Research on the Application of Parametric Methods in Submarine Conceptual Design

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Keywords: Parameterized, Overall Submarine Design, Conceptual Design, Mathematical Model.

Abstract: Traditional submarine conceptual design relies on representation models established in the form of symbols to describe the design scheme. However, the representation model cannot well cooperate with the computer-aided design system to improve design efficiency. This article proposes to parameterize the submarine layout in the conceptual design stage of the submarine based on the three levels of pressure hull, cabin, and equipment layout, and based on this, build a mathematical model of the simple submarine layout in the conceptual design stage. This mathematical model can be used as part of the digital design and construction of submarines, and can be used in conjunction with computer-aided design technology to improve design efficiency. At the same time, relying on this method will help scientific researchers understand the inherent laws in the design of submarines and unmanned underwater vehicles and come up with the best design solutions.

1 INTRODUCTION

Conceptual design is a plan demonstration design carried out in the top-level design stage of submarine. It is the overall conceptual activity in the early stage of submarine design. It is the materialization process from abstract thinking to the determination of specific design plans. The basic idea of current submarine conceptual design is to use expression models in the form of symbols, words, etc. to describe the complex behaviors and implementation steps of submarine equipment conceptual design. Then, by solving the expression model, we can understand the design process and reveal the overall function and structural attributes of the submarine. The internal laws to obtain the best design solution (Ma Yunyi, 2020).

With the development of science and technology, computer technology is gradually applied to all aspects of weapons and equipment development (Chen Jianguo, Nie Yuqiang). In this process, the expression model in the submarine conceptual design did not match well with the computer-aided design system (CAD). This problem directly affects the efficiency of the conceptual design stage of modern submarines (Bai Tao - Zhou Nianfu).

In order to improve the efficiency of the submarine conceptual design stage, domestic and foreign experts conducted parametric design research. Ki-Su Kim, Myung-Il Roh (Kim K-S, Jung S-K) proposed a layout design study based on expert systems based on parameterization. Sebnem Helvacioglu and Mustafa Insel (Helvacioglu S, Helvacıoğlu Ş) proposed research on ship layout design based on reasoning. Jiang Wenying and Lin Yan (Jiang Wenying, 2016) conducted research on the layout design of the main hull of ships based on parameterization. T. Ray, R.P. Gokarn, O.P. Sha(Ray T, 1995) established a global optimization model for ship design, and treated the ship design optimization problem as a multi-criteria constrained multi-variable nonlinear optimization problem for research. Yu Yanyun (Yu Yanyun, 2009) proposed a design method for ships and offshore platforms based on three-dimensional solid modeling technology and parametric technology by discussing the design principles and design methods of the overall design of ships and offshore platforms. In summary, establishing a submarine

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Li, J., Peng, F., Qi, W. and Wang, Z.
Research on the Application of Parametric Methods in Submarine Conceptual Design.
DOI: 10.5220/0012281500003807

In *Proceedings of the 2nd International Seminar on Artificial Intelligence, Networking and Information Technology (ANIT 2023)*, pages 285-290
ISBN: 978-989-758-677-4

mathematical model based on parametric expression is the key to improving design efficiency (Roh M-I, 2007).

This paper mainly studies the problem of parametric expression of submarine general arrangement in the conceptual design stage. Parametric expression is carried out at three levels: pressure hull shape, compartment division, and equipment layout. Based on this, the submarine's general layout in the conceptual design stage is expressed as a mathematical model that can be calculated and analyzed. This method helps carry out multi-disciplinary and multi-objective design optimization of submarines, improves design efficiency, and realizes parameter-driven requirements for submarine design solutions.

2 PARAMETRIC EXPRESSION METHOD FOR SUBMARINE LAYOUT

2.1 Parametric Expression Method for Pressure-Resistant Shells

At present, the pressure-resistant shell of submarines is mainly a rotary body, which can be described by the mathematical ship shape method. A Cartesian rectangular coordinate system is constructed with the center point of the submarine's rotary body axis at the pressure hull as the origin, the direction of the origin toward the bow of the ship as the X-axis, the ship's width direction as the Y-axis, and its vertical direction as the Z-axis. The spherical bodies at the bow and stern of a submarine can be approximated by the following formulas:

$$z=r(x)=R\left[1-\left(\frac{x-x_1}{x_2-x_1}\right)^2\right]^{\alpha} \qquad (1)$$

Among them: R is the maximum radius of the submarine's rotating body;

x_1 is the starting point coordinate of the spherical surface on the X axis;

x_2 is the coordinate of the end point of the spherical surface on the X axis;

α is the shape factor.

The middle part of the submarine pressure hull can be considered as a cylinder with a constant radius or a linear change in radius, that is,

$$z=r(x)=R \quad \text{or} \quad z=r(x)=z(x,R) \qquad (2)$$

The $r(x)$ obtained from formulas (1) and (2) is the radius of the submarine pressure hull rotary body. In formula (2), $z(x,R)$ represents the linear equation related to x and R.

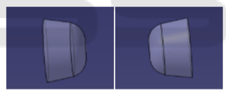
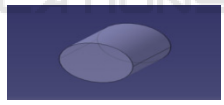
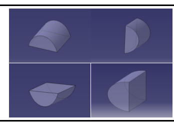
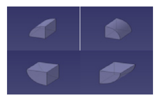
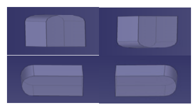
2.2 Cabin Parameterization Expression Method

Submarine equipment is numerous and the space is small, so the pressure-resistant shell curved surface needs to be taken into consideration when designing the cabin layout.

1) Submarine cabin classification

In order to achieve an accurate parametric expression of the submarine cabin, the submarine cabin can be divided into 16 basic shapes as shown in Table 1 according to the different constituent elements (the figures in the figure are for demonstration only, and the dimensions of each cabin type are not necessarily Proportion):

Table 1. Classification of cabin composition.

No.	Cabin composition	Appearance diagram
1	1 bulkhead and hull curved surface	
2	2 bulkheads and hull curved surfaces	
3	3 bulkheads and hull curved surfaces	
4	4 bulkheads and hull curved surfaces	
5	5 bulkheads and hull curved surfaces	
6	6 bulkheads	
7	Several bulkheads and several hull curved surfaces	——

2) Parametric expression method of submarine cabin

It can be seen from "Submarine cabin classification" that submarine cabins can be basically divided into 6 categories and 16 types according to different constituent elements, of which 5 categories and 15 types are related to the main hull surface. For these 15 types of cabins, the curve characteristics of the submarine pressure hull need to be. The parametric implementation of the cabin provides the basis.

According to the parametric approximate expression of the submarine's main hull surface, combined with the classification of submarine cabins, under the same coordinate system, the position parameters of each bulkhead in the submarine cabin are combined with the submarine's main hull surface to realize the classification of submarine cabins. Parametric expression, such as formula (3) to formula (8).

$$C_{\text{I-i}} = \left(x_{1-i} \quad x_{2-i} \quad y_{l-i} \quad z_{l-i} \quad z\left(r(x),y\right) \quad y\left(r(x),z\right) \right) \tag{3}$$

$$C_{\text{II-i}} = \left(x_{1-i} \quad x_{2-i} \quad y_{l-i} \quad z_{l-i} \quad z\left(r(x),y\right) \quad y\left(r(x),z\right) \right) \tag{4}$$

$$C_{\text{III-i}} = \left(x_{1-i} \quad x_{2-i} \quad y_{l-i} \quad z_{l-i} \quad z\left(r(x),y\right) \quad y\left(r(x),z\right) \right) \tag{5}$$

$$C_{\text{IV-i}} = \left(x_{1-i} \quad x_{2-i} \quad y_{l-i} \quad z_{l-i} \quad z\left(r(x),y\right) \quad y\left(r(x),z\right) \right) \tag{6}$$

$$C_{\text{V-i}} = \left(x_{1-i} \quad x_{2-i} \quad y_{l-i} \quad z_{l-i} \quad z\left(r(x),y\right) \quad y\left(r(x),z\right) \right) \tag{7}$$

$$C_{\text{VI-i}} = \left(x_{1-i} \quad x_{2-i} \quad y_{1-i} \quad y_{2-i} \quad z_{1-i} \quad z_{2-i} \right) \tag{8}$$

Among them, $C_{\text{I-i}}$, $C_{\text{II-i}}$, $C_{\text{III-i}}$, $C_{\text{IV-i}}$, $C_{\text{V-i}}$, and $C_{\text{VI-i}}$ represent the six types of submarine compartments in Table 1;

x_{1-i}, x_{2-i} represent the head and tail position coordinates of the submarine cabin on the X-axis.

y_{1-i}, y_{2-i} represent the head and tail position coordinates of the submarine cabin on the Y-axis.

z_{1-i}, z_{2-i} represent the head and tail position coordinates of the submarine cabin on the Z-axis.

y_{l-i} represents the limited range of the submarine cabin on the Y-axis of the coordinate axis.

z_{l-i} represents the limited range of the submarine cabin on the Z-axis of the coordinate axis.

$z(r(x),y)$ represents the expression formula of the Z coordinate of the hull surface and the $r(x)$ and Y coordinates of the radius of rotation in the submarine cabin;

$y(r(x),z)$ represents the expression formula of the Y coordinate of the hull surface and the $r(x)$ and Z coordinates of the radius of rotation in the submarine cabin;

The details are shown in Figure 1.

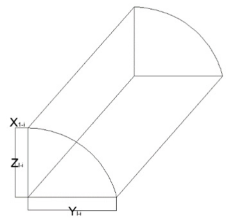


Figure 1: Concept diagram of parameterized expression of submarine cabin.

2.3 Equipment Layout Parameterized Expression Method

There are a large number of equipment arranged in the submarine pressure hull, and each belongs to different systems/subsystems. The quality of submarine equipment layout directly affects the overall performance of the submarine, the use of combat personnel and the convenience of subsequent maintenance of the submarine.

Submarine equipment layout parameterization mainly consists of the following two aspects:

(1) Parametric expression of device appearance.

(2) Parametric expression of equipment layout location.

There are many devices involved in submarines, with different shapes and sizes, and most of them are irregular shapes. In order to realize the parametric expression of the equipment, the appearance of the submarine equipment should be simplified accordingly. The boundary method is used to simplify the model of each equipment into a cuboid according to its size, and the equipment position is expressed through the center of the cuboid, as shown in Figure 2.

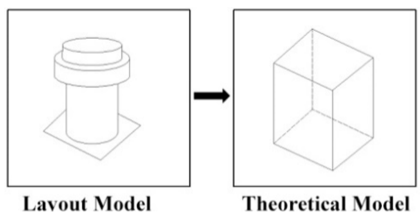


Figure 2: Simplified schematic diagram of submarine equipment.

Therefore, the arrangement of equipment in the submarine is as shown in equation (9).

$$arrangement(i) = (location(i), shape(i), weight(i)) \quad (9)$$

Formula (9) respectively represents the center position of the equipment, the simplified cuboid size of the equipment, and the weight of the equipment.

Among them:

$$location(i) = (x_i, y_i, z_i) \quad (10)$$

$$shape(i) = (length_i, width_i, heigth_i) \quad (11)$$

x_i, y_i, z_i are the positions of the equipment center in the Cartesian coordinate system constructed in 2.1.

$length_i, width_i, heigth_i$ respectively represent the length, width, and height of the device after it is simplified into a rectangular parallelepiped.

3 EXAMPLES

"Agosta" is a conventional submarine designed by the French Navy. The hull design adopts a double-hull design and the pressure-resistant hull is round. The power system is equipped with two diesel generator sets, two sets of lead-acid batteries, a main propulsion motor and an economical navigation motor, and has good navigation capabilities. In terms of weapons, it is equipped with four torpedo launch tubes, which can prepare 16 torpedoes. The detection capability is also equipped with a sonar, which can work in an active and passive manner.

As a conventional submarine, the "Agosta" basically includes all the elements of a modern submarine and has room for modification. From this, the design of the "Agosta" submarine can be expressed parametrically to achieve subsequent research.

Since the "Agosta" submarine is a double-hull submarine, its inner shell, the pressure-resistant shell, can be considered to be an elongated oval. According to the existing drawings and data, combined with the expression in 2.1, and in accordance with relevant requirements, a Cartesian submarine that meets the usage requirements is constructed. The coordinate system can be expressed parametrically in the following form:

$$z = r(x) = \begin{cases} 1.1665\left(1-\left(\frac{-30-x}{1}\right)^2\right)^{0.3} & x \in (-31,-30) \\ 0.1267x + 4.9665 & x \in (-30,-22.5) \\ 0.0458x + 3.1478 & x \in (-22.5,-10.5) \\ 2.6665 & x \in (-10.5,25.5) \\ -0.1111x + 5.4998 & x \in (25.5,30) \\ 2.1665\left(1-\left(\frac{x-30}{1}\right)^2\right)^{0.25} & x \in (30,31) \end{cases} \quad (12)$$

The parameterized expression of the main compartments in the submarine can also refer to the description in "parametric expression method of submarine cabin", as shown in Table 2 below:

Table 2: Parameterized representation list of submarine main compartments.

Cabin Name	NO.	Parametric Expression
Torpedo room	1	$C_{\text{I-1}} = \left(31 \quad 16 \quad (-2.665, 2.665) \quad (-2.665, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$
Command module	2	$C_{\text{III-2}} = \left(16 \quad -10.5 \quad (-2.665, 2.665) \quad (-0.15, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$
Front battery compartment	3	$C_{\text{III-3}} = \left(16 \quad 7.75 \quad (-2.661, 2.661) \quad (-0.15, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$
Rear battery compartment	4	$C_{\text{III-4}} = \left(4 \quad -3.5 \quad (-2.661, 2.661) \quad (-0.15, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$
Auxiliary engine room	5	$C_{\text{III-5}} = \left(7.75 \quad -3.5 \quad (-2.661, 2.661) \quad (-0.15, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$
Motor compartment	6	$C_{\text{III-6}} = \left(-3.5 \quad -10.5 \quad (-2.661, 2.661) \quad (-0.15, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$
Main cabin	7	$C_{\text{I-7}} = \left(-10.5 \quad -31 \quad (-2.665, 2.665) \quad (-2.665, 2.665) \quad z=\sqrt{r^2(x)-y^2} \quad y=\sqrt{r^2(x)-z^2}\right)$

The main equipment in the submarine can be preliminarily parametrically arranged as described in 1.3. For the convenience of explanation, the equipment that has a greater impact on the submarine layout and power is selected for expression. The details are shown in Table 3:

Table 3: Parametric representation list of submarine main equipment.

Cabin Name	No.	Parametric Expression
Main motor	1	$arrangement(1) = ((-21.5, 0, -0.8), (7, 2.75, 4.5), 32)$
No. 1 diesel engine	2	$arrangement(2) = ((-13.5, 0.9, -0.8), (4.75, 1.3, 2), 7)$
No. 2 diesel engine	3	$arrangement(3) = ((-13.5, -0.9, -0.8), (4.75, 1.3, 2), 7)$
Air conditioning unit no. 1	4	$arrangement(4) = ((-6.5, 0.5, -1.1), (4, 1.5, 1.75), 1.5)$
Air conditioning unit no. 2	5	$arrangement(5) = ((-6.5, 2, -1.1), (4, 1.5, 1.75), 1.5)$
No. 1 battery pack	6	$arrangement(6) = ((0.5, 0, -1.1), (7.5, 3.6, 1.9), 0.5)$
No. 2 battery pack	7	$arrangement(7) = ((7.5, 0, -1.1), (7.5, 3.6, 1.9), 0.5)$
Torpedo tube	8	$arrangement(8) = ((29, 0, 0), (8.25, 2.5, 2.5), 1.5)$
Left torpedo mount	9	$arrangement(9) = ((20, 1.25, 0.5), (6.5, 2, 3.5), 0.3)$
Right torpedo mount	10	$arrangement(10) = ((20, -1.25, 0.5), (6.5, 2, 3.5), 0.3)$

The three-dimensional model of the submarine pressure hull is generated in the software according to Equation (12), and compared with the submarine pressure hull constructed in CAD based on the data, as shown in Figure 3. At the same time, the pressure-resistant shell volume can be calculated according to equation (12) to be 1986 m^3 , and according to the data, the pressure-resistant shell volume of the agosta submarine is 1983 m^3 , with an error of 0.2%. Considering that the middle part of the pressure-resistant shell is a streamlined rotary body with a longitudinal section of multiple straight lines, the error after mathematical expression of this part is small. The bow and stern of the pressure-resistant shell are both streamlined rotary bodies with elliptical longitudinal sections. After this part is expressed mathematically, the mathematical expression method can only be modeled theoretically, so there may be large errors. Calculated from the current pressure-resistant shell volume, the error is only 0.2%, which is within the allowable range.

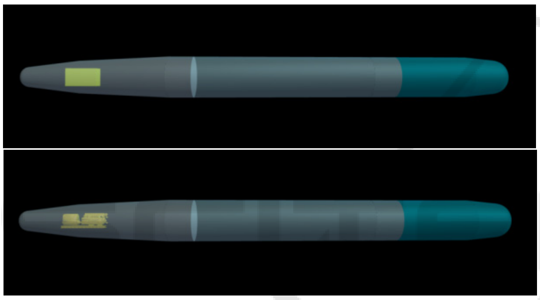


Figure 3: CAD construction of submarine pressure hull and parametric method to generate submarine pressure hull comparison diagram.

In the software, a three-dimensional model of the submarine pressure-resistant shell can be generated according to Equation (12). The constructed three-dimensional model of the main motor and the simplified model of the main motor are put into the submarine three-dimensional model for comparison, as shown in Figure 4.

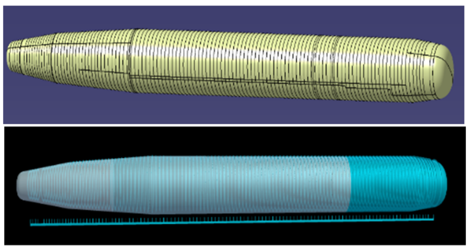


Figure 4: Comparison diagram between a 3D model of submarine main motor and a simplified model of submarine main motor.

It can be seen from the figure 4: It can be considered that in the conceptual design stage of the overall submarine design, after the equipment is parameterized and simplified, it will not have an impact on the design effect of this stage, and at the same time, it can meet the design requirements of researchers at the data calculation level.

4 CONCLUSION

This article studies the application of parametric methods in the overall design of submarines. In order to realize the combined use of computer-aided design systems and the overall design of submarines, this article conducts the overall layout of the submarine in terms of pressure hull shape, cabin division, equipment layout, etc. Parametric expression is used to establish a mathematical model of the general layout of the submarine in the conceptual design stage. Based on this, the "Agosta" submarine was used as the object for practical verification. The verification results show that the parametric expression method proposed in this article can realize the combined application of computer-aided design system and overall submarine design, help carry out multi-disciplinary multi-objective optimization design of submarines, and realize parameter-driven submarine design solutions.

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