Research on hydrodynamic characteristics of conical bottom oscillating float based on AQWA

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Abstract. This paper simulates the conical oscillating float by hydrodynamic calculation software. It mainly focuses on the modelling and simulation of the float cone angle, and analyses the frequency domain of the respective radiation damping, added mass, exciting force and Response Amplitude Operators (RAOs). The results show that when the frequency is greater than 0.9 Hz, the exciting force and the added mass of the float are smaller. When the frequency is less than 0.6 Hz, the radiation damping increases as the wave frequency increases, RAOs will change slightly. When the frequency is greater than 0.6 Hz, the radiation damping and RAOs decrease as the frequency increases. For an oscillating float of the same mass and different cone angles, the added mass reaches a maximum value when the wave frequency is about 0.2 Hz, and the added mass change is small when the frequency is greater than 0.9 Hz.

1. Introduction

With the decreasing of fossil fuels, new energy sources are receiving more and more attention, especially marine energy represented by wave energy. At present, many wave energy generating devices in China and abroad have been put into daily use. For example, Portugal's "Sea Snake Wave" power generation device (Pelamis) [1] and Archimedes Wave Swing [2], the US Power Buoy point absorption wave power station. A point absorption wave energy conversion device developed by Guangzhou Energy in China has completed the sea state test [3-4]. Among the many wave energy capture methods, the oscillating float type has attracted the attention of many wave energy developers because of its lower cost and higher efficiency [5-6]. The shape of the floating float has a cylinder, a cone and a sphere. The conical angle of the conical bottom oscillating float is a key factor affecting the hydrodynamic characteristics of the float. The device mainly drives the reciprocating motion of the hydraulic cylinder by the up and down movement of the oscillating float, so that the added mass and the radiation damping of the float can be reduced as much as possible to increase the heave amplitude of the float. Therefore, studying the cone angle is an important entry point for a cone-shaped oscillating float. By comparison, the cone angle that is most suitable for working in the marine environment is selected to improve the power generation efficiency of the oscillating float.

In this paper, the professional hydrodynamic software AQWA is used to simulate the hydrodynamic characteristics of cone-shaped oscillating floats with different angles. The wave excitation force, Response Amplitude Operators (RAOs), the added mass and the radiation damping of the oscillating float at different wave frequencies are compared and analysed.
2. Research object

2.1. Simulation parameters and hydrodynamic model

During the analysis, the method of controlling the variables is used to keep the radius and mass of the float constant and change the cone angle of the oscillating float. Draw a 3D model with SolidWorks and calculate the draft, centroid position, and moment of inertia. The main parameters of the float device are shown in Table 1, and the three-dimensional model of the float is shown in Figure 1.

Table 1. Main parameters of oscillating float.

| Cone angle | Draught depth/m | Moment of inertia/(kg*m^2) |
|------------|----------------|--------------------------|
|            |                | Ixx | Iyy | Izz |
| 90°        | 0.78           | 821.094 | 821.094 | 319.836 |
| 110°       | 0.62           | 773.937 | 773.937 | 352.937 |
| 120°       | 0.54           | 752.238 | 752.238 | 363.931 |
| 130°       | 0.47           | 730.653 | 730.653 | 372.005 |
| 140°       | 0.41           | 713.182 | 713.182 | 379.851 |
| 150°       | 0.34           | 694.441 | 694.441 | 385.164 |
| 160°       | 0.28           | 675.048 | 675.048 | 390.216 |
| 180°       | 0.16           | 648.375 | 648.375 | 398.386 |

Figure 1. Three-dimensional model of oscillating float.

2.2. Calculation principle

Under the action of the micro-amplitude wave, it is assumed that the water in which the cone-shaped oscillating float is located is a non-viscous, incompressible fluid, and the flow field is a non-rotating motion. According to the linear formula, the hydrodynamic force acting on the oscillating float can be seen as a superposition of Froude-Krylov force, radiation force and diffraction force.

The motion of the object is represented by Eq. (1), where \( \omega \) is the wave frequency; \( Z(\omega) \) is the heave motion function; \( M \) is the float mass; \( F_e(\omega) \) is the wave excitation force, \( F_r(\omega) \) is the radiation force generated by the float motion; \( F_{hs}(\omega) \) is the hydrostatic force.

\[
-\omega^2 MZ(\omega) = F_e(\omega) + F_r(\omega) + F_{hs}(\omega)
\]  

(1)

The hydrostatic recovery and hydrostatic stiffness are calculated by Equation 2 and Equation 3. In the formula, \( \rho \) is the density of water, \( g \) is the acceleration of gravity, and \( A' \) is the cross-sectional area of the wet surface.

\[
F_{hs}(\omega) = KZ(\omega)
\]

(2)

\[
K = \rho g A'
\]

(3)
In a regular wave, the exciting force of the oscillating float can be seen as a superposition of the radiating force and the Froude-Krylov force. The excitation force is expressed by the formula 4. In the formula, $F_{FK}(\omega)$ is the Froude-Krylov force and $F_d(\omega)$ is the diffraction force.

$$F_e(\omega) = F_{FK}(\omega) + F_d(\omega)$$  \hspace{1cm} (4)

The radiation force is generated by the movement of the cone bottom oscillating float in the water, and can be decomposed into two parts: the radiation damping term and the added mass term. The radiation damping term and the motion of the oscillating float are different phases, and the added mass term and the motion of the float are in phase. Radiation force can be calculated by Equation 5. In the formula, $j$ is an imaginary unit, $C(\omega)$ is radiation damping, and $M_a(\omega)$ is an added mass.

$$F_r(\omega) = -(j\omega C(\omega) - \omega^2 M_a(\omega))Z(\omega)$$  \hspace{1cm} (5)

The value of RAOSs can be calculated by Equation 6.

$$\text{RAO}(\omega) = \frac{F_e(\omega)}{K - \omega^2(M + M_a(\omega)) + j\omega C(\omega)}$$  \hspace{1cm} (6)

2.3. Meshing and parameter setting

In the hydrodynamic calculation software AQWA, the range of frequency domain analysis is determined according to the size of the grid. In the simulation process, the minimum grid size is set to 0.05m, the frequency range is 0-1.2 Hz, and the curve precision is set to 20 interpolation to determine a curve. The grid is automatically divided. The grid is shown in Figure 2.

![Figure 2. Oscillating float meshing.](image_url)

3. Hydrodynamic analysis results

The cone angle of the conical bottom oscillating float has a great influence on the power generation effect, and it is analyzed by frequency domain analysis by AQWA software. The hydrodynamic performance of the cone-bottomed oscillating float at different angles is analyzed mainly for the four factors, the exciting force, Response Amplitude Operators (RAOs), the added mass and the radiation damping.

3.1. The exciting force

The exciting force of the oscillating float in the water can be understood as the superposition of the diffraction force, the Froude-Krylov force and the radiation force generated by the motion of the object. Under the action of regular waves, the exciting force of the float is a superposition of the diffraction force and the Froude-Krylov force. As shown in Fig. 3, at the same frequency, when the cone angle is gradually increased from 90° to 120°, the exciting force of the float is getting larger and larger. During the change of the cone angle from 130° to 180°, the exciting force of the float hardly changes. For the same float, as the wave frequency increases, the exciting force of the float becomes smaller and smaller.
When the wave frequency is less than 0.5 Hz, the exciting force changes greatly, and the wave frequency is between 0.5 and 1.2 Hz, and the exciting force changes slowly.

3.2. RAOs
In order to explore the influence of different frequency waters on the conical bottom oscillating float, the maximum efficiency of wave energy generation is determined by analyzing Response Amplitude Operators. As shown in Fig. 4, when the wave frequency is between 0.01 and 0.5 Hz, the RAOs value of the cone bottom float is the largest at different angles, and the RAOs value rapidly decreases when the frequency is between 0.5 and 1.2 Hz. When the frequency is large, the cone bottom floats at different angles are compared. The 90° cone-bottomed oscillating float has the largest RAOs, followed by 110° and 120°.
3.3. The added mass

Figure 5. Added Mass versus frequency.
As shown in Fig. 5, the added mass of the cone-bottomed oscillating float at different angles is compared under the premise that the float mass is the same. At a lower frequency, the added mass changes greatly during the process of changing the angle from 90° to 130°. When the cone angle is changed from 130° to 180°, the added mass variation of the oscillating float is small. When the frequency is greater than 0.7 Hz, the added mass of the oscillating float at each angle hardly changes.

3.4. Radiation damping

Radiation damping is generated by the movement of the oscillating float in the water and is an important parameter for calculating the radiation force. As shown in Fig. 6, at the same frequency, the cone angle is in the range of 90° to 120°, and the radiation damping increases as the cone angle increases. When the cone angle is in the range of 130° to 180°, the radiation damping decreases as the cone angle increases. For the oscillating float of the same angle, as the frequency increases, the radiation damping shows a trend of rising first and then decreasing. When the frequency is less than 0.6 Hz, the radiation damping increases with the increase of the wave frequency. When the frequency is greater than 0.6 Hz, the radiation damping decreases as the wave frequency increases.

![Figure 6. Radiation damping versus frequency.](image)

4. Conclusion

Under the same frequency of waves, the hydrodynamic characteristics of the oscillating floats with different cone angles are quite different. When the frequency is greater than 0.9 Hz, the exciting force and the added mass of the float changes are small. When the frequency is less than 0.6 Hz, the radiation damping increases as the wave frequency increases; Response Amplitude Operators (RAOs) will change slightly. When the frequency is greater than 0.6 Hz, the radiation damping and Response Amplitude Operators decrease with increasing frequency, when the cone angle is in the range of 90° to 120°, the radiation damping of the oscillating float changes little. For an oscillating float with a cone angle greater than or equal to 130°, the radiation damping decreases faster; the RAOs of different cone angle oscillating floats decrease rapidly. The different cone angle oscillation floats reach a maximum value when the wave frequency is about 0.2 Hz, and when the frequency is greater than 0.9 Hz, the added mass change is small. The corresponding results obtained in this paper can provide reference for the design of the cone-bottomed oscillating float.
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