

A Study on Simplified Modeling Using Spatial Permeability for Analyzing the Effects of Degaussing of Warships

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This study proposes the development of a simplified model for the efficient design of degaussing coils of war ships. The research focuses on the complex structure of the ship made of magnetic materials, including internal equipment and detailed models. To simplify modeling, a technique is explored that excludes components such as bulkheads, decks, and major equipment, while assigning uniform permeability values to specific spatial regions. To validate the proposed model, the detailed model is compared with the actual ship measurement results, and the simplified model is confirmed to be valid by comparing it with the analysis results of the detailed model.

Index Terms—Magnetic Field, Spatial Permeability, Warship

I. INTRODUCTION

THE OUTER HULL and internal equipment of naval vessels are composed of ferromagnetic materials with high magnetic permeability. Each component generates magnetic signals due to various factors such as exposure to the geomagnetic field and mechanical stress, which can compromise the survivability of the vessel. Notably, magnetically responsive mines detect such magnetic signals to activate, making the cancellation of magnetic fields generated by naval vessels essential.

The magnetic signals of a vessel are primarily categorized into two components: the induced magnetic field, which results from magnetization due to the Earth's magnetic field, and the permanent magnetic field, which arises from the vessel's construction and prolonged exposure. The permanent magnetic field is an independent component relative to the geomagnetic field and can be depermed through deperming processes in magnetic treatment facilities. In contrast, the induced magnetic field varies with the magnitude and direction of the geomagnetic field. Therefore, onboard degaussing systems must be installed to enable real-time cancellation of magnetic fields during vessel navigation.

The arrangement of degaussing coils within a naval vessel is critical to achieving satisfactory performance of degaussing systems. Designing the coil arrangement requires analysis and optimization using finite element analysis (FEA) to validate the magnetic field generated by coils at various locations. Through FEA, the optimal positions and current values for the coils can be determined. However, modeling and analyzing every component of a vessel involves significant time and computational costs. Therefore, developing a simplified model

of the vessel is essential to reduce computation time and enhance the efficiency of coil design.

This study investigates a method to derive a simplified model that generates magnetic signals equivalent to those of a detailed model, which includes bulkheads, decks, frame structures and major equipment within the vessel. The simplified model retains the exterior geometry of the vessel and divides the internal compartments containing equipment into distinct zones, assigning equivalent spatial permeability to each zone. The inverse problem is performed using an optimization technique that minimizes the error by using the investment rate of each zone as a variable and the induced magnetic field value of the trap as an objective function.

Section II. explains the shape of the ship and the division of the domain for deriving the simplified model. Section III. explains the variables and objective functions employed in deriving the simplified model. After the simplified model was developed, degaussing coils were arranged, and the effects of the coil currents were analyzed.

The result of degaussing performance obtained from the simplified model was compared with those from the detailed model to validate the appropriateness of the simplified modeling approach. An analysis of the spatial permeability optimization results for deriving the simplified model, as well as a comparative evaluation of degaussing coil performance between the detailed and simplified models, will be explained in the full paper.

II. SPATIAL PERMEABILITY ZONING FOR SIMPLIFIED MODEL

Fig. 1. Illustrates the exterior and internal equipment of the detailed naval vessel model. The gray areas represent the outer hull and internal bulkheads of the vessel, while the other

colored shapes denote equipment installed within the vessel's interior. The line at the bottom of the vessel indicates the measurement line for induced magnetic field signals.



Fig. 1. Exterior and Measurement Planes of the Detailed Naval Vessel Model

To accurately compute magnetic field signals under arbitrary geomagnetic conditions, fine meshing is required across the entire vessel model. However, this significantly increases the computation time. Notably, the internally colored equipment, made of high-permeability ferromagnetic materials, are the primary contributors to this increase in computational demand.

Using COMSOL Multiphysics to analyze the detailed model, the total number of mesh elements reached 6,635,988 pcs, with a computation time of 1 hour and 39 minutes. The design of degaussing coil arrangements requires repeated analyses of the degaussing effects and magnetic signals under varying geomagnetic conditions to achieve optimal placement and configuration.

For efficient design, it is imperative to develop a simplified model that accelerates the analysis process. In this study, a simplified model was developed by consolidating internal equipment and bulkheads into zones with equivalent magnetic permeability. This approach significantly reduces computation time while maintaining the accuracy of magnetic field simulations.

To implement spatial permeability analysis, the vessel was divided into multiple sections. The internal structures and bulkheads were considered, and the vessel was segmented into a total of 10 zones. For smooth optimization, the segmentation was based on regions where internal equipment is located or where variations in wall thickness cause differences in magnetic distribution. Spatial permeability was designated as a variable in these zones for optimization purposes.

To evaluate computation time, spatial permeability values were arbitrarily assigned to each zone, and the magnetic signal of the simplified model was analyzed. The computation time for the simplified model was 10 minutes and 33 seconds, representing an 89% reduction in time compared to the detailed model.

This significant reduction in computation time demonstrates the efficiency of the simplified model, making it a practical tool for iterative optimization in degaussing coil design.

III. OPTIMIZATION OF SPATIAL PERMEABILITY IN THE SIMPLIFIED MODEL

The spatial permeability values within the vessel interior ($\mu_r, 1 \dots \mu_r, 10$) were calculated using an optimization method to ensure that the analysis results of the simplified model align with those of the detailed electromagnetic analysis. These values were derived based on the positions, shapes, and quantities of bulkheads and equipment within the vessel. The

optimization method employed in this study is based on the fundamental idea of iteratively approximating the objective function using a valid quadratic model within the current local region. This approach was used to calculate the spatial permeability values for each case. Detailed optimization methods will be explained in the full paper.

IV. ANALYSIS RESULTS OF MAGNETIC FIELD SIGNALS OF WARSHIP USING INTERNAL PERMEABILITY

The internal spatial permeability values obtained through the optimization process were applied to the interior of the simplified model. An external geomagnetic field was then applied. In this analysis, the internal equipment, bulkheads, and decks of the vessel were not modeled explicitly; instead, only the spatial permeability values for each designated zone were assigned. This approach enabled the analysis of the magnetic signals generated by the vessel.

As a result of the analysis of the model, the results were confirmed to be similar to the signal measured in actual ships, and the validity of the spatial permeability was verified accordingly. More detailed results will be described in the full paper.

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