

Electromagnetic Simulation Software Plays a Crucial Role in Design of Naval Vessels



Mitigation of electric and magnetic field signatures is an important part of the design process in a modern naval vessel. In this article, the reasons for these signatures and the need for mitigation are explained. The article also discusses the role of simulation in the design and looks at new optimization software incorporated in Vector Fields' Opera Version 12.

Magnetic and electric signatures are the terms that describe the perturbation of the ambient magnetic and electric fields by the presence of a vessel. There are two reasons why these perturbations are produced: the vessel interacts with an existing ambient field; and on-board equipment produces significant field external to the vessel.

Looking at the first of these, the interaction is usually with the Earth's magnetic field. Most vessels are constructed from large volumes of ferrous material which offer a path of lower reluctance to the Earth's field than the sea-water (or atmosphere). Hence, the ambient field is bent into the vessel - producing volumes in the sea where the "uniform" Earth's field can be temporarily decreased or increased as the ship passes. These field gradients can be significant and, consequently, can be used to trigger a mine - as well as indicate where a particular ship is. Consequently, mitigation is required. One obvious solution is to use non-ferrous metals, but even these can produce electromagnetic signatures. Non-ferrous metals (primarily aluminum alloys) have a high electrical conductivity and the motion of the vessel through the Earth's field induces eddy currents (especially from the rocking of the ship) which, in turn, produce a reaction field. The primary route for mitigation of magnetic effects is to include "de-gaussing" coils - a complex system of current carrying conductors that produce magnetic field to oppose the perturbations caused by the vessel. Of course, potentially, these need to be able to operate at any latitude and longitude with any heading of the vessel.

The most important on-board equipment that produces external field is the cathodic protection (CP) system. CP systems are installed on ships to reduce corrosion caused by the different electrochemical potentials exhibited by materials in contact with a conducting fluid (sea-water). They achieve this by modifying the electric field distribution in the vicinity of the ship, primarily injecting additional DC current into the sea through impressed current anodes. These currents can be sufficiently large to create substantial electric and magnetic fields - which again can be detected. Mitigation is achieved through the placement of the anodes such that the desired modifications to the electric field for corrosion protection are achieved but the minimum signature field is produced.

The concept of the more-electric or, even, all-electric boat

comes nearer every day. One result from this is the increased amount of equipment operating with electromagnetic fields, notably the use of large synchronous motors to drive the vessel. This equipment also produces significant stray field which adds to the signature.

From all of the above, it is very apparent that significant design effort must be used to reduce the magnetic and electric field signature. Computer based simulation of the vessel has played a significant role in this design process for more than 20 years, along side physical scale modeling. Using numerical solutions to the magnetic or electric field equations - primarily with the finite element or boundary element method - a wide variety of scenarios can be modeled to test the designs. Vector Fields has worked closely with agencies and their suppliers throughout the world to provide the necessary tools in the Opera software to perform these calculations. For example, post processing that expresses the magnetic signature in terms of multipole moment coefficients was developed, while tools to help easily reposition the de-gaussing coils were provided for optimization. Further information on the range and accuracy of calculations that can be achieved can be found in [1].

In Opera version 12 [2] released in October 2007, an optimization manager was introduced making it possible to automate the design process. Any aspect of the design of a model can be parameterized and the user may define complex objective functions to

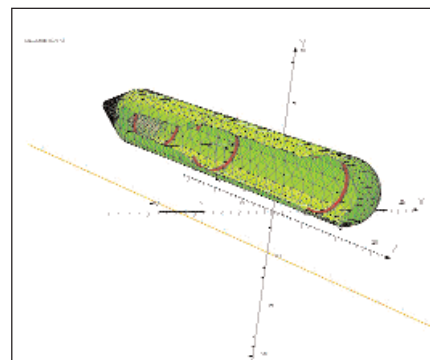


Figure 1.

be minimized or maximized using the programmable post processing. The optimizer supports multiple objectives and controls the Opera simulation software to find Pareto optimal designs in objective function space [3].

In this application area, positioning and operational currents of de-gaussing coils, CP anodes and other equipment are the design space that must be explored. A simple example of this illustrates the usefulness of the software. Figure 1 shows a simplified cutaway model of a pressure hull in a submarine subjected to a 67 A/m DC magnetic field along the beam of the vessel. There are three (red) solenoid de-gaussing coils shown, which can be moved axially from their initial positions by up to 2 meters in either direction and can operate at any current density in the range ± 6 A/mm², subject to the constraint (imposed by the power supply) that the maximum average density is 5.33 A/mm² - for example, one coil operating at +6, another at -6, and the third at -4.

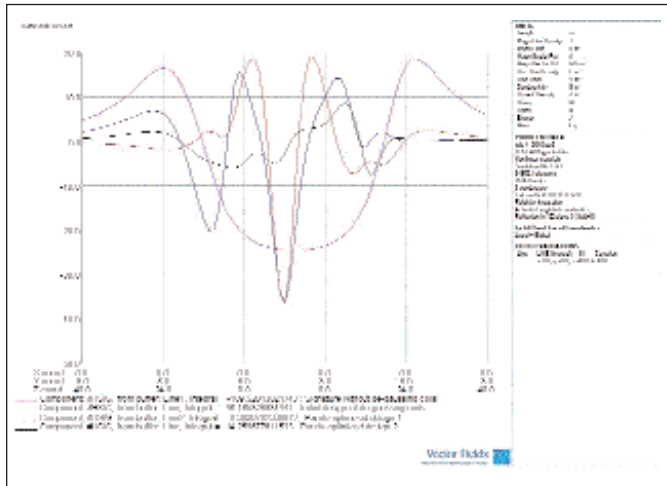


Figure 2.

There are two objective functions for the optimization - that the integral of the signature field on a line 5 meters below the pressure hull (orange line shown in figure 1) is minimized and that the peak value of the signature field on this line is also minimized. The optimizer produces two rank 1 Pareto optimized designs - one where the integral is lowest and the second where the integral is higher but the peak value is lower. The signature field for each design is shown in figure 2, along with the initial signature before mitigation (magenta line) and the signature with the initial design before optimization (blue line). As can be seen,

the low integral in Pareto design 1 (red line) is achieved by having one high negative peak and two balancing positive peaks - an unsatisfactory solution. Consequently, Pareto optimal design 2 achieves the best result.

This article introduces one aspect of the increasing complexity in design of naval vessels and the necessary steps that must be taken to mitigate the threat from a vessel's signature. Electromagnetic simulation software has a crucial role to play in this important, safety critical design. The inclusion of an integrated multi-objective optimization tool helps automate the process of reducing signature fields.

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[1] "Electromagnetic Signature of a Ship Rolling in Earth's Magnetic Field", Paula Y. Zivi et al, *Proceedings of Compumag Conference, 2001*

[2] www.vectorfields.com

[3] "A Scalarizing One-Stage Algorithm for Efficient Multi-Objective Optimization", Glenn I. Hawe and Jan K. Sykulski, *Proceedings of Compumag Conference, 2007*

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