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Hull-form optimization of a container ship based on bell-shaped modification function

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ABSTRACT: *In the present study, a hydrodynamic hull-form optimization algorithm for a container ship was presented in terms of the minimum wave-making resistance. Bell-shaped modification functions were developed to modify the original hull-form and a sequential quadratic programming algorithm was used as an optimizer. The wave-making resistance as an objective function was obtained by the Rankine source panel method in which non-linear free surface conditions and the trim and sinkage of the ship were fully taken into account. Numerical computation was performed to investigate the validity and effectiveness of the proposed hull-form modification algorithm for the container carrier. The computational results were validated by comparing them with the experimental data.*

KEY WORDS: Hydrodynamic hull-form optimization; Bell-shaped modification function; Sequential quadratic programming (SQP); Container carrier; Rankine source panel method.

INTRODUCTION

The fundamental elements of a hydrodynamic hull-form optimization technique consist of an optimizer, a numerical solver and a hull-form modification.

As an optimizer, gradient-based optimization technique has been widely used because of fast convergence. The Non-Linear Programming (NLP) technique has been principally challenging various gradient-based optimization techniques. SQP algorithm that uses an active set strategy in solving Quadratic Programming (QP) and QP sub-problems proves to be efficient in locating the points of local optima and the most successful method for solving non-linearly constrained optimization problems.

As a numerical solver for finding the ship resistance which is used as an objective function in the optimization process, the Navier-Stokes solver should be applied to take viscous effects into account. However this approach consumes excessive computation time in generating computational grid and numerical computation and faster and more reasonable approach therefore need to be available in the practical stage. A potential flow solver based on the Rankine source panel method has been widely applied as an alternative to the Navier-Stokes solver. The hull-form optimization were performed applying the Rankine source panel method to achieve the wave-making resistance as the objective function focusing on the optimization of the bow-body shape (Suzuki et al., 2005; Zhang et al., 2009; Zhang, 2012).

A hull-form modification technique is very important in hydrodynamic hull-form optimization. During the optimization process, we only need to modify the original hull-form, which is called the mother ship, and the development of an efficient

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hull-form modification technique for the mother ship is essential in order to make the optimization process efficient and practical.

Three principal approaches have been widely used in hull-form modification (Chen et al., 2006; Han et al., 2012; Maisonneuve et al., 2003; Peri et al., 2005; Tahara et al., 2004; Tahara et al., 2006).

The first approach, which originated from ship designers in yards, is to use parametric modeling where the original hull geometry can be easily deformed as well as modeled by a direct selection of design parameters. This method is very practical for designers since the parametric modeling can be easily linked to the optimization process. However, it is difficult to describe highly complex geometries of a modern commercial ship with all of the form parameters.

The second approach is to directly handle the original hull-form by modifying a ship lines which consists of a body plan, a sheer plan and a half breadth plan. However, this method requires a great deal of computation time in the optimization process and has a critical drawback in that the fairness of the generated hull-form cannot always be guaranteed.

The third approach is to use perturbation surfaces generated by modification functions such as B-spline and Bezier techniques. This method is much improved from the second approach in terms of computation time and the fairness of the generated hull-form and has been successfully employed for the optimization of commercial ships. However, this approach needs a few of control vertex to describe the original hull-form and difficult to maintain the ship-like shape of the modified hull-form during the optimization process and a great deal of computation time is required because of a lot of design variables.

In the present study, a bell-shape modification function was developed in order to solve the problems of previous researches. This approach could use a small number of design variables to modify the hull-form and easy to maintain the ship-like shape of the modified hull during the optimization process. *SQP* was used as an optimizer and the Rankine source panel method was adopted to compute the objective function in which the fully non-linear free surface condition and the trim and sinkage of the ship were taken into account. Numerical analysis was performed to investigate the validity of the proposed algorithm using a container ship. The numerical analysis was validated by comparison with the experimental analysis.

BELL-SHAPED MODIFICATION FUNCTION

The bell-shaped modification functions are applied to modify the original hull in the optimization process. The original hull is modified by multiplying the functions and design variables. The design variables represent the moving distance of the specific coordinates which is selected by the user.

Two types of the bell-shaped modification functions are applied to modify the hull profile and the hull surface as shown in Figs. 1 and 2.

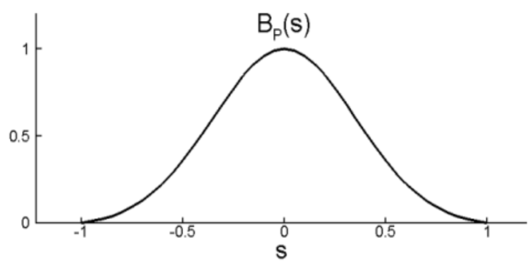

Fig. 1 Bell-shaped modification function for modifying the hull profile.

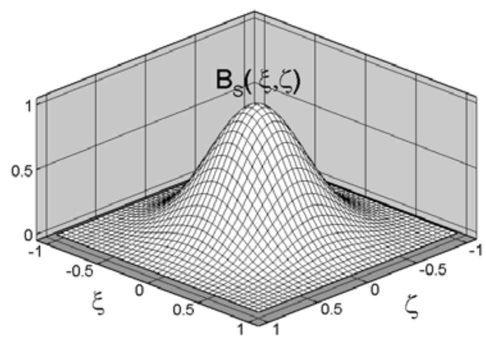

Fig. 2 Bell-shaped modification function for modifying the hull surface.

The bell-shaped modification function for modifying the hull profile is defined as

$$B^P_{i,i_p}(s) = e^{-4s^2} - |s|e^{-4} \tag{1}$$