Study on the influence of float parameters on the efficiency of oscillating float wave power generation

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Abstract: The world's environmental pollution is more and more serious, and the human society for the energy demand is more and more large, so o the research of clean new energy is very necessary. In this paper, flow-3D software is used to simulate and study the motion state, velocity, kinetic energy, wave force and amplitude of cone and cylinder floats under different masses with the same wave height, so as to obtain the influence of mass on wave absorption efficiency and output power of these two kinds of floats. The results show that :(1) when the wave height is 0.25m, the wave energy absorption efficiency of the cylindrical and conical float increases first and then decreases with the increase of mass. The absorption efficiency of the 6kg cone float is the best, which is 27.77%. (2) With the increase of mass, the output work of the conical float firstly increases and then decreases, and reaches its maximum value at 6kg, which is 1.27w.

1 Introduction

Wave energy is one of the most abundant energy resources in the ocean and has been studied for more than 30 years [1]. China has more than 3 million km^2 of Marine land [2], so our country has huge Marine energy reserves. Wave energy, as a kind of energy with high energy density in ocean energy, has the characteristics of convenient development and utilization, and it can be obtained through a simple wave energy conversion device [3]. Therefore, the extensive use of wave energy can reduce the environmental pollution caused by the use of traditional energy in China. At present, there are more than 4,000 wave power generation devices in the world[4]. At present, the main wave power generation devices mainly include wave-crossing type [5], oscillating water column type and oscillating float type [6]. Because of the advantages of high efficiency, low cost and good reliability of the oscillating float wave energy acquisition device [7], it is widely used in the research of wave energy generation system. Fuwei Li designed three kinds of floats and used ADINA software to simulate three kinds of floats. He analyzed the conversion rates of the three floats. The conversion rate of the third float is higher than that of the other two, because the change trend of the vertical component of the wave force on the side of the third float is the same as that of the buoyancy, and the change trend of the buoyancy is the same as that of the vertical inertial force of the water particle[8]Hongzhao Zhang used star-CCM + software to calculate the oscillating float device of the cubic float. Under the action of damping force, the pro-wave width of the float is 6m and the conversion efficiency of wave energy is the highest. Under the action of spring force, 10m is needed. Under the action of damping force, when the vertical wave direction length is greater than 2m, it is inversely proportional to the efficiency with the length. Under the spring force, 6m has the highest efficiency. [9]

At present, there are a lot of researches on the influence of the single variable of float shape on the oscillating float type power generation system, and there are few reports on the relationship between the parameters of float shape and mass. In this paper, numerical simulation method is used to study the influence of the shape and mass parameters of the wave-generated oscillating float on the wave energy absorption efficiency and output power, and to find the optimal collocation of the float shape and mass.

2 The numerical simulation

2.1 Introduction to Mathematical Model

In this paper, the boundary wave-making method is used to track the position of free liquid level with VOF, the three-dimensional flume of Navier-Stokes equation is established, and the wave elimination method of double hole plate is used to achieve the wave parameters required by floating wave generation. The VOF

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method[11], namely the fluid volume function method, refers to the ratio F of the volume of the target fluid to the volume of the grid in each grid in the flow field. VOF is currently the commonly used method to track the free liquid level. In the process of numerical simulation, it is assumed that the liquid forming the wave is incompressible viscous fluid, and the movement of the fluid must follow the conservation equation of mass, momentum and energy [13].

(1) Conservation of mass equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho \mathbf{u}_i)}{\partial \mathbf{x}_i}=0 \tag{1}$$

ρ is the fluid density and $\mathbf{u}_i$ is the fluid velocity

(2) Momentum conservation equation

$$\rho\frac{\partial u_i}{\partial t}+\rho u_i\frac{\partial u_i}{\partial x_i}=f_i-\frac{\partial p_i}{\partial x_i}+\mu\frac{\partial^2 u_i}{\partial x_i \partial x_j} \tag{2}$$

$\mathbf{f}_i$ is the fluid mass, $\mathbf{p}_i$ is the fluid pressure, and μ is the hydrodynamic viscosity coefficient.

(3) Energy conservation equation

$$\frac{\partial(\rho T_0)}{\partial t}+\frac{\partial(\rho T_0 \mathbf{u_i})}{\partial \mathbf{x_i}}=\frac{\partial}{\partial \mathbf{x_i}}\left(\frac{k_0}{c_p}\frac{\partial T_0}{\partial \mathbf{x_i}}\right)+S_T \tag{3}$$

c_p is the specific heat capacity of the fluid, T_0 is the fluid temperature, k_0 is the heat transfer coefficient of the fluid, and S_T is the viscous dissipation term.

(4) The output power of the float

$$N_Z=\frac{1}{T}\int_0^T P_Z dt=\frac{F_0\omega Z_0}{2} \tag{4}$$

N_Z is the output power of the float,F_0 is the amplitude of the float subjected to wave force, and Z_0 is the amplitude of the float oscillating motion.

(5) Wave energy inputting in the width domain of floating body

$$E_i=\frac{1}{4}\rho g H^2 B \tag{5}$$

E_i is wave energy inputting in the width domain of floating body, B is the width of the float, H is the height of the incident wave.

(6) The wave absorption efficiency of a float

$$\eta=\frac{E_v}{E_i} \tag{6}$$

η is the wave absorption efficiency of a float,E_v is the kinetic energy of the float.

2.2 Similarity criterion

This project takes the offshore area of Tianjin as the research object. By inquiring the coastal conditions of Tianjin [12], the average wave height of the offshore area of Tianjin is 0.5 ~ 1.2m, the average wave cycle is 2 ~ 7s, the average wave wavelength is 0.5 ~ 3m, and the wave velocity is v=0.03 ~ 1.5m /s. The research direction of this experiment mainly focuses on the motion of fluid and float, and the dominant force is gravity. Froude criterion is adopted in this subject. The froude number of the model and the prototype is equal.

$$\frac{v_n}{\sqrt{g_n l_n}}=\frac{v_m}{\sqrt{g_m l_m}} \tag{7}$$

Taking the actual ocean depth of 10m as the experimental simulation object and considering the factor of wave height, the experimental wave flume size is designed to be 4m×1.5m×1.5m, then the simulated scale is 10. According to the above formula, the height of the incident wave in the physical model test is about 10cm ~ 30cm. The incident wave had a period of 2 ~ 7s and 0.67 ~ 2.33s respectively.

The model of cylindrical float is shown in fig.1. In this numerical simulation, a regular wave with a period of 1.5s and a wave height of 0.25m is selected. The height of the conical float is 200mm, the top and bottom surfaces are round surfaces with a diameter of 400mm and the bottom surfaces are round surfaces with a diameter of 200mm. A cylindrical float with a height of 400mm and a round surface with a top and bottom of 400mm.

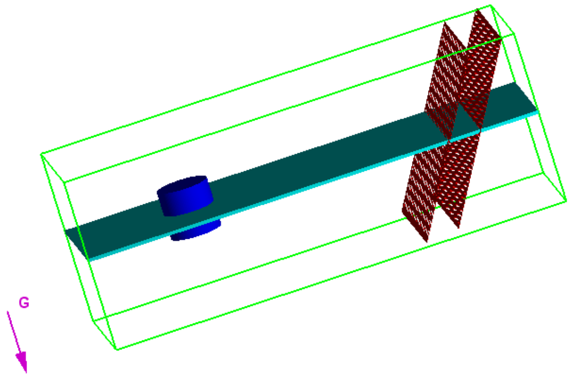

Fig. 1 Cylinder float flume model

2.3 The introduction of simulation initial conditions, boundary conditions and numerical simulation conditions

At the initial moment of this simulation, the static water surface was set as 0.8m, and the hydrostatic pressure in the region of 0 Pa was calculated.

Detailed boundary condition Settings of the numerical flume model are shown in table 1.The numerical simulation conditions are shown in table 2.

Table 1. Boundary condition Settings

Wave boundary	Stokes wave
Outlet boundary	Outflow
Lower boundary	Wall
Upper boundary	Specified pressure
Left boundary	Symmetry
Right boundary	Symmetry

Table 2. Numerical simulation conditions

Operating condition	Float type	The quality of float（Kg）	The wave height（m）
A_1	conical float	2	0.25
A_2	conical float	4	0.25
A_3	conical float	6	0.25
A_4	conical float	8	0.25
A_5	conical float	10	0.25
B_1	cylindrical float	2	0.25
B_2	cylindrical float	4	0.25
B_3	cylindrical float	6	0.25
B_4	cylindrical float	8	0.25
B_5	cylindrical float	10	0.25

2.4 Comparison of the influence of mass on the motion performance of float

The wave direction is from left to right with a period of 1.5s. After the time of starting the wave reaches 4.3s, the wave tends to be stable. A wave period is analyzed and studied, that is, the time period ranges from 4.3s to 5.8s.

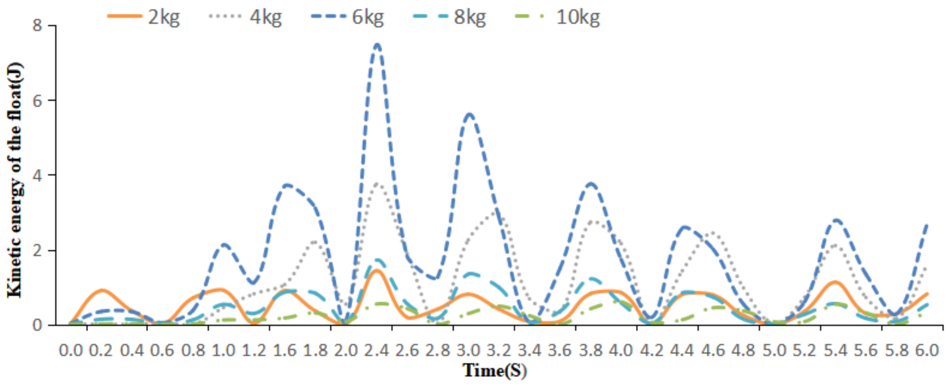

Fig.2 Kinetic energy curves of conical float of different masses

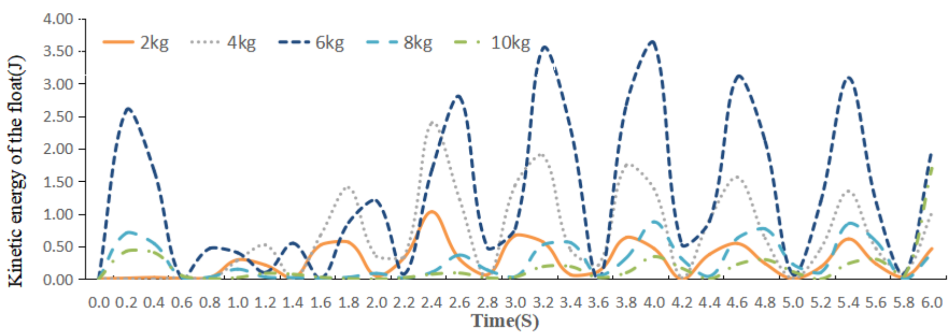

Fig.3 Kinetic energy curves of cylindrical float of different masses

Fig.2 and Fig.3 show kinetic energy curves of conical floats and cylindrical floats at different masses. It can be seen from the figure that the kinetic energy of the 6kg conical float and the 6kg cylindrical float increases the fastest and the kinetic energy is the largest. The maximum kinetic energy of conical float is 7.46j, and that of cylindrical float is 3.61j. When the kinetic energy of the float reaches its maximum value, it gradually decreases and tends to be stable. The stable kinetic energy of the 6kg conical float is similar to that of the 4kg conical float, both of which are 2.78j. The stable values of 2kg, 8kg and 10kg conical floats are 1.22j, 0.84j and 0.60j. The stable kinetic energy value of the cylindrical float at 6kg is 3.09j, which is larger than that of other weights. The stable kinetic energy of the cylinder float at 2kg, 4kg, 8kg and 10kg are 0.67j, 1.56j, 0.85j and 0.34j. Thus, it can be concluded that, under the same wave height, the kinetic energy of a 4-6kg conical floats are greater than that of a float of other weights, and the kinetic energy of a 6kg cylinder float is greater than that of other weights.

2.5 Comparison of the effects of mass on float wave absorption efficiency

The difference of the kinetic energy of the float shows the difference of the wave energy absorbed by the float under different mass of the float.According to formula (6), wave energy efficiency of conical float and cylindrical float with different masses can be obtained, as shown in fig.4.

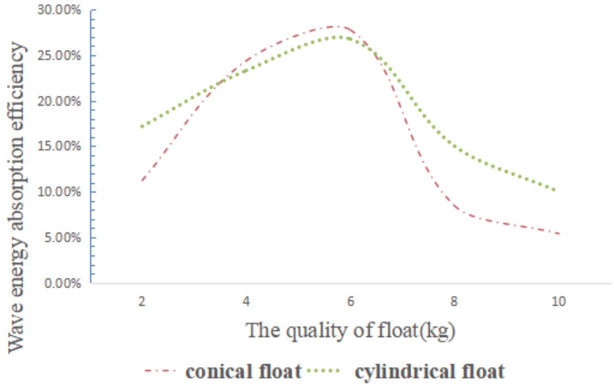

Fig.4 Influence of mass on the wave energy absorption efficiency of float

As shown in fig.4, the energy absorption efficiency of the float increase significantly from 2kg to 6kg, while that of the conical float from 6kg to 10kg show a linear decrease.It was caused by the float kinetic energy being the coupling between the float mass and the float fluctuation velocity. For a conical float of 2kg to 6kg, the float's mass increases and the inertia increases. The velocity of the float increases and the float reaches its maximum velocity at the equilibrium position of the wave. At the same maximum wave capture width, the conical float and the cylindrical float with a mass of 6kg had the best wave energy absorption efficiency, the conical float and the cylindrical float had the maximum absorption efficiency of 27.77% and 26.77% respectively. After the float is over 6kg, the wave energy absorption efficiency decreases rapidly, because with the same wave height, the motion velocity of the float decreases and the wave energy of the float decreases with the increase of the float's mass. When the float with a mass of 10kg had the worst wave energy absorption efficiency, the conical float's minimum absorption efficiency was 5.39%, and the cylindrical float's minimum absorption efficiency was 10%. It can be concluded that the absorption efficiency of these two kinds of floats is the highest at 6kg, among which the wave energy absorption efficiency of conical float is higher than that of cylindrical float.

2.6 Comparison of the influence of mass on the output power of cone float with open filling

The vertical wave forces of conical floats and cylindrical floats were directly simulated by flow-3D software, as shown in fig.5 and fig.6 below.

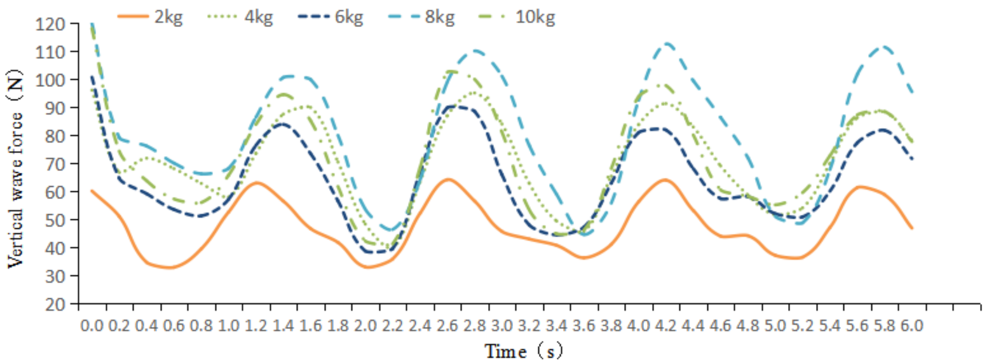

Fig.5 Curve of wave forces on conical floats of different masses

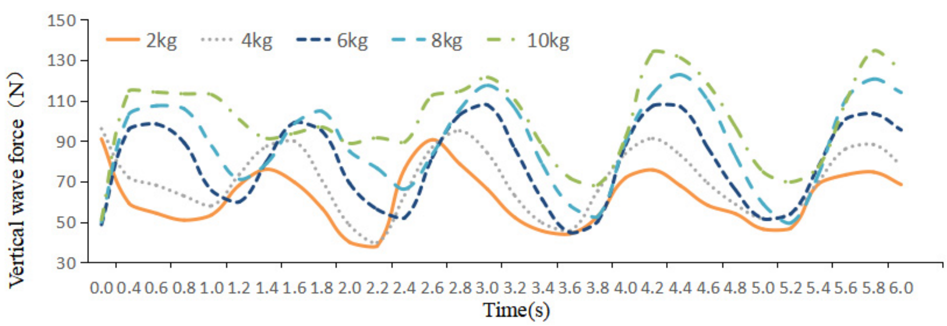

Fig.6 Wave forces on cylindrical floats of different masses

The wave force on the float changes periodically with the wave action. The float is at the crest of the wave and captures the least vertical wave force. The float is at the trough, the float is more below the surface of the water, and the wave force on the float is the greatest. As shown in fig. 5, when the mass of the conical float increases from 2kg to 8kg, the wave force on the float increases, but the wave force on the cone float decreases from 8kg to 10kg. When the mass of the conical float was 8kg, the amplitude of wave force received reached the maximum value of 110.02N. As shown in fig.6, when the mass of the cylindrical float increases from 2kg to 10kg, the wave force on the float increases. When the mass is 10kg, the amplitude of wave force on the float reaches the maximum value of 121.51N. When the mass of the conical float is greater than 8kg, the wave force on the float starts to decrease.With the increase of mass, the depth of the conical float into the water surface increases. As the advances of wave, part of the water passes over the float, and finally the vertical wave force amplitude decreases.

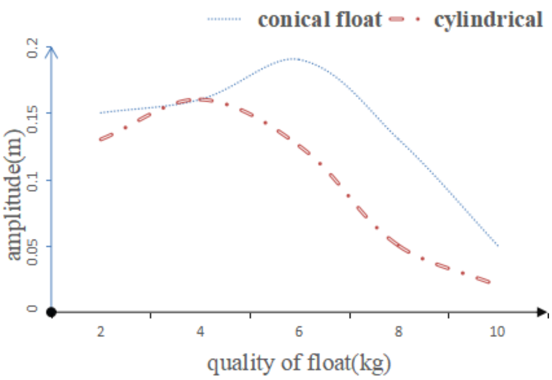

Fig.7 Comparison of the effect of mass on float amplitude

As shown in Fig.7, the amplitude of the float varies with the change of the float mass. When the mass of the conical float increases from 2kg to 6kg, the inertia of the conical float increases, the wave force exerted on the float increases, and the amplitude of the float increases slowly. When the mass increases from 6kg to 10kg, as the mass increases, the wave force required by the float motion increases, and the depth of the float into the water increases. As the wave advances, part of the water passes over the float, and the pressure of the water above the float causes the amplitude to drop rapidly. When the mass of the cylindrical float increases from 2kg to 4kg, the inertia of the float increases and the wave force and amplitude of the float increase. When the mass goes from 4kg to 10kg, the wave force required by the float motion increases, and the wave height of 0.25m is not high enough to make the float move better, so the amplitude decreases. It can be concluded that the amplitude of conical float is 0.19m when the mass is 6kg. The maximum amplitude of the cylindrical float is 0.16m when the mass is 4kg.

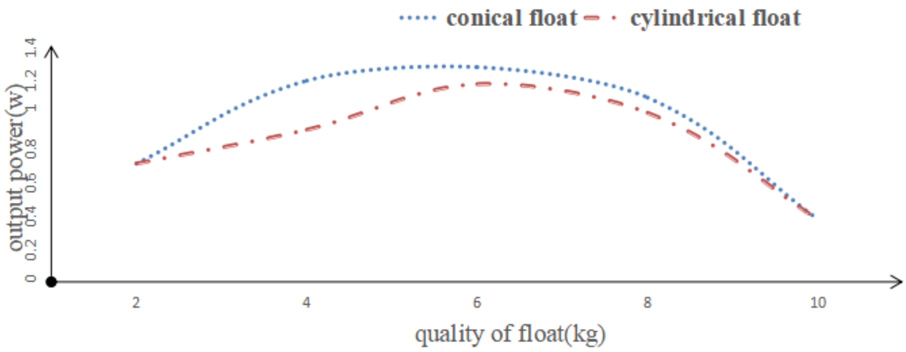

Fig.8 Comparison of the influence of mass on the output power of float

As shown in fig.8, when the wave height is 0.25m, the mass of the conical float and the cylindrical float increases from 2kg to 6kg, and the output power of the cylindrical float rises slowly. The output power is the coupling of wave force amplitude, float amplitude and wave period. As the mass increases, the wave force on the float increases and the amplitude increases, so the output power increases. However, the amplitude of the cylindrical float does not increase much when the mass is from 2kg to 6kg, so the output power increases slowly. When the mass is from 6kg to 8kg, the float output drops, but the conical float declines faster than the cylindrical float. Since the mass ranges from 6kg to 8kg, the wave force amplitude and amplitude of the cone float decrease, so the output power decreases rapidly. The wave force amplitude of cylinder float increases, but the amplitude is small, which finally shows the output power decreases, and the decreasing trend is slow.

3 Conclusion

(1) By numerical simulation, the wave energy absorption efficiency of conical and cylindrical floats with masses of 2kg, 4kg, 6kg, 8kg and 10kg were calculated at a wave height of 0.25m. The effects of float mass and shape on the wave energy absorption efficiency of an oscillating float wave power system are obtained. The wave energy absorption efficiency of both conical and cylindrical floats increases first and then decreases with the increase of mass. Both kinds of floats reach their maximum value at 6kg. The maximum value of conical float is 27.77%, and that of cylindrical float is 26.77%. Therefore, the wave energy absorption of conical float is better than that of cylindrical float.

(2) Through numerical simulation, the output power of conical and cylindrical floats with masses of 2kg, 4kg, 6kg, 8kg and 10kg were calculated under the condition of wave height of 0.25m. The influence of float mass and shape on the output power of the oscillating float wave power generation system is obtained. The output power of both conical and cylindrical floats increases first and then decreases with the increase of mass. When both floats are at 6kg, the output power reaches the maximum. The maximum value of the conical float is 1.27W, and the maximum value of the column float is 1.17W. Therefore, the output power of the conical float is better than that of the column float.

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