Simulation Experiment on Drag Reduction Effect of the V-shaped Groove Structure of Bionic Water Strider Robot

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Abstract. The drag reduction of the groove surface is inspired by the shark skin structures, the groove structure is transplanted onto the water-repellent robot and subjected to drag reduction simulation experiments. The effect of the width, height and apex angle of the V-shaped groove on the drag reduction coefficient is studied. When the dimensionless parameters of the width, height and apex angle of the groove are 16, 11 and 70°, the best drag reduction effect is obtained, the drag reduction rate is about 6.5%. The characteristic parameters obtained through simulation experiments can provide a design basis for the drag reduction research of bionic water hammer robot.

Keywords: Bionic Water Strider Robot, Drag Reduction, V-Shaped Groove

1 Introduction
The drag reduction of the groove surface is inspired by the shark skin structure, the shark's skin is not smooth, but has a certain shape of the groove texture. This non-smooth skin structure is generally considered to be an important reason why sharks can swim at high speed in the water. The NASA Research Center found that the micro-trench can effectively reduce the frictional resistance of the wall surface, which break through the traditional way of thinking that the smoother the surface is the smaller the resistance [1-3]. Bechert compared the grooves of triangles, rectangles and semicircles to show that the V-grooves are considered to be the most favorable structure for drag reduction [4-6]. This paper will study the characteristic dimensions of V-grooves. It is planned to transplant the groove structure to bionic water strider robot to reduce the resistance. Bionic water strider robot has a wide range of applications in water detection and environmental monitoring.

2 Experimental program
In this paper, the simulation experiment is carried out by Computational Fluid Dynamics software (CFD), which can obtain the drag coefficient of the bionic water strider robot. The general steps consist of four parts, which are to establish three-dimensional model, discrete grid, fluent simulation and analysis of experimental results [7, 8].
2.1 Establish three-dimensional model

The foot of the bionic water strider robot is a rectangular parallelepiped with a length, width and height of 50 mm × 10 mm × 2 mm. The bottom surface of the rectangular parallelepiped has a V-shaped groove, and its characteristic dimensions are shown in Fig. 1.

![Figure 1](image_url)

Fig 1 the characteristic dimension of the V groove

The V-shaped groove depth is \( h \), the groove pitch is \( s \), and the apex angle of the groove is \( \alpha \). Due to the small scale of the V-shaped groove structure, the simulation experiment encounter the problems of large calculation amount and difficulty in mesh division. Therefore, the parameters of the groove depth and the groove pitch are infinite according to the equations (1) (2) and (3).

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\begin{align*}
    h^+ &= \frac{h \mu}{v} \quad (1) \\
    s^+ &= \frac{s \mu}{v} \quad (2) \\
    \mu_r &= 0.172U \left( \frac{D}{{\mu}} \right)^{-\frac{1}{10}} \quad (3)
\end{align*}
\]

Where \( h \) is the groove depth, \( h^+ \) is the dimensionless depth of the groove, \( s \) is the groove width, \( s^+ \) is the groove dimensionless width, \( v \) is the velocity of the fluid, and \( \mu_r \) is the wall friction velocity.

2.2 Discrete grid

When dividing the grid, create the part of the bottom surface groove, the upper part is part of smooth, and the part of wall on both sides, the minimum mesh size of the groove surface is set to 0.05, the other faces are set to 1, and the final mesh is divided into about 500,000, and the mesh quality is checked.

2.3 Fluent simulation

The divided mesh is imported into Fluent for numerical simulation [9, 10], and the turbulence intensity is set to 5%. The model is solved by K-WSST and second-order upwind calculation, and the control convergence precision is set to 10^{-5}.

3 Analysis of experimental results

3.1 Effect of groove spacing on drag coefficient

For the V-shaped groove structure, firstly study the influence of the groove spacing on the drag reduction rate, the fluid velocity is 0.5 m/s, the dimensionless depth of the trench is \( h^+=10 \), and the corresponding groove dimensionless spacing is 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20. Through
simulation experiments, the same groove depth and resistance of V-grooves at different groove spacing are known. The coefficient is shown in Fig 2. It can be seen that the V-shaped groove has a smaller drag reduction coefficient at s+=16.

![Fig 2 Effect of groove spacing on drag coefficient](image)

3.2 Effect of groove height on drag coefficient
The effect of groove depth on the drag reduction rate is studied. The fluid velocity is 0.5 m/s, the dimensionless spacing of the groove is s+=15, and the corresponding groove dimensionless depth is 6, 7, 8, 9, 10, 11, 12, 13, 14, and 15. Through simulation experiments, it can be seen that the same groove spacing, the drag reduction ratio of the V-shaped groove at different groove depths, and the drag coefficient are as shown in Fig. 3. When h+=11, V-shaped groove has a smaller drag reduction coefficient.

![Fig 3 Effect of groove height on drag coefficient](image)

3.3 Effect of apex angle on drag coefficient
After selecting the two feature sizes of the trench depth h and the trench pitch s, the influence of the top angle α of the V-shaped trench on the drag reduction coefficient is analyzed. Here we assume that the top of the trench is symmetrical at the bottom. We set the groove top angles to 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, 100°, 110°, and 120°, respectively. Simulation experiment, h+=11, s+=16, v=0.5m/s. In the simulation results, the resistance coefficients corresponding to different top angle
numbers are shown in Fig. 4, in the V-shaped groove. When the apex angle of the groove $d$ is 70°, the V-shaped groove has a small drag reduction coefficient.

![Graph showing the effect of apex angle on drag coefficient](image)

**Fig 4** Effect of apex angle on drag coefficient

4. Conclusion
The V-shaped groove achieves the best drag reduction effect when the depth dimensionless parameter is 11, the width dimensionless parameter is 16, and the apex angle is 70°, compared with a smooth surface, the drag reduction rate is about 6.5%. The characteristic parameters obtained through simulation experiments can provide a design basis for the drag reduction research of bionic water hammer robot.

Acknowledgments
This research was supported by National Natural Science Foundation of China (Grants No. 51875249), Jilin Province Natural Science Foundation (Grants No. 20180101066JC), Education Department of Jilin Province Funded Project (Grants No. JJKH20180498KJ), Program for Innovative Research Team of Jilin Engineering Normal University.

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