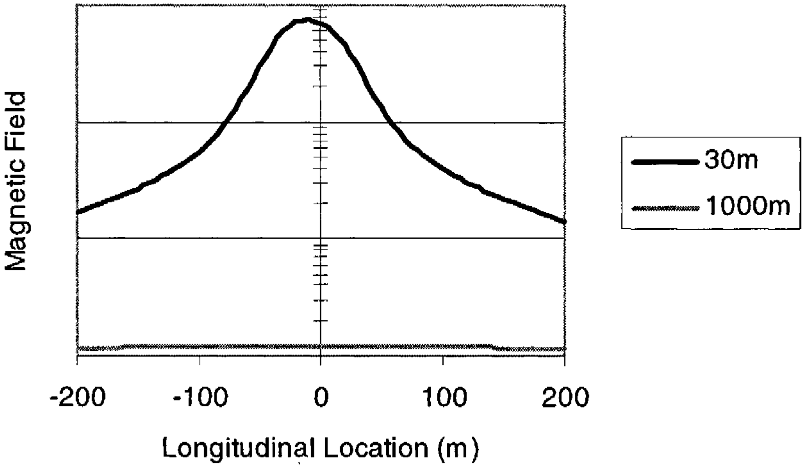

Figure 7: Magnitude of CRM field at 30m and 1km athwartships