Application of Direct-driven Multistage Supercharging Technology in Water Jet Propulsion Devices

Xuan Cheng¹, Shoutian Chen¹, Wu Ouyang ¹* and Yan Zhang ¹

¹ Shenlan technology Innovation Team, School of Energy and Power Engineering, Wuhan University of Technology (WUT), Wuhan, Hubei Province, 430063, China
*Corresponding author’s e-mail: ouyangw@whut.edu.cn

Abstract. In order to solve the problems of complex transmission and low power density of water jet propulsion devices, a direct-driven multistage supercharging structure suitable for such devices is designed, and the computational fluid dynamics (CFD) method is used for numerical calculation and verification analysis. The results show that the designed structure can improve the performance of water jet propulsion devices, which is of great significance to the integrated development of such devices.

1. Research Background
A water jet propulsion device[1] is an important marine propulsion device, which mainly consists of inlet channel, water jet propulsion pump and nozzle. Compared with the propeller, it has many advantages such as strong anti-cavitation ability, excellent maneuverability and high efficiency at high speeds, and has gradually developed into a mainstream ship propulsion device.

However, in the process of using the water jet propulsion device, there are still many disadvantages compared with the propeller such as low efficiency at low speeds and complex transmission mechanism. In order to solve these problems, the industry has put forward many improvement and optimization methods for the design scheme and structure of water jet propulsion devices. For example, Zhang Mingyu proposed a prediction method for the hydraulic performance of water jet propulsion devices, which plays an important role in improving the design level of water jet propulsion devices. The research of water jet propulsion devices has become a hot spot in the industry.

In order to deal with the problems of complex transmission mechanism and low power density of water jet propulsion, this paper proposes a direct-driven multistage supercharging structure suitable for water jet propulsion by analogy with the structures of aero-engine[2] and multistage centrifugal pump[3]. Compared with the traditional water jet propulsion device, this structure adopts the direct-driven design, which avoids the power loss caused by shafting transmission; and at the same time, the multistage supercharging structure can improve the power density and the performance of water jet propulsion devices.

2. Numerical Calculation Model and Method
Since the theoretical analysis has been unable to accurately describe the complex flow inside the water jet propulsion device, and the experimental method is expensive and requires a long time, this paper is to use the method of computational fluid dynamics to study and verify the scheme proposed, and then analyze the numerical results.
2.1. Numerical Calculation Model

The research object of this paper is the direct-driven multistage supercharging structure proposed. According to the scheme, a three-dimensional model is established, and the rationality of this design is verified by the method of computational fluid dynamics. The established grid is shown in Figure 1. In the meanwhile, in order to demonstrate the improvement of the performance of the propeller by the multistage supercharging structure described in this paper, a model without the multistage supercharging technology but with the same other parameters is established for comparative verification. Through the same method, it is concluded that the direct-driven multistage supercharging structure described in this paper can improve the power density and promote the performance of water jet propulsion devices.

![Figure 1. The Grid used in Numerical Calculation](image1)

2.2. Numerical Calculation Method[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:

\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j) = 0
\]  

(1)
\[
\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j}(\mu \frac{\partial u_i}{\partial x_j} - \rho u_i u_j^i) \tag{2}
\]

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

3. Performance Calculation and Data Analysis
The numerical calculation model established in this paper is simulated numerically at different rotational speeds and navigational speeds, and the correlation that thrust varies with rotational speed and navigational speed is shown in Table 1.

| Working Condition | Thrust/N |
|-------------------|----------|
| Navigational Speed/m/s | Rotational Speed/r/min | Using New Design | Without New Design |
| 0.2 | 1100 | 159 | 147 |
| 0.2 | 1400 | 206 | 189 |
| 0.2 | 1700 | 308 | 281 |
| 0.4 | 1100 | 149 | 139 |
| 0.6 | 1100 | 124 | 116 |

Take several working conditions of the same navigational speed (0.2 m/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 obtained by adopting the direct-driven multistage supercharging structure described in this paper is 8.9% higher than that obtained by not using the direct-driven multistage supercharging structure.

Figure 3. 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 obtained by using the direct-driven multistage supercharging structure described in this paper is increased by an average of 7.4% compared to that obtained by not using the direct-driven multistage supercharging structure.
4. Conclusion

In order to solve the problems of complex transmission and low power density of water jet propulsion devices, a direct-driven multistage supercharging structure suitable for water jet propulsion devices is designed by analogy with the structure of aeroengine and multistage pump. The main research information is as follows:

The advantages and disadvantages of water jet propulsion devices are briefly discussed, and the research direction of this paper is clearly pointed out.

The concept of multistage supercharging structure suitable for water jet propulsion devices is proposed and verified by modeling.

The scheme proposed in this paper is verified and analyzed by the numerical calculation method, and the direct-driven multistage supercharging structure designed in this paper is compared with the model without this structure. The results show that the average thrust is increased by 8.9% at the same rotational speed and 7.4% at the same navigational speed, and the comprehensive thrust is increased by 8.1%, which proves that the design can improve the hydraulic performance of water jet propulsion devices.

The direct-driven multistage supercharging structure proposed in this paper can overcome the disadvantages of complex transmission and low power density of water jet propulsion devices, and promote the development of water jet propulsion devices.

Acknowledgments
This paper was support by Wuhan University of Technology National innovation and entrepreneurship training program for college students (Item Number: S202010497143).

References
[1] Zhang Mingyu, Yu Weiqiang, Wu Xiaoyang, et al. Design and Hydraulic Performance Prediction Methods of Water Jet Propulsion Devices [J]. Marine Equipment/Materials & Marketing, 2020, (10): 13-18.
[2] Zhou He, Zhang Zhixuan. Research on Aeroengine Principles and Progress [J]. China Southern Agricultural Machinery, 2015,46 (10): 43-44.
[3] Huang Junhu, Liu Yonghui, Miao Jun, et al. Application Affect Evaluation of Multistage Centrifugal Pump Supercharging Unit [J]. Chemical Engineering & Equipment, 2018, (05): 255-258.
[4] Wang Xuebao. Research on the Inner Flow of Water-jet Propeller [D]. 2017.