A New Type of Marine Solar-energy Sail System

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Abstract. In this paper, a new type of marine intelligent solar-energy sail system is designed. According to the state and environmental parameters of the ship, it can increase the illuminated area of the sail by changing the sail attitude, realize the intelligent control of the sail, realize the efficient utilization of wind energy and light energy, and effectively increase the endurance capacity and application range of the clean energy ship. The promotion of the research results can greatly save the operation cost of cruise ships, have greater economic and environmental benefits in the long run, and conform to the concept of sustainable development.

1. Research background
There are many rivers and lakes in China, and waterway transportation is an indispensable part of China's transportation. With the implementation of domestic ship emission control area, under the environment of sustainable development, the emission control standard of ship air pollutants becomes more and more strict. Therefore, the design of energy-saving ship types that meet the requirements of relevant policy standards and industry norms, and the realization of energy-saving and emission reduction of cruise ships, not only produce economic benefits for enterprises, but also fully conform to the overall strategy of the country.
Therefore, combined with the situation that the existing green ships mostly use solar power generation and sail assisted navigation, this paper designs an adaptive control system, which can increase the illuminated area of the sail by changing the sail attitude, realize the dual utilization of wind energy and light energy, improve the efficiency utilization ratio, and is conducive to energy conservation and emission reduction.

2. Overall design
In the system, an attitude driving device is designed to control the position change of the sail, so that the sail can be adjusted to the corresponding functional mode according to different environmental parameters. The rotation of the screw motor drives the rack connected with the slide rail to slide, and the rack drives the gear to rotate to realize the axial angle change of the mast. The rolling cylindrical tube is connected with another motor, and the rotation of the motor can drive the rotation of the rolling cylinder to realize the attitude conversion of the mast. To sum up, it can fully meet the motion requirements of the driving device.

3. Design of attitude driving mechanism
The device is composed of sail, screw slide rail, rack, gear, sail support mast, rolling cylindrical tube and servo stepping motor (as shown in Fig. 1).
The mast is sleeved in the rolling cylindrical tube through the bearing in the way of interference fit; the gear and mast are screwed and engaged with the rack; the rack is fixed on the slide rail (screw motor type), one end of the slide rail is connected with the servo motor, and the movement of the rack is controlled by the motor to control the wind direction tracking of the sail wing; the inner part of the rolling cylinder is connected with the slide rail through the welding structure, and the outer part is in contact with the groove on the top of the ship, so as to increase the stability of the moving parts during operation, and finally it is fixed by the fixed device.

4. Feasibility analysis

4.1. Analysis of the force on the bottom of the sail rod when flating the sail
In order to test the safety of the stress concentration part at the bottom of the sail rod under the light energy utilization mode, this project uses the static stress analysis module in COMSOL Multiphysics to import the three-dimensional model established by SolidWorks software and display its interface. As shown in Fig. 3.

Determine the coordinate axis, and determine the materials of each part of the model from bottom to top: hull (aluminum alloy), rotating cylinder (45 steel), sail shaft (cast steel), sail (k = aluminum alloy), finally determine the Poisson's ratio, Young’s Modulus and other parameters.
After the boundary conditions of the model are set, the initial load is added, and the force is applied on the connecting part of the cylinder and the sail, and the magnitude is the gravity and static friction force of the sail itself; the calculation starts after the grid is divided: according to the direction of the wind sail force on the cylinder, the pressure field acts vertically on its connection surface, and the maximum stress is on the contact surface between the cylinder and the sail rod (according to fig. 4), with the maximum value of about 63.59MPa. According to the comprehensive comparative analysis of several material properties, the bearing stress is obviously within the allowable stress range of common materials, meeting the strength requirements.

4.2. Analysis of the force on the bottom of the sail rod when erecting the sail
In order to test the safety of the stress concentration part at the bottom of the sail rod when the wind is assisting the navigation, the project calculates the stress at the bottom of the scheme under each level of wind through theoretical calculation.

When the wind direction angle $\varphi = 105^\circ$, the maximum thrust coefficient $C_{Tm}$ of the sail is 1.51, so the maximum thrust $T_s$ of the sail:

$$T_s = C_{Tm} \cdot \frac{1}{2} \cdot \rho_a V_b^2 S$$  \(1\)

Maximum bending moment $M_{max}$:

$$M_{max} = \frac{T_s L}{2}$$  \(2\)

$L$ is the sail height. For circular sections, the bending section factor $W_Z$ is:

$$W_Z = \frac{I_Z}{y_{max}} = \frac{\pi d^4}{4} = \frac{\pi d^3}{32}$$  \(3\)

In the formula, $I_Z$ is the moment of inertia of circular section, $d$ is the diameter of sail rod 150 mm, and $y_{max}$ is the centroid position.

So the maximum normal stress $\sigma_{max}$:

$$\sigma_{max} = \frac{M_{max}}{W_Z}$$  \(4\)

The wind speed is substituted into $V_b$ and then into the formula, and the results are shown that under the normal wind speed (level 3-7), the maximum stress on the sail rod is still within the allowable bending stress range. When the wind speed exceeds level 8, the calculation result shows that the maximum bending stress is exceeded, so the sail is put on the top of the ship at this time to reduce the harm of wind to the cruise ship.

4.3. Simulation analysis of wind resistance variation
In order to test the feasibility of the sail we designed on the ship, and to verify the influence of wind resistance on the ship's hull during the operation of the ship, we use COMSOL to analyze the coupling of multi physical fields and build the simulation model. In this project, the FluidFlow module of ANSYSWorkbench is used to simulate the wind resistance of the simplified ship model under different wind speed conditions, and the variation of the resistance is compared to determine the maximum wind resistance of the sail under the flat sail condition. In the modeling, according to the design size, use SolidWorks software to establish a simplified ship model, and import the SolidWorks
model (as shown in Fig. 5). The speed is set to 3.287m/s, 3.361m/s, 4.792m/s and 5.924m/s respectively according to the actual working conditions. The initial setting is until convergence. After our calculation, the maximum wind resistance of a single sail is 10.236N (5.924m/s), so the total wind resistance of the device in photovoltaic power generation mode is 61.416N, which only accounts for 3.12% of the total resistance of the cruise ship in normal operation (1963.20N). In theory, it does not affect the normal operation of the cruise ship.

![Fig 5. Meshing generation map](image)

![Fig 6. Influence diagram of resistance in flat sail state](image)

5. Conclusion
This paper analyzes the existing cruise ships, and finds out the disadvantages of the new energy cruise ships, designs the intelligent solar-energy sail system, which can realize the conversion between the flat sail and the erect sail, expand the light receiving area, realize the efficient utilization of the scenery, meet the design requirements in safety, and effectively increase the endurance capacity and application scope of the clean energy ships. This research will also fill the gap in this field in China, and is expected to make breakthroughs in some key technologies, with good promotion value and great market potential.

References
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