An Approach to Optimization in Ship Structural Design Using Finite Element and Optimization Techniques

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ABSTRACT

This paper explores a practical application of shape optimization in combination with finite element analysis in ship structural design. For an improved structural design of ships, different optimization techniques are outlined. A basic problem of linear strength analysis is solved to validate the proposed optimization strategy. Parametric models are used to accommodate changing dimensions during the optimization process. As a practical example, a floor of a double-bottom structure is optimized with respect to weight.

KEY WORDS: optimization techniques, finite element analysis, floor, double-bottom.

INTRODUCTION

Typically, ship structural design is largely based on experience. If optimization is performed, it is often done on a manual basis by the interpretation of results of finite element analysis (FEA) by structural experts. While this is a very valid approach for basic structural design, further improvements could be expected by the use of integrated optimization algorithms.

Structural optimization deals with methods and applications of mathematical optimization to the computer-aided optimization of structures. The task of the mathematical optimization process is to find the optimum point, from any starting point, and to do so with as little computation as possible (Hughes, 1983). A certain number of design variables (e.g. thickness, shape or cross section area of a structure) has to be determined in a way that the objective function (e.g. minimal weight of a construction) is best fulfilled in compliance with the state variables (e.g. strength, stiffness or production).

Depending on the design variables, structural optimization can be classified as follows (Sekulski, 2009):

- Shape optimization
- Topological optimization
- Choice of material
- Scantling optimization

For scantling optimization (dimensioning), the design variables are restricted to parameters that are used for direct determination of the structural element stiffness. However, Rahman (1996, 1998) illustrates the applicability of scantling optimization to marine structures. Regarding the weight of a certain ship, different panel and girder designs are optimized.

In contrast to scantling optimization, shape optimization changes the geometry of a structure while maintaining the topology. The main task of shape optimization lies in finding suitable design variables to change the geometry. Kitamura et al. (2009) applied shape optimization techniques in ship structural design. In the present paper, ship structural components are represented by finite elements and selected node coordinates are varied for the design optimization. In this way the shape of perforations can be altered.

Modifications of the global structural shape and its topological properties are only achieved with topological optimization. Sekulski (2009) used topological optimization techniques for minimizing structural weight of a high speed vehicle-passenger catamaran. However, that kind of optimization procedure is not the subject of this paper.

Further examples for the application of different optimization methods in naval architecture are given by Hughes et al. (1980), Klanac (2004), Kong et al. (2006), Yang et al. (2007) and Zanic et al. (2009).

In the present paper, the underlying theory of the optimization task – as used here – is briefly presented as a possible starting point for other structural designers and validated against an analytical solution. As a practical example, a double-bottom structure is optimized with respect to weight. Modeling aspects of the finite element model are discussed with respect to the aim of optimization. Parametric models are used throughout the paper as only such models allow for an easy change of shape and dimensions in the optimization process.

MATHEMATICAL CONSIDERATIONS OF COMPUTATIONAL STRUCTURAL OPTIMIZATION

A thorough introduction to the theory of the optimization problem can be found in several text books, e.g. Eschenauer et al. (1997) and Bendsoe (1995). An introduction to optimization in the context of naval architecture is given by Hughes (1983). Here, the essentials of