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Ship inner shell optimization based on the improved particle swarm optimization algorithm

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ABSTRACT

To improve the changeability of ship inner shell (SIS), so that both performance and design efficiency of transport ship can be improved, a new method for SIS optimization is proposed in this study. The method is based on the parametric expression model of SIS, which is a fully-associative model driven by dimensions. Based on the parameters of SIS, the computing system of hold capacity is developed to calculate the floating status and stability automatically. Furthermore, a parametric SIS optimization model is created, including optimization objective, constraints, optimization model solving etc., in which the maximized hold capacity and minimized ballast capacity are optimization objectives, the requirements and rules for SIS design are used as the constraints. The particle swarm optimization (PSO) algorithm is improved to solve this optimization model. The proposed method is applied to a 50,000 DWT product oil tanker, and it is proved to be feasible, highly efficient, and engineering practical.

1. Introduction

Ship subdivision is an important part in the general arrangement of transport ships, which could greatly affect the ship's performance [7]. Subdivision is performed at the initial stage of ship design, after the hull and deck surfaces are given [16]. The essence of subdivision is to subdivide the hull space reasonably with satisfying ship owner's requirements, international rules, and regulations [17]. Currently, subdivision design still depends on the experience of ship experts and parent ships [12]. It requires much time and efforts to find a feasible design, especially the optimization design, as the designer usually only has a general concept about the compartments without knowing the exact dimensions in the preliminary design stage [5]. In order to initiate the design, a set of dimensions must be assumed. Usually, these assumed dimensions do not satisfy all the requirements, and need to be adjusted according to the subsequent calculation results. This process needs to be repeated times and times again until all the requirements are satisfied. It is a laborious work [6]. Hence, it is great significance to research on the design and optimization method for subdivision.

Generally, subdivision mainly includes the design of bulkhead positions and the shape of SIS. So far some approaches have been proposed by the researchers. Some researchers proposed some methods to improve the performance of ship by bulkhead optimization. Ölçer et al. [19] integrated multi-objective optimization with bulkhead positions as variables, and developed a multiple criteria decision-making methodology to optimize design of the Ro-Ro ships. Ivanov et al. [11] proposed a simplified sheer force and bending moment calculating method and applied it in ship subdivision optimization with bulkhead positions as variables. George et al. [4] developed a systematic sensitivity analysis of bulkhead number, bulkhead positions for RoPax vessels to improve the damage stability. Chen et al. [1] proposed a tank subdivision optimization method to minimize the bending moment under sequential ballast water exchange conditions. Lyu et al. [18] proposed a method of the transverse watertight bulkhead position optimization design for improving anti-wind capacity (rated wind velocity) after damage.

The methods of bulkhead optimization are efficient to improve the ship performance, such as damage stability, ballast water exchange efficiency etc [13]. However, some other performance could not be improved by these methods, such as increasing cargo hold (CH). The optimal design of SIS is an efficient way to realize the volume optimization of the ship's cargo compartments. Yu and Lin [20] proposed a SIS optimization method to improve the safety of transport ship. It takes the section areas of SIS at knuckle position as optimization variables, so it could not optimize the longitudinal dimensions of SIS. Besides, the gradient-based method is used to solve the optimization model, which could only find the local optimum solution. Guan et al. [6] proposed a parametric subdivision method of the top-down approach to reduce the

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Symbols and abbreviations

CH	cargo hold
COT	cargo oil tank
GA	genetic algorithm
IPSO	improved particle swarm optimization
PSO	particle swarm optimization
SIS	ship inner shell
WBT	water ballast tank

complexity of subdivision and realize the rapid calculation of hold capacities. Yu and Lin [21] proposed a parametric inner shell optimization method, which takes both section dimensions and longitudinal dimensions as design variables, and Genetic Algorithm (GA) is used to solve the optimization problem. But the SIS model in this method is much more complex, so the population size is large, and the convergence speed is slow.

Aiming at these problems, this paper focuses on the design and optimization of SIS, a new method for parametric design and optimization of SIS based on the IPSO algorithm is proposed. According to the rules and functional requirements of different types of transport ships, the basic shape and the parametric expression of SIS are established. On the basis of this, a three-dimensional design model of ship's cargo compartments is established. By adjusting the design parameters, the design scheme of subdivision could be obtained, and the rapid design and modification of subdivision could be realized. The requirements and rules for SIS design are used as the constraints to determine the feasible range of the design parameters of SIS. Based on the parametric expression of SIS and considering the constraints, the PSO algorithm is improved to optimize the parameters of SIS to get the maximum capacity of CH and the minimum capacity of water ballast tank (WBT).

2. Parametric design of SIS

SIS design is an important part in the ship subdivision design, which not only affects the capacity of CH and WBT, but also influences the operating expenditures of the ship [3]. SIS is composed of a number of knuckle planes. The determination of the knuckle position should take full consideration of many aspects, such as the capacity of CH and WBT, floating status, minimum distance between the inner shell and outer shell as well as related specifications. This section focuses on the expression and design method of SIS for transport ships. According to the rules and functional requirements of ships, a parametric expression method of SIS is put forward and a parametric 3D design model of SIS is established. Then, the rapid design and modification of the ship subdivision can be realized by adjusting the design parameters.

2.1. Parametric expression of SIS

In order to adapt to the sharp change of lines at bow and stern, a number of knuckles are set in the inner shell along the longitudinal direction of the transport ship. As shown in Fig. 1, the cross sections of inner shell along the longitudinal direction of the transport ship have the same form, that is, the inner shell structures at knuckle positions have the same components and only the position and size of the components are different. These characteristics of the transport ship's inner shell provide the basis for the realization of the parametric expression of SIS.

Due to the different characteristics of the cargo loaded by the transport ship, the design of the inner shell should be determined according to the characteristics of the cargo. The common structure styles of the three main types of the transport ships, bulk carrier, oil tanker and container ship are shown in Fig. 2.

As shown in Fig. 2, although there are some differences in the SIS form of different types of ships, the basic characteristics of them are the

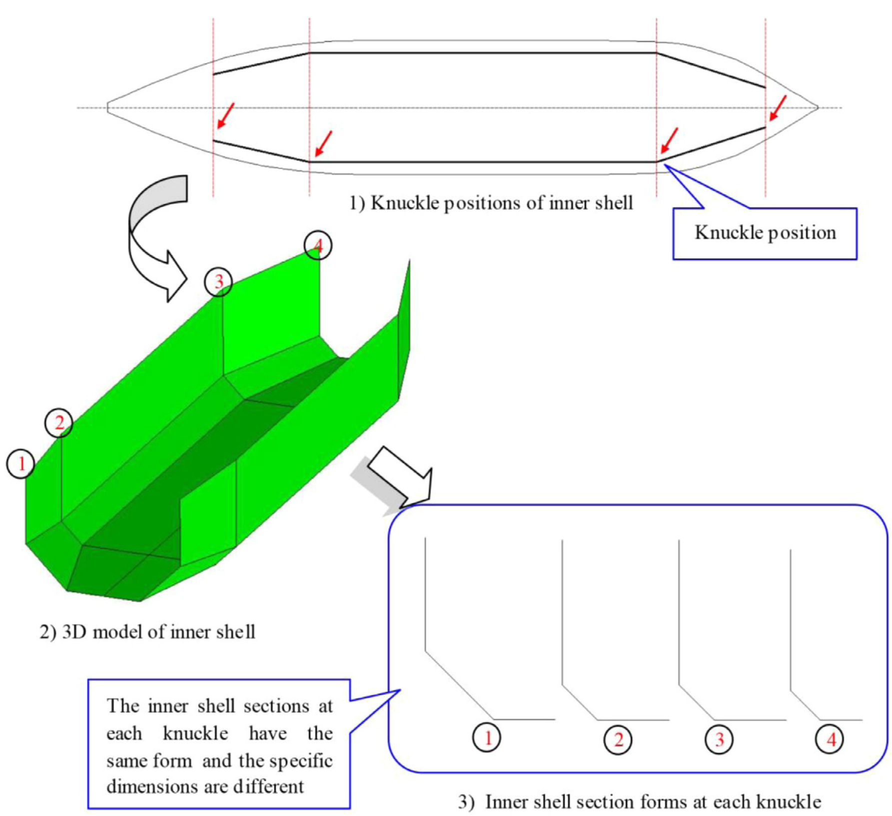

Fig. 1. Knuckle positions of the SIS.