The Study of Preliminary Comprehensive Optimization for the Performance of Inland River Green Energy SWATH-USV

Wang jing, Yang Songlin, Gao Shasha, Cheng Zhanyuan

Abstract— **This paper a kind of inland river green energy SWATH - USV has carried on the comprehensive optimization analysis, taking the comprehensive performance of SWATH including its rapidity, maneuverability and green energy system into consideration, a comprehensive optimization mathematical model of SWATH-USV has been established. By combining mathematical model with intelligent optimization algorithm, and then comprehensive optimization software was compiled. The stability algebra of GA optimization was discussed and the variation of the total objective function with different length, propeller speed and propeller diameter was analyzed. The program has been verified to be reliable and stable by a large number of calculations, which can provide important technical support for the overall design of SWATH-USV, and is of great significance for the further research on green energy and SWATH-USV in inland rivers.**

Index Terms— **inland river SWATH-USV, green energy, genetic algorithm, comprehensive optimization of mathematical model**

I. INTRODUCTION

China has a vast territory, with large rivers running from east to west, tributaries connecting north and south, rivers, lakes and seas, forming a natural water network. According to statistics, there are more than 50,000 rivers with a basin area of more than 100km2, with a total length of about 430,000 km. The navigable length of inland waterways is about 133,000 km, ranking first in the world. In recent years, the ship types of inland river ships have also undergone great changes. The Ship design is a highly integrated multidisciplinary science and technology, the process is thought to be in the premise of satisfied the requirements of a particular task (or conditions), the initial fitting out several feasible scheme, and the feasible scheme for single or comprehensive analysis, and according to certain criteria to evaluate and select a few design scheme of high quality, further scale for its parameter optimization process. This process involves empirical knowledge, basic or professional theoretical knowledge, and is a process of comprehensive balance and gradual approximation between multiple factors and multiple constraints (correlation). Ship optimal design is a multi-disciplinary, multi-domain and multi-objective comprehensive design optimization problem, which often requires a large number of searches for feasible fields of variables[1]. In recent years, the genetic algorithm has been applied to ship engineering optimization problems to some extent. Li xuebin et al applied multi-objective genetic algorithm to the optimization design of surface ship rapidity[2]. Wei Zifan et al analyzed the comprehensive optimization of the performance of a new type of surface unmanned boat based on improved genetic algorithm[3]. However, with the increase of design considerations, design variables keep increasing. In order to improve the optimization results, this paper studies the design considerations and design variables based on the genetic algorithm for the catamaran integrated optimization of SWATH-USV in inland rivers.

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II. MATHEMATICAL MODEL OF PERFORMANCE OPTIMIZATION OF THE INLAND RIVER SWATH-USV

1.Optimal design variables

As a kind of ship with good resistance performance at high speed, catamaran with small waterplane in inland river has a great difference from ordinary single ship. Considering the complexity of its hydrodynamic performance and its use as a surface unmanned craft, this paper mainly takes the three aspects of rapidity, maneuverability and green energy layout as the research objects to establish a comprehensive optimization mathematical model for the navigation performance of catamaran with small waterplane in inland rivers.

Optimization design variable selection in this article the following parameters: the length of the submerged body L_h, the diameter of the submerged body D_1, the length of the pillar L_s, the pillar width of the largest t_s, the length of craft L, the beam B, the draft T, the longitudinal position of buoyancy L_{cp}, the propeller diameter D_P and area ratio A_{eo}, pitch ratio P_{DP}, screw speed N and design speed V_S, water wingspan ZC, water wing chord length XC, the initial attack angle α, the hydrofoil square coefficient C_b, the length on waterline L_w, waterline coefficient C_w, catamaran hull spacing C_0, center of gravity height Z_g. For simplicity of description, these 21 design variables are represented by a vector, namely:

$$X_{sp}=\{L_h,D_1,L_s,t_s,L,B,T,L_{cb},D_p,A_{eo},P_{dp},N,V_s,ZC,XC,\alpha,C_b,L_w,C_w,C_0,Z_g\}$$

2 The objective function

2.1 Objective function of rapidity

The speed of a ship mainly depends on two factors: the resistance of the ship and the efficiency of the propulsion device. Therefore, we can use these two aspects to measure the fast performance of the ship and the open water performance of the propeller.

In terms of resistance, the resistance under unit drainage volume is adopted as a sub-objective function of the ship's speediness optimization objective function:

$$f_1(x) = R_{total} / \nabla \quad (2.1)$$

In terms of propulsion, the propulsion coefficient is selected as part of the objective function of fast propulsion:

$$f_2(x) = P.C = \eta_H \eta_R \eta_S \eta_0 \quad (2.2)$$

Where: ∇ is the volume of displacement ; R_{total} is the total resistance ; η_S is shafting transmission efficiency ; η_R is relative rotation efficiency ; η_0 is open water efficiency of propeller ; η_H is hull efficiency.

To sum up, the total objective function of rapidity is the weighted product of two sub-objective functions, and its expression is shown in the following equation:

$$f(x) = f_1(x)^{\beta 1} \times f_2(x)^{\beta 2} \quad (2.3)$$

Where: β_1, β_2 are the weights of the $f_1(x), f_2(x)$ ($\beta_1 > 0, \beta_2 > 0$) .

2.2 Objective function of maneuverability

The objective function of maneuverability optimization selects linear stability as the objective function of maneuverability of SWATH - USV. The linear stability is expressed by the linear stability criterion coefficient, and the maneuverability objective function is:

$$f_3(x) = C = Y_v' N_r' - N_v'(Y_r' - m') \quad (2.4)$$

2.3 Objective function of solar energy

The solar layout area needs to be maximized and economic factors should be taken into account. Assuming that the working time of the unmanned boat is 4.5h, the solar layout area is taken as the objective function of solar optimization:

$$f_4(x) = \left(\frac{48\pi \times K_Q \times \rho \times n^3 \times D_p^{\ 5}}{\eta_s \times \eta_R} + 1.7\right) \times \frac{4.5h}{0.2484} \quad (2.5)$$

The larger the solar layout area is, the better it will be if it meets the requirements of economy and navigation performance.

2.4 Objective function of comprehensive optimization

The objective functions of the three subsystems, namely, rapidity, maneuverability and green energy system, of the unmanned craft on SWATH - USV are synthesized, and the overall objective function of the performance comprehensive optimization is constructed by taking the form of power exponential product as follows.

$$f(x) = \frac{f_2(x)^{\alpha 2} \cdot f_3(x)^{\alpha 3} \cdot f_4(x)^{\alpha 4}}{f_1(x)^{\alpha 1}} \quad (2.6)$$

Where, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are the weights of rapidity, maneuverability and solar energy system of unmanned craft. Referring to relevant literature and expert experience, it is known that they need to be met. In this paper, the larger the value of the total objective function of performance synthesis optimization is required, the better.

3 optimize constraint conditions

As the most basic navigation performance, which buoyancy must be met, so its displacement train should remain unchanged. In addition, the variation range of design variables should be within the constraints of the given boundaries and should satisfy the balance of forces. Constraint conditions can be divided into equality constraint conditions and inequality constraint conditions.

3.1Equality constraints

(1) The static water buoyancy constraint, the ship must meet the state of positive buoyancy, that is, displacement is equal to gravity:

$$\Delta = \rho LBTC_b \quad (2.7)$$

(2) The thrust resistance balance constraint, that is, the sum of propeller effective thrust and the hydrofoil thrust is equal to the total navigation resistance:

$$N_p K_T \rho N^2 D_p^4 (1-t) + F_x = R_t + R_x \quad (2.8)$$

(3) The torque balance constraint, that is, the torque supplied by the main engine to the propeller is equal to the hydrodynamic torque borne by the propeller:

$$\frac{\eta_R \eta_s P_s}{2\pi N} = K_Q \rho N^2 D_p^5 \quad (2.9)$$

A. *3.2 Inequality constraint conditions*

(1) The propeller should meet the requirements of cavitation, which can be obtained from Keller's formula:

$$(1.3 + 0.3Z)T_e / ((P_0 - P_V)D_P^2) + K = (A_E / A_0)_{\min} \quad (2.10)$$

Then, the inequality constraint condition is:

$$(1.3 + 0.3Z)T_e / ((P_0 - P_V)D_P^2) + K - (A_E / A_0) \le 0 \quad (2.11)$$

Where： P_0 is the static pressure at the center of the propeller shaft ; P_V is the evaporation pressure of seawater at 15 degrees Celsius ; T_e is the propeller thrust ; Z is the number of blades of propeller ; K is constant，the high speed ship is 0，other sculls is 0.1，the single scull is 0.2.

（2）According to the regulations of seagoing ships, the initial stability: $GM > 0.7m$; rolling period : $T_\varphi = 1.05B / \sqrt{GM} < 6.0s$.

（3）The solar panel area should meet this condition : $S < 3BL$.

（4）The upper and lower limits of design variables.

III. Comprehensive Optimization Calculation of Inland River SWATH-USV

1 Genetic algorithm

Genetic algorithm (GA) to "weed out the survival of the fittest" principle of biological evolution in optimizing parameters of coding series, according to the selected fitness function and of the individual through reproduction, crossover and mutation in the genetic screening, make high fitness individuals be preserved, and form a new group, the new group inherits the generation of information, and is better than the last generation. Over and over again, the fitness of individuals in a group increases until certain conditions are met. The algorithm of genetic algorithm is simple, parallel processing, and can get the global optimal solution.

The steps of the standard genetic algorithm are as follows: 1) randomly initialize the population. 2) calculate the fitness value of each individual in the population. 3) if the optimal solution of the problem is found or the maximum genetic algebra is reached, exit the loop. 4) according to the fitness value of each feasible solution, the selection operation is carried out to generate a new population. 5) perform crossover operation and mutation operation. 6) return to step 2. The specific steps of the algorithm are shown in figure 1:

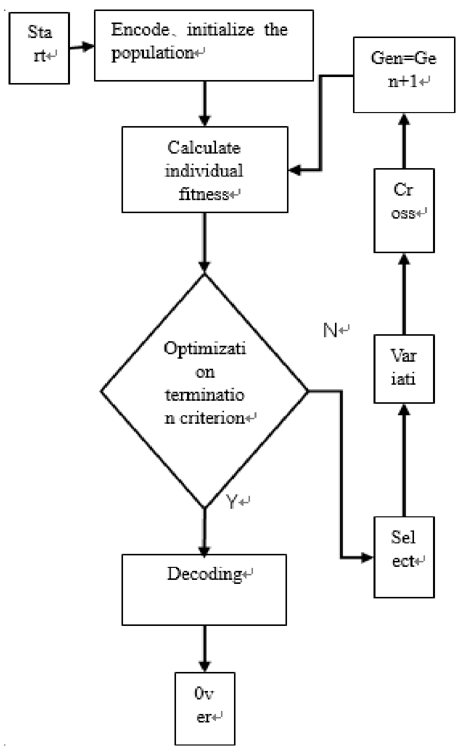

Fig.1 Flow chart of genetic algorithm

In the genetic algorithm, the fitness function is used to represent the adaptability of each individual in the population to its living environment, and each individual has an adaptive value. Adaptive value is the only deterministic index of individual survival chance in a group. The form of fitness function directly determines the evolutionary behavior of groups. The fitness function is basically determined according to the optimized objective function. In order to directly connect the fitness function with the merits and demerits of individuals in the population, the fitness value in the genetic algorithm is defined as non-negative, and in any case, the larger the better.

2 Analysis of optimization calculation

This paper takes a catamaran with a displacement of 6.9t as an example. The variable range of the optimal design of this catamaran is shown in table 1:

Design variables	Upper limit	Lower limit	Design variables	Upper limit	Lower limit
L_h(m)	7.3	7	*ts*	0.35	0.29
L_s(m)	6.6	6.3	L (m)	8.1	7.8
D1(m)	0.8	0.7	*B*(m)	3.85	3.7
T(m)	1.15	0.9	*N*	350	270
Cb	0.232	0.2	V_S(kn)	8.2	7.5
Lcp	0.1	-0.1	*c0*(m)	3.15	2.95
Dp(m)	0.85	0.84	*Lw*(m)	6.6	6.3
A_{eo}	0.45	0.4	*Zg*(m)	1.6	1.54
P_{DP}	1.05	0.95	*Cw*	0.155	0.145

Table 1 Design variable value ranges

Within the range of the design variables, 3000, 4000, 5000, 6000, 7000, 8000 and 9000 generations were calculated respectively, and the average value of each generation was calculated three times. The optimization results are as follows:

Table 2 Objective function values under different genetic algebras

Algebra	objective function	Penalty value	Algebra	objective function	Penalty value
3000	55.2	1	6000	60.1	1
4000	57.8	1	7000	62.5	1
5000	59.4	1	8000	62.6	1

As can be seen from the above table, with the increase of genetic algebra, the value of the total objective function shows an increasing trend. When the number of a certain generation (7000 generations) is reached, the total objective function tends to be stable with only small fluctuations. So 7,000 generations as stable algebra.

3 The value of the total objective function varies with the length

Table 3 Total objective function values of length between 7.8-8.1m

Length	Total objective function	Length	Total objective function
7.8	41.3	7.98	52.1
7.86	44.8	8.04	51.1
7.92	48.2	8.1	48.7

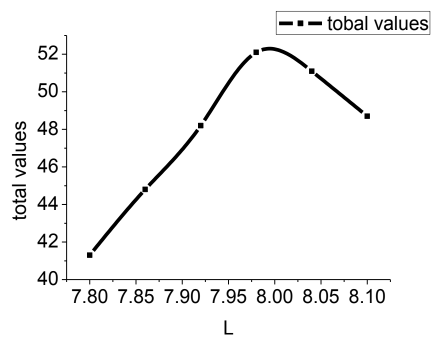

Fig.2 The curve of the total objective function value with the length

According to the figure above, the value of the total objective function fluctuates with the length between 7.8m and 8.1m, but the overall trend is increasing. However, when the length is 7.98m, the total objective function value is the largest. Therefore, it can be judged that when the length is around 7.98m, it is conducive to the optimal navigation state.

4 The value of the total objective function varies with the propeller speed

Table 4 Total objective function values of propeller speed between 300-350rpm

Propeller speed	Total objective function	Propeller speed	Total objective function
280	47.16	320	49.98
290	49.21	330	48.35
300	52.50	340	44.07
310	51.2	350	43.02

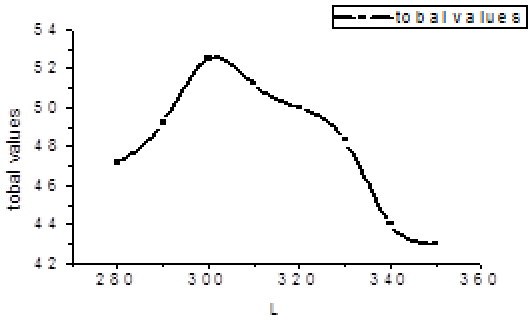

Fig.3 The curve of the total objective function value with the propeller speed

As can be seen from the figure above, when the speed is 280-300rmp, the value of the total objective function changes sharply, and when the speed is 300-350rmp, the value of the total objective function decreases, and the peak point appears when the speed is 300rmp. Therefore, when the rotation speed is about 300rmp, it is favorable for the sailing state to reach the optimal value.

A. 5 The value of the total objective function varies with the propeller diameter

Table 5 Total objective function values of propeller diameter between 0.75-0.8m

Propeller diameter	Total objective function	Propeller diameter	Total objective function
0.75	46.51	0.78	47.91
0.76	48.27	0.79	46.50
0.77	50.10	0.80	44.30

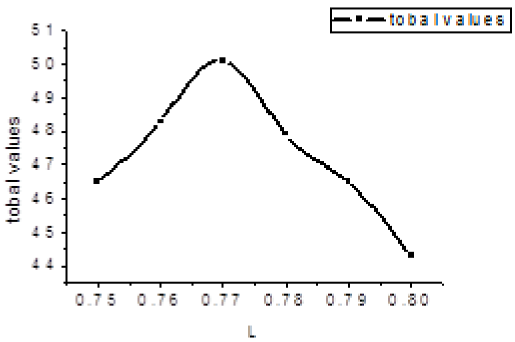

Fig.4 The curve of the total objective function value with the propeller diameter

As can be seen from figure 4, the value of the total objective function fluctuates between the propeller diameter of 0.75 and 0.80m, and reaches the maximum when the propeller diameter is 0.77m. It can be concluded that the diameter of propeller can be selected at about 0.77m in order to achieve the optimal sailing state.

IV. Conclusion

Aiming at the SWATH-USV in inland waters, a comprehensive optimization mathematical model of SWATH-USV in inland waters was constructed by considering its rapidity, maneuverability and green energy system. Combined with genetic algorithm, the comprehensive performance calculation of SWATH-USV was completed, and the stable algebra 7000 generations of genetic algebra in the optimization process were finally obtained. By drawing curves and analyzing the changes of the total objective function value in different length, propeller speed and the propeller diameter, it is concluded that the captain is 7.98m, the propeller speed is 300rmp and the propeller diameter is 0.77m in favor of reaching the optimal navigation state. This will provide important technical support for the overall design of SWATH-USV in inland waters.

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