Research on a New Type of Polar Icebreaking Guide Ship based on MATLAB

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Abstract. Polar regions are rich in natural resources and have valuable scientific research value. In recent years, with the deepening of polar exploration and the development of marine resources in the frigid zone, the development of icebreakers, as an important marine equipment in polar rescue, channel opening, and material supply, has attracted more and more attention and attention from various countries. Aiming at the current common icebreakers and icebreaking methods, through theoretical research and simulation analysis, the author designs a polar icebreaking guide ship with a new icebreaking method. While adjusting the ice breaking device in real time according to the thickness of the ice layer, according to the forward and inverse solution algorithm for the motion planning of the robot arm, the precise control of the ice breaking robot arm is completed, and the purpose of energy saving and emission reduction is achieved at the same time. Provide more intelligent and energy-saving options for the construction and development of icebreaker equipment in my country.

Keywords: Icebreaker; Ice-Breaking Technology; Five-Point Bending Ice-Breaking; Ice-Breaking Intelligent Control System.

1. Research Background and Significance

At present, because polar icebreakers play an important role in polar scientific research, resource development, and rescue, various ocean powers are also carrying out further development of icebreaker structural design and icebreaking methods.

The traditional ice-breaking methods of icebreakers mainly include: the jacking method, which relies on the momentum of the icebreaker to move forward, as well as the propulsion of the propeller, its own hard shell and the upturned bow to split the ice and smash it. It is suitable for breaking ice. Thin ice layer; head pressure method[1]. That is using the adjustment of hull weight and ballast water to make the icebreaker rush on the ice layer to crush the ice; impact method (ice breaking method on foot), mostly used when the ice layer is thick, Taking advantage of the shallow draft at the bow of the icebreaker, increase the horsepower to rush to the ice surface. The hull relies on its own weight to break the ice once, and then the icebreaker backs up a certain distance, and then drives the full horsepower again to rush to the front ice layer for a second icebreak. However, the above-mentioned ice breaking methods all require the huge thrust of the propeller and the high engine load, which greatly increases the energy consumption of the ship[2].

At the same time, especially for icebreakers powered by diesel engines, there are relatively few polar ports, and fuel supply is difficult, which brings difficulties to the navigation and normal work of icebreakers. At the same time, ice breaking through the direct contact of the hull with the ice layer puts forward very high requirements on the structural strength of the hull, which is easy to cause fatigue and damage to the hull, and the propeller may be mechanically damaged by hitting the crushed ice generated by the collision of the bow[3]. The ice-breaking range of traditional icebreakers is also fixed due to the fixed structure of the ship and the design of the ice-breaking device, so it is impossible to flexibly adjust the ice-breaking range. In this context, innovating traditional ice-breaking methods, improving the intelligence of ice-breaking devices, reducing the energy consumption of ice-breaking ships, protecting the hull structure, and flexibly adjusting the ice-breaking range have become important directions for ice-breaking research and development[4].

2. Structural Design of Polar Icebreaking Guide Ship

2.1 Ship Structure Design

In order to improve the ice-breaking efficiency and adjust the ice-breaking direction, this project adopts a heavy-duty double-propeller polar ice-breaking guide ship. Two ice-breaking robotic arms are installed at the stern deck, and at the stern, an icing column that protrudes obliquely upwards extends from the bottom[5]. The ice-breaking robotic arm cooperates with the ice-breaking work. Ice breaking at the stern is beneficial to the stability of the hull structure and requires special structures. The basic parameters of the hull structure are shown in Table 1 below.

Table 1. Basic parameters of hull structure

project	Parameter index
Waterline length L	75.20m
Waterline width B	18m
Type deep H	
Draft T	6.5m
Displacement Δ	$5.79 \times 10^6 kg$
Propulsion shaft power N	13440kW
Robot arm boss size b×h	
The distance between the icicle and the deck is z	

2.2 Structural Design of Hydraulic Manipulator

The hydraulic manipulator used in this project is a 6-DOF joint configuration, which consists of four joints: base, big arm, middle arm and end forearm. The end of the forearm is connected with a disc serrated ice blade. In view of the compact structure of the manipulator and the large end load, in order to increase the ice-breaking effect, the manipulator joints are hydraulically driven. There is a hydraulic cylinder, which relies on the hydraulic oil pump and the hydraulic motor to provide the conversion of hydraulic energy to realize the pitch and swing of the joint. The overall architecture of the robotic arm is shown in Figure 1 [6].

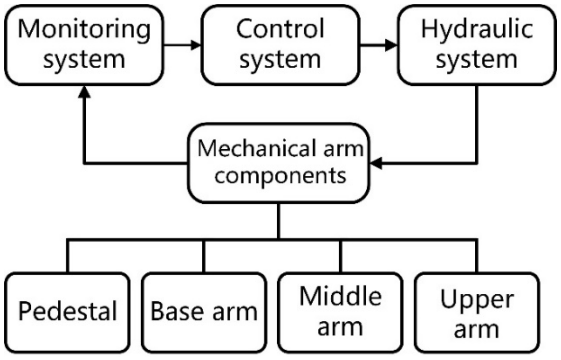


Figure 1. Overall architecture of the robotic arm

2.3 The Working Principle of Ice Breaking

The new polar ice-breaking guide ship can measure the thickness of the ice layer in real time. Through the analysis of the intelligent ice-breaking control system, the ballast water volume can be changed, the stern draft can be adjusted to move its bottom dead center, and the hydraulic system of the mechanical arm can be controlled to make the mechanical arm move in a certain size and direction. The force movement, so as to contact the ice layer, and cooperate with the icicle to break the ice under the principle of five-point bending ice breaking[7]. In addition, according to the forward and inverse solution algorithm for the motion planning of the robotic arm, the precise control of the ice-breaking robotic arm is completed, and the purpose of energy saving and emission reduction is achieved at the same time. The flow chart of the working principle of ice breaking is shown in Figure 2.

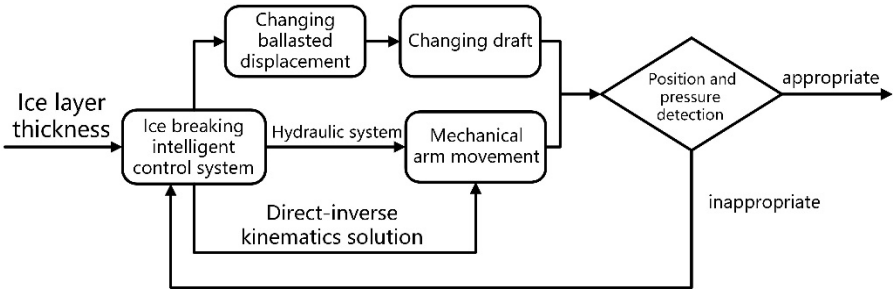


Figure 2. Flow chart of the working principle of ice breaking

3. Research on the Key Technology of Five-Point Bending Ice Breaking

3.1 Calculation of Five-Point Bending Ice Breaking Principle

The three-point bending test is to place a sample with a rectangular or circular section on the bending device, adjust the span, and load the sample to perform a bending test until it reaches the specified bending degree or breaks [8]. Applying this principle to a three-point icebreaker, whereby the ice is broken, the bending strength σ_f is calculated by using the linear elasticity theory according to the beam bending theory with three-point loading as follows:

$$\sigma_f = 3PL / 2bh^2$$

The formula for calculating the strain and strain rate at the bottom of the load application point is as follows:

$$\varepsilon = 6h\delta / L^2$$

$$\dot{\varepsilon} = 6h\dot{\delta} / L^2$$

In the formula: P is the load when the beam fails, MPa;L is the span of the beam, m; h is the height of the pattern, m; δ is the deflection at the point where the load is applied, mm.

The type of failure surface of the ice three-point bending test specimen is relatively simple, mainly root failure, X-shaped failure and Y-shaped failure. More than 50% of the failure surfaces are Y-shaped failures. When the bending specimen is damaged, the upper compression zone appears milky white due to compression, and the lower tension zone is mostly broken triangular prism blocks. Figure 3 shows the type of bending failure surface[9].

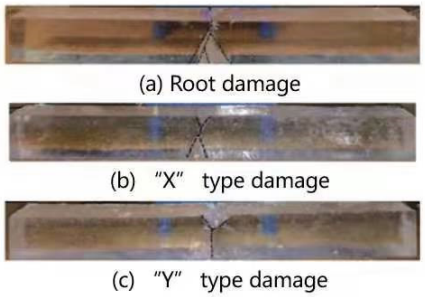


Figure 3. Form of bending failure surface

Through the verification of the three-point bending test, the three-point bending icebreaking test can be applied to icebreakers[10].

3.2 Simulation Analysis of Five-Point Bending Ice Breaking

An icebreaker with a ship width of 18m and a length between ship verticals of 75.20m is used for simulation analysis.

Table 2. Simulation using ice parameters

parameter	symbol	Numerical value	unit
sea ice density	ρ_i	880	$kg\ /\ m^3$
Young's modulus	E	5400	MPa
Poisson's ratio	γ	0.33	
Compressive strength	σ_c	2.3	MPa
Bending strength	σ_f	0.55	MPa
friction coefficient	μ_i	0.15	
ice thickness	h_i	0.6	m

Continuous ice breaking through the contact of the bow with the ice surface causes the ice to begin to crush and break; as the ship advances the ice begins to bend downward along the bow; then the ice breaks and rotates in the direction of the hull at the center of the break; the resulting ice fragments continue to rotate and slides along the hull; the bow begins to contact new ice and cycles the above process, as shown in Figures 4 and 5:

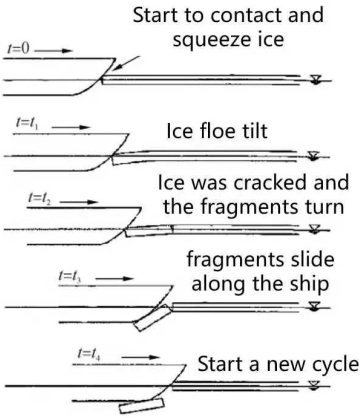


Figure 4. Continuous ice breaking process

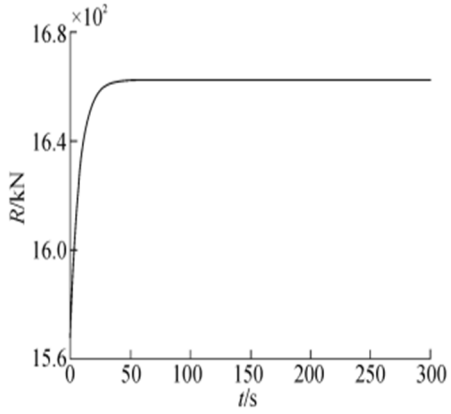


Figure 5. Ice resistance curve of hull

In the continuous ice breaking process, the Lindqvist empirical method is used to estimate the ice breaking resistance. The parameters included in this method are main scale, ship type, ice thickness, friction force and ice strength. This method can calculate the corresponding hull ice resistance of 16.6kN based on the continuous ice breaking mode. The five-point ice breaking simulation data is shown in Table 3:

Table 3. Five-point ice breaking simulation parameters

length	thickness	width	Action point 1	Action point 2	Action point 3	point of application angle
44m	1m	6m	6m	11m	16m	30°
	2m	6m	6m	11m	16m	
	3m	6m	6m	11m	16m	
	4m	6m	6m	11m	16m	
	5m	6m	6m	11m	16m	

By comparing the ice resistance of the five-point ice breaking and the continuous ice breaking, it can be found that the five-point ice breaking method is better and the ice breaking is easier [12].

4. Icebreaker Icebreaking Control System

4.1 Hovering Technology of Hydraulic Manipulator

In order to keep the ice blade stable and maintain high precision when the ice-breaking robotic arm is breaking ice, the robotic arm needs to adopt the hovering technology[13]. Therefore, in this

project, under the premise of considering the kinematics and dynamic constraints of the robotic arm, the end motion of the six-axis robotic arm is designed. Plan forward and inverse solution algorithms. The algorithm uses the standard D-H modeling method and matrix operation library to establish the mathematical model of the manipulator. The forward kinematics of the manipulator is analyzed and simulated by Robotics Toolbox in MATLAB; then the inverse kinematics model is derived by algebraic method, and the simulation verification is carried out, and the most economical power is used as the performance index to determine The only way to know. The correctness of the derivation process is verified and simulated by Robotics Toolbox based on MATLAB platform. Figure 6 shows the standard D-H parameter method[14].

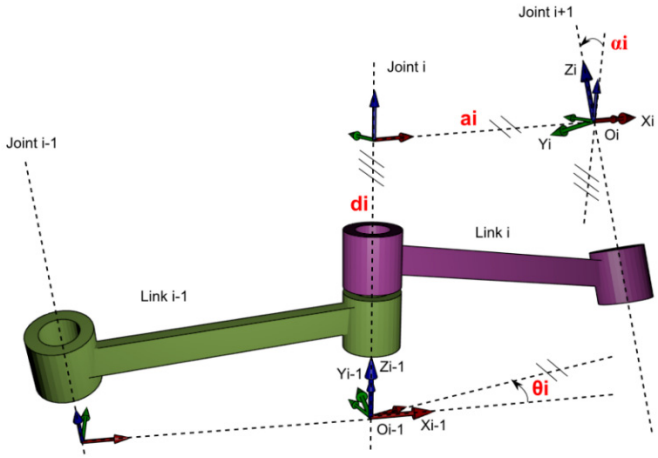


Figure 6. Schematic diagram of Standard DH

The reference coordinate system is set on the base of the 6R robotic arm, so it can be transformed from the base to the first joint, then to the second joint, and then to the end gripper. If each transformation is defined as An, then the total transformation between the base and the hand of the 6R robotic arm is:

$$ {}^{R}T_{H} = {}^{R}T_{0}\,{}^{0}T_{1}\,{}^{1}T_{2}\,{}^{2}T_{3}\,{}^{3}T_{4}\,{}^{4}T_{5}\,{}^{5}T_{H} = A_0\,A_1\,A_2\,A_3\,A_4\,A_5\,A_H $$

The desired pose expression of the robot:

$$ {}^{R}T_{H} = \begin{pmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

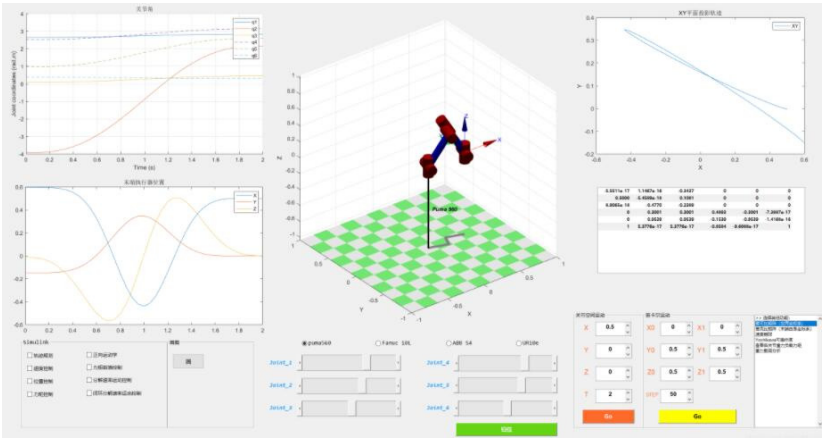


Figure 7. MATLAB simulation of robotic arm

Through the change matrix, the value of each joint rotation angle can be calculated. According to the joint rotation angle solved above, reverse the sum of the squares of the rotation angle changes of each joint of the 6R robot arm end gripper from the initial pose to the next path point pose. minimal solution [15]. Through MATLAB simulation, the simulation data of the manipulator as shown in Figure 7 can be obtained.

4.2 Model Making of Polar Icebreaker Guided Ship

The model diagram of the polar icebreaking guide ship is shown in Figure 8

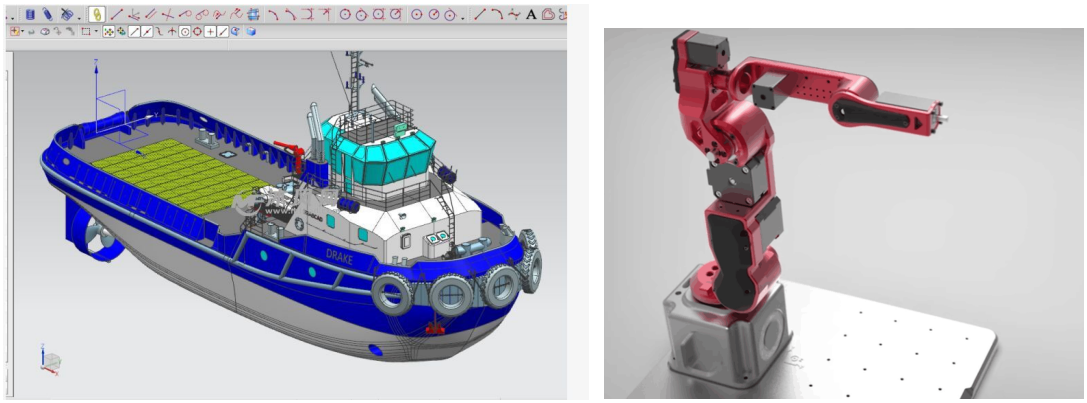


Figure 8. Model diagram of polar icebreaking guide ship

4.3 Control Circuit Design and Fabrication

When the circuit receives the ice layer detected by the IPS ice profiling sonar, it calculates the optimal water level of the ship, the optimal pressure of the manipulator and the optimal speed of the ship through the circuit processing, and controls the output of the relevant parameters through the feedback adjustment mechanism to Guaranteed to achieve the best ice breaking effect[16].

Use the 485 bus to control the hydraulic oil pump, use the serial port control signal of STM32, and then use the MAX485 chip to convert the RS485 level into a level signal on the 485 bus to control multiple hydraulic oil pumps using the bus. Figure 9 is a schematic diagram of the control circuit board.

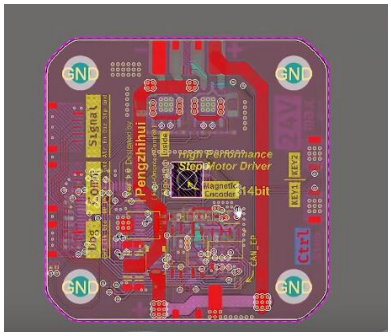


Figure 9. Control circuit board

5. Conclusion

This project focuses on the five-point bending properties of ice, which make it easier for the ice to break through the middle. The two ice-breaking robotic arms and the stern icicle on the stern deck of the icebreaker can respectively exert pressure on the ice layer from the surface layer and the bottom layer of the ice, so as to achieve the ice-breaking effect. The stability and safety of icebreakers during icebreaking operations. In this project, the hydraulic manipulator arm structure is designed to be used in ice-breaking operations. The hydraulic ice-breaking device can ensure sufficient ice-breaking force. The ice-breaking control system can also control the ballast water according to the thickness of

different ice layers to change the draft of the ship and flexibly adjust the force of the manipulator arm. and direction, and at the same time control the propeller's propulsion speed in combination with the ice-breaking situation, so as to realize the intelligentization of the ice-breaking system. In addition, a forward and inverse solution algorithm for the motion planning of the robotic arm is introduced, so that the robotic arm can work more stably during ice breaking operations, improve ice breaking efficiency and reduce energy loss.

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