Application of Coanda Effect in Water Jet Propulsion Devices

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Abstract. In order to improve the problem of low efficiency of water jet propulsion devices at low speeds, a special multi-ring structure of water jet propeller nozzle is designed based on the Coanda effect. On the basis of the credibility of numerical calculation methods, the hydraulic performance of the special structure is analyzed by using the method of computational fluid dynamics. The results show that the designed structure can effectively improve the problem of low efficiency of water jet propellers at low speeds, which is of great significance to better the performance of water jet propellers.

1. Research Background

1.1. Coanda Effect [1]

Coanda effect, also known as wall attachment effect, can be simply described as follows: for Newtonian fluid, it always tends to flow along the contour of the curved surface contacted by the fluid. It has been widely used in aviation, jet control technology and wall-attached jet devices, such as the principles of air cushion, circumfluence control rotor, circumfluence suction pump, fuel injection control.

Figure 1. Schematic Diagram of Kangda Effect
1.2. Water Jet Propellers [2]
A water jet propeller is an important way of marine propulsion, which mainly consists of water jet propulsion pump (including rotating impeller and stationary guide vane), inlet channel, nozzle and reversing device. Compared with the propeller, the water jet propeller has the advantages of good maneuverability, strong anti-cavitation ability and high efficiency at high speeds. It has gradually become one of the preferred propulsion methods for high-speed ships.

However, there are many problems in the use of water jet propellers such as complex transmission mechanism, low thrust vectorization, low efficiency at low speeds and so on. In order to solve the above problems, the industry has put forward many ideas on the design methods and structure improvement of water jet propellers. For example, Zhang Mingyu proposed a prediction method for the hydraulic performance of water jet propellers, which plays an important role in improving the design level of water jet propellers. It can be seen that the research on water jet propellers has become a hot spot in the industry. This paper proposes a special multi-ring nozzle based on Coanda effect, which can enhance the kinetic energy of water jet at high speeds and guide the flow running out of the nozzle at low speeds, so as to improve the efficiency of water jet propellers at low speeds.

2. Numerical Calculation Model and Method
Since the internal flow of water jet propellers is very complex, theoretical analysis can not accurately describe the flow, and the experimental method has high requirements on the site and equipment, and the cost is expensive. In this paper, the method of computational fluid dynamics (CFD) is adopted to study and verify the scheme.

2.1. Numerical Calculation Method [3][4]
The method of computational fluid dynamics (CFD) described in this paper adopts the Reynolds Average Navier-Stokes (RANS), which is widely used in the field of propeller performance analysis. Its equation expression is as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i) = 0$$

(1)

$$\frac{\partial}{\partial t} (\rho u_i) + \frac{\partial}{\partial x_j} (\rho u_i u_j) = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_i} (\mu \frac{\partial u_i}{\partial x_j} - \rho u_i u_j)$$

(2)

$p$ denotes the pressure; $\rho$ refers to the fluid density; $\mu$ stands for the fluid viscosity; $u_i u_j$ represents the items of Reynolds stress; $u_i$ and $u_j$ signifies the velocities in different directions.

2.2. Numerical Calculation Model
The research object of this paper is the design scheme proposed in this paper. According to the scheme, a three-dimensional model is established to verify the rationality of the scheme through numerical calculation. In the numerical calculation, the grid is divided as shown in Figure 1. At the same time, in order to compare the performance of the propeller without using the design scheme described in this paper, a model with the same parameters other than the multi-ring structure described in this paper is established for comparison calculation. It has been verified that the scheme mentioned in this paper can improve the performance of water jet propellers.
3. Performance Calculation and Data Analysis

Numerical simulation is carried out for the model established in this paper at different navigational speeds and rotational speeds, and the correlation that thrust varies with navigational speed and rotational speed is shown in Table 1.

| Working Condition | Thrust/N |
|-------------------|----------|
| Navigational Speed/m/s | Rotational Speed/ρ/min | Using New Design | Without New Design |
| 0.2               | 1100     | 106        | 98           |
| 0.2               | 1400     | 171        | 157          |
| 0.2               | 1700     | 261        | 237          |
| 0.4               | 1100     | 89         | 83           |
| 0.6               | 1100     | 79         | 74           |

Take several working conditions of the same navigational speed (0.2m/s) for analysis, and draw the curve of thrust varying with rotational speed, as shown in Figure 2. It can be seen from the figure that the thrust of the nozzle with the structure which is designed based on Coanda effect is significantly higher than that without the structure, with an average thrust increase of 9%.
Figure 4. Thrust Varying with Rotational Speed at a Navigational Speed of 0.2 m/s
Take several working conditions of the same rotational speed (1100 r/min) for analysis, and draw the curve of thrust varying with navigational speed, as shown in Figure 3. It can be seen that the thrust of the nozzle with the structure which is designed based on Coanda effect is significantly higher than that of the propeller without the structure, with an average thrust increase of 7.3%.

Figure 5. Thrust Varying with Navigational Speed at a Rotational Speed of 1100 r/min

4. Conclusion
In order to solve the problem of low efficiency of water jet propellers at low speeds, a new type of nozzle structure is designed based on Coanda effect and computational fluid dynamics. The main research information is as follows:

The advantages and disadvantages of water jet propellers are introduced, and the research direction of this paper is clearly pointed out.

The basic theory of Coanda effect and numerical calculation is briefly introduced, and the theoretical basis for the research is established.

Through numerical calculation, the thrust of the new structure designed in this paper is compared with that of the new structure under different working conditions. The thrust under various conditions is increased by 9% at the same navigational speed and 7.3% at the same rotational speed. The
comprehensive thrust is increased by 8.3%. It is proved that the new design has better hydraulic performance.

The new nozzle structure proposed in this paper can be applied to water jet propulsion devices, which can effectively overcome the shortcomings of low efficiency of water jet propellers at low speeds and promote the better development of water jet propellers.

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