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Development of intelligent ship ballast water allocation in the future

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Abstract

Maritime navigation is an important mode of transportation in the country. With the development of the country and the world, there will inevitably be higher requirements for the safe transportation of ships in the future. Therefore, intelligent ships have become the latest research direction in ship design. And with the gradual development and improvement of big data and artificial intelligence technology in the industrial field, smart ships are an inevitable trend in the development of the shipbuilding industry. Smart ships need to maintain the stability of the ship to ensure the safety of the ship when operating at sea. Therefore, the research on the autonomous stowage of ballast water for smart ships in the future is very important. This paper analyzes the development background of intelligent ships, introduces the ship optimization model and optimization design algorithm, and speculates the future development direction of intelligent ships.

Keywords: Intelligent ship, Optimized design, ballast water allocation

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1. Introduction

In recent years, the traditional industry of the shipbuilding industry is increasingly in a sluggish predicament. The increasing construction costs and complex operation processes, as well as the environmental protection regulations required by the country and the world, are constantly promoting research and investment in smart ships. Ship intelligence has become a popular trend, and the development of intelligent ships will update the development direction of the ship industry and make ships rise to a new height. There are also many intelligent crane-type ships in the intelligent ship, which can also complete some loading and unloading tasks without human beings. Therefore, the ship is required to complete the load adjustment autonomously, so that the ship can maintain its balance without overturning. Combined with the existing ship ballast water distribution system, this paper predicts and deduces the design of future intelligent ship ballast water distribution.

2. The development background and definition of intelligent ship

2.1 Definition of intelligent Ship

Intelligent ships use the Internet, the Internet of Things, communication technologies and various physical sensors to independently perceive and collect various kinds of information, such as ports, driving path obstacles and ship logistics. They also have new technologies such as unmanned driving, autonomous contact, autonomous integration, autonomous loading and unloading, autonomous customs clearance, autonomous load adjustment, and autonomous inspection and analysis, which will bring new applications and new forms to the intelligent transportation industry, The use of such technology can ensure the safety of navigation and ship management requirements.

2.2 Background of intelligent ship development

In 2015, China Classification Society released the world's first complete specification for intelligent ships, the Code for Intelligent Ships, which clearly stated the technical requirements of intelligent ships in terms of intelligent navigation, intelligent hull, intelligent engine room, intelligent energy efficiency management, intelligent cargo management, intelligent integration platform, etc; In 2018, the Ministry of Industry and Information Technology began to research and develop the high-tech ship research project of Smart Ship 1.0, and conducted intelligent research on container ships and bulk carriers; In 2019, the Ministry of Science and Technology launched the research on key technologies of intelligent navigation and control of ships based on ship shore collaboration, which mainly focuses on shore based information support, communication and network security and remote navigation technologies to support intelligent navigation of ships, and develops intelligent navigation systems for inland ships in key navigation segments, intelligent optimization of coastal ship routes and autonomous navigation systems. In 2020, the Ministry of Industry and Information Technology will launch a special project for innovation of green and intelligent inland ships, carry out research on the technical system architecture of inland ships, define the development path of intelligent and green technologies, and carry out demonstration applications. In 2021, the first inland river green 64TEU intelligent container ship “Guo chuang” independently developed and designed in China will be officially launched.

Today, with more and more frequent global trade, maritime transportation is increasing, so ships are gradually moving towards intelligent direction. The development of intelligent ships can effectively improve the environmental pollution problems caused by traditional ships during navigation, and can also ensure the safety of navigation, as well as various human cost problems. Ships sailing at sea will inevitably cause pollution to the marine environment, most of which is reflected in greenhouse gas emissions. Therefore, the International Maritime Organization has issued corresponding policies to reduce exhaust emissions. The corresponding measures mainly include: the use of energy-saving engines and clean energy, the manufacture of ship types to reduce resistance, and the use of energy efficiency control technology. These measures can not only reduce operating costs, but also achieve the effect of energy conservation and emission reduction, and reduce energy consumption. If a ship collides on the sea, it will cause serious economic losses and even casualties. In this case, the safety of the ship can be improved through security early warning, status monitoring, information perception and other technology applications. For the rapid development of the offshore operation industry, due to the increasing wages of seafarers and the maintenance costs of ships, the operating costs will continue to rise, while the development of intelligent ships will greatly reduce their operating costs. The economic benefits of offshore operation can be improved by realizing unmanned ship operation, auxiliary posture technology and unmanned engine room watch technology. It is very necessary for the marine transportation industry to develop intelligent ships. Today, the Internet of Things application is relatively mature. Digital technology and various sensors can be used to feed back customer behavior, and then provide targeted needs to improve people's life experience. In this way, intelligent ship is not only a separate technology, but also the embodiment of the combination of various advanced technologies. The mutual absorption and utilization of technologies by various industries has a great effect on the development of today's society.

3. Application of intelligent ship ballast water allocation

3.1 Research status of ballast water allocation at home and abroad

At present, domestic intelligent ships are still in the initial stage, but they are developing rapidly. The world's first intelligent ship “Dazhi”, independently developed by China Shipbuilding Industry Group, was officially delivered for use on December 5, 2017. Since then, CSCEC and CSIC have built 400000 tons of intelligent super large ore carrier “Ming yuan”, “Ming zhuo” and super large intelligent cruise ship “Kai zheng”, which means that more large tonnage intelligent ships will continue to be built in the future, so the research and design of intelligent ship ballast water allocation is particularly important. Pan Wei and others put forward a ballast water allocation model for the full slewing crane ship based on the principle of moment balance, which can make the crane ship produce the heel angle and trim angle within the allowable range of the specification; Guo Lei designed a barge stowage scheme to meet the requirements of the actual project, realized the procedural stowage operation, and established a human-computer interactive stowage system; Jiang Jianyu and others optimized the ballast water allocation of crane ships with different ballast systems by using dynamic programming methods; Lei Kun and others established the optimization model of ballast water allocation scheme, and realized the optimization calculation of water injection and drainage of ballast tanks during barge operation; Liu Chunqing and others developed a simulation system for the ballast allocation process of semi submersible offshore crane platform in combination with practical operating experience; Xia Huabo and others optimized the barge's stowage process and water volume adjustment based on the improved genetic algorithm, shortening the original stowage time and improving the stowage efficiency; Qin Junchao proposed a multi-objective particle swarm optimization algorithm in the load adjustment simulation of the "Blue Whale" crane ship. By slightly reducing the speed term in the particle swarm optimization algorithm, the convergence and evolution efficiency of the solution are improved. Bara and others proposed an optimal control strategy for the stability of the ballast system when lifting cargo on the basis of graph theory.

Therefore, for intelligent ships, the research on ballast water allocation of other ships can be used for design. This paper introduces an optimization model and an optimization algorithm that can be used for intelligent ships.

Figure 1. “Da zhi”

Source: https://zhuanlan.zhihu.com/

Figure 2. Super large ore carrier “Ming yuan”

Source: https://zhuanlan.zhihu.com/

3.2 Intelligent ship optimization model

3.2.1 Ballast water transfer mode

During the operation of the ship, the ballast water is transferred between various compartments through energy conversion, which is usually achieved through three ballast methods: compressed air ballast method, ballast pump ballast method and gravity gravity flow ballast method.

3.2.2 Ballast water optimization design

(1) Optimization idea

When we deal with problems through optimization thought, we usually have: ① put forward optimization problems according to specific conditions and sort out relevant materials; ② Establish the mathematical model of the optimization problem, and determine the objective function, constraint conditions and variables; ③ According to the established mathematical model, select the appropriate optimization method; ④ Write program to run and use computer to solve; ⑤ Check and implement the optimal solution.

(2) Optimization mathematical model

In the optimization design problem, all the values obtained are nothing but the maximum or minimum real number solutions. Therefore, the mathematical models of the optimization design can be unified into one formulated model:

$$\begin{cases} minF(X) \quad X = [x_1 x_2 x_3 \ldots \ldots x_n]^T \\ s.t. \quad g_u(X) \le 0 \quad \left(u = 1\ ,\ 2\ ,\ \ldots p\right) \\ h_v(X) = 0 \quad \left(v = 1\ ,\ 2\ ,\ \ldots\ ,\ m < n\right) \end{cases} \tag{1}$$

In the formula, X is called design variable, It contains design parameters $x_1 x_2 x_3 \ldots x_n$ called design variable components, totaling n ; Constraints on design parameters $g_u(X)$ and $h_v(X)$ are functions of design variables X, called constraint functions, $g_u(X)$ is an inequality constraint function, a total of p, and $h_v(X)$ is an equality function constraint, a total of m(If $m = n$, the formula has a unique solution; if $m > n$, the formula has no solution); Design objective $F(X)$ is a function of design variable X, which is the objective function.

3.2.3 Optimization variables

When the ship is operating, it is necessary to adjust the ballast water in each compartment to keep the ship in balance without capsizing. At this time, the water volume in the ballast tank will change. This requires taking the change of cabin water volume as the optimization variable. The water volume of each ballast tank under the initial condition of the ship is known, and the water volume of each ballast tank after load adjustment is unknown. The optimization variable formula is:

$$h_u = |h_k - h_i| \tag{2}$$

In the formula, h_u is the water level change of the ballast tank (unit: m) ; h_k is the water level of each ballast tank after ballast water regulation (unit: m) ; h_i is the initial height of water level of each ballast tank before load adjustment (unit: m).

3.2.4 Optimization objective function

When the ship is operating, in order to improve the working efficiency of the ship, the minimum amount of ballast water adjustment should be taken as the best optimization goal. If the amount of ballast water adjustment is reduced, the ship will recover more quickly and the working efficiency will be improved. In this model, there is a single objective of load regulation, so it is a single objective optimization problem. The objective function is:

$$\min \ P_c(h) = \sum_{i=1}^{i=n} h_u \cdot S_i \cdot \rho_{sw}/2 \tag{3}$$

In the formula, P_c is the amount of ballast water transfer (unit t); S_i is the bottom area of each ballast chamber (unit: m^2) ; ρ_{sw} is the density of seawater (t/m^3); n is the number of ballast tanks.

For the convenience of calculation, the ship's ballast tank can be simplified as a rectangle, and the total amount of ballast water of the ship will remain unchanged during one operation, that is, the ship's ballast tank will neither absorb water nor drain water. After the ship's ballast water allocation, the water volume in each compartment of the ship is different due to different load adjustment methods. The size of the ship's ballast water allocation can be obtained from the difference of the tank water volume before and after the ballast adjustment and the area of the bottom of the tank.

3.2.5 Constraints of the optimization model

According to various requirements during the actual construction of the ship, the following constraints should be met: (1) The ship is in equilibrium in the initial state;

(2) Ballast water volume remains unchanged before and after ship ballast water allocation; (3) The water level of the ship's ballast tank shall be lower than the cabin height; (4) The ship's ballast tanks shall be arranged symmetrically; (5) Balance of the hull after loading.

3.3 Ballast water allocation optimization algorithm

NSGA-II algorithm is a non dominated sorting genetic algorithm with elite strategy. This algorithm adopts a non dominated sorting mechanism when dealing with the problem, and adds the optimization algorithm of crowding degree and elite retention strategy to make the result closer to the Pareto optimal value. For the problem of intelligent ship ballast water allocation, although the above model only takes the load adjustment amount as a single objective, it is sometimes appropriate to modify the model to take the draft, trim angle and heel angle as optimization objectives. The independent variable is still the changing water volume of the cabin, and the number is determined by the number of ballast tanks.

Implementation of NSGA - II algorithm: (1) Genetic coding. The algorithm can take the percentage of the changing water volume of the ballast tank to the tank capacity as an independent variable. Set the initial water volume percentage of a ballast tank as x; Then the maximum value of water volume change of ballast tank is 1-x; Minimum -x. (2) Fitness function. The fitness function is constructed according to the selected ballast water allocation target. If the set ballast water allocation target is average draft and inclination, the schemes that meet the conditions at the same time will be sorted according to the ballast water allocation amount, and the scheme with the least ballast water allocation amount will be the best. (3) Non dominated sorting. By adding elite strategy, the population satisfying the range of independent variables is non dominated, and the population is divided into multiple non dominated layers. (4) Crowding. The sum of two adjacent sides of the smallest rectangle composed of an individual and adjacent individuals on the same layer is defined as the crowding degree of the point, and the individuals with large crowding distance are retained. (5) Genetic operators. Randomly obtain half of the individuals in the population mating database as the parent, and then combine the population with the child population to generate a new population, and generate a dominant level through non dominated sorting. After secondary sorting, select the best solution with high congestion degree from each level as the parent of the next cycle, and then repeat the cycle population until there is an optimal solution. There is a selection crossover mutation operator. (6) Ballast water allocation parameters. Set ballast water allocation target, initial water volume information of ballast tank, constraints, population size, genetic algebra, constraint relaxation factor, crossover probability, mutation probability, etc. By changing reasonable parameters, a better ballast water allocation scheme is obtained.

Figure 3 shows the flow chart of NSGA - II algorithm.

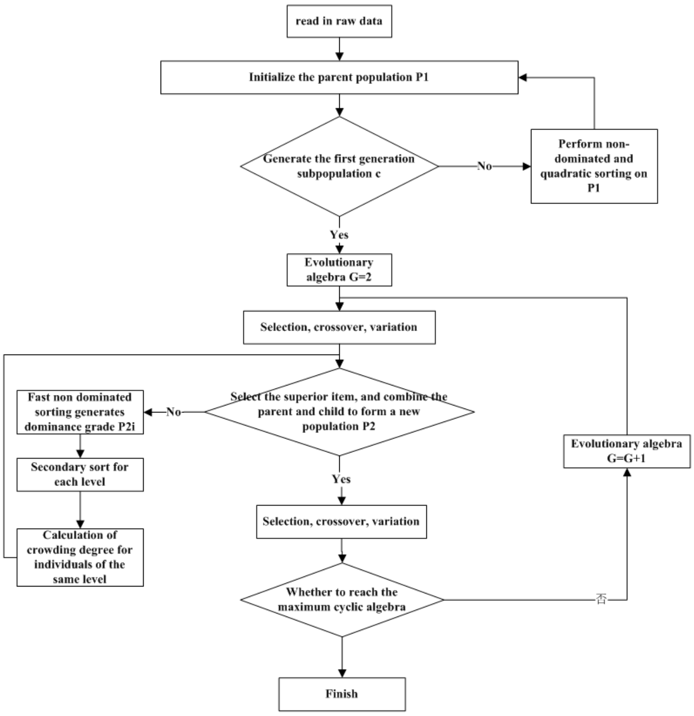

Figure 3. NSGA - II Algorithm Flow Chart

4. Expectation

Intelligent ships need to use intelligent navigation and other technologies to navigate autonomously, and use control technology, computer technology and other technologies to process perceived information to guide ship navigation. The intelligent operation ensures the safety of the ship during navigation, and the excellent automatic ballast water allocation system can ensure the safety of the ship during operation. Although the development of smart ships in China is limited at this stage, smart ships must follow the principle of gradual progress, design and construction should be carried out slowly according to specifications and plans, and large-scale loading and unloading operations cannot be carried out independently, China has focused on the establishment of smart ship platforms based on intelligent equipment. With the continuous development of science and technology, smart ships in the future will inevitably develop towards the reduction of the number of crew members or even unmanned, The manufacture of large unmanned intelligent ships is just around the corner. Therefore, it is necessary to optimize the design of ballast water allocation for intelligent ships in the future. This paper introduces a ship ballast water allocation optimization algorithm, which can be used for reference to the research and design of traditional ship ballast water allocation optimization algorithms, such as particle swarm optimization algorithm, ant colony algorithm, etc. In the future, BP neural network learning can also be used in combination with artificial intelligence. As long as there is enough data and a certain rule is learned through training, the expected results can be obtained.In the future, BP neural network learning can be used in combination with artificial intelligence. As long as there is enough data, a rule can be learned through training, and the desired results can be obtained. This paper puts forward the problem of ballast water allocation optimization in intelligent ships, and the related content should be further studied.

References

Pan Wei, Xie Xinlian, Bao Tiantian, Wei Zhaokun .Ballast water allocation optimization of revolving crane vessels[J]. Journal of Harbin Engineering University, 2019,40(01):189-195.

Guo lei. Research on the System of Engineering Problems for Barge Stowage[D]. Dalian University Of Technology,2012.

Jiang Jiangyu. Research on Ballast Water DynamicAllocation Optimization and Experiment forPump-based Ballast System of Revolving[D]. Dalian Maritime University,2019.

Lei Kun, Lin Yan, Ji Zhuoshang. Optimization of Ballast Plan Based on Interior-point Method in Barge for Load-out[J]. Shipbuilding of China, 2010,51(02):149-154.

BARA C, CORNOIU M, POPESCU D. An optimal control strategy of ballast systems used in ship stabilization[C]//Proceedings of 2012 20th Mediterranean Conference on Control & Automation (MED). Barcelona:IEEE, 2012: 878-883.

Liu Chunqing, Zhang Kezheng, Zhang Zhimin. Optimization for ballast process of semi-submerged offshore crane platform[J]. China Sciencepaper, 2018,13(07):809-812.

Xia Huabo, Ji Zhuoshang, Zhang Mingxia. Application of lmproved Genetic Algorithm in Barge Stowage Planning Analysis[J]. Chinese Journal of Ship Research, 2010,5(06):51-55.

Qin Junchao. Research on Load Adjustment Simulation Technology of Blue Whale Floating Crane Craft[D]. Shandong Jiaotong University, 2019.

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