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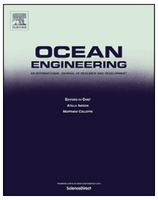

Hydrodynamics research of a two-body articulated wave energy device

Zhang Chao[a,b,c,d], You Yage[a,b,c,d,*], Chen Aiju[a,c]

[a] Guangzhou Institute of Energy Conversion, Chinese Academy of Science, Guangzhou 510640, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] CAS Key Laboratory of Renewable Energy, Guangzhou 510640, China
[d] Guangdong Provincial Key Laboratory of New and Renewable Energy Research and Development, Guangzhou 510640, China

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ABSTRACT

The paper proposed a calculation method for a two-body articulated wave energy device with a complex geometric shape. The hydrodynamic performance of the Eagle wave energy device as an example was studied. The hydrodynamic calculation was carried out by the boundary element method based on the simple Green's function to solve the wave excitation force and hydrodynamic coefficients. Based on the above, the motion equation was obtained. Using the motion equation, the hydrodynamic response and capture width ratio of the device at different wave frequencies were calculated. In summary, this computational result can be used to evaluate and optimize the performance of the articulated wave energy device.

1. Introduction

As a renewable green energy resource, wave energy is inexhaustible and has a high density. In view of the importance of wave energy development and utilization, wave energy is bound to be an important part of the future energy supply (You et al., 2003; Clement et al., 2002).

In order to realize the use of wave energy, scholars have done a great deal of work on the hydrodynamic research. For devices with simple geometry, analytic solutions have been developed. Matsui et al. (1991) and Emmerhoff and Sclavounos (2006) derived analytic solutions for uniform cylinders in finite and infinite water depth. Bao and Kinoshita (1993) expended the theory to truncated cylinders. Zheng et al. (2005) researched the interaction of a submerged rectangular buoy with incident linear waves in a finite water depth. However, in engineering practice, the shape of the device is complex and numerical methods have to be applied. The numerical method has been developed by Newman (1992) and Brebbia (1978), and Nossen et al. (2006), among others.

Boundary element method is more effective than other methods such as finite element method and finite difference method when the fluid domain is infinite. The hydrodynamic calculation in this paper was carried out by using the boundary element method based on the simple Green's function to fit the complex shape of the device. Using 1/r as the simple Green function, a large part of the calculation of the integral equation coefficients is independent of frequency, which improves the computational efficiency, especially in the case that many frequencies need to be calculated.

The difficulties of hydrodynamic research of the articulated wave energy device are that under the action of waves, two hinged floating bodies interact with each other, the hinged constraint cannot be destroyed in the process of calculation, and movement should meet the constraint conditions at any time. For solving such problems, in the device's surface condition, the device movement and the radiation velocity potential are decomposed according to the constraint condition. In the meantime, in order to make the computing domain become limited and reduce the amount of calculation, the infinity surface boundary is replaced by the characteristic function expansion of the velocity potential as radiating surface condition.

This calculation method has the characteristics of a small computation and wide application range and it can be applied to many articulated wave energy devices, such as the Pelamis wave device (Henderson, 2006), Oyster wave device (Whittaker et al., 2007), Duck wave device (Salter, 1974) and Eagle wave device (Sheng and Zhang, 2015).

The hydrodynamic performance of the Eagle wave energy device as an example was studied in this paper. The Eagle device is a type of two-body articulated wave energy device with a complex shape that was developed by the Guangzhou Institute of Energy Conversion, and it performs with high power generation efficiency in real ocean environments. The device has a total height of 8.8 m and a draft depth of 7.4 m.

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* Corresponding author.
E-mail address: zhangchao@ms.giec.ac.cn (Y. Yage).

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The underwater base of the device is 22 m long, 8 m wide and 1.8 m high. The eagle head is12.6 m long, 6 m wide and 7 m high. The calculation in the paper gives the force, displacement and capture width ratio of the device. Furthermore, the parameters given in the calculation process can be used as a basis for evaluating and optimizing the device.

2. Theoretical analysis

2.1. Mathematical model

Fig. 1 shows the simplified model of the two-body articulated wave energy device. The main structure of the device includes two parts: the eagle beak, which is used to capture the wave energy, and the underwater base, which keeps the device stable. The symbols in Fig. 1 are defined as follows: S_F is the hydrostatic surface; S_D is the seafloor surface; S_I is the outer surface of the external computing domain; S_L is the interface between the internal computing domain and the external computing domain; S_w is the surface of the device; h is the water depth; B is the intersection point between the far left of the eagle beak and the water surface in the oxz section; and L is the horizontal projection distance between the hinge point and the B-point in the x-axis direction.

In the oxz section, draw a straight line through the centroid of the eagle beak and the hinge point, and then draw another straight line through the centroid of the eagle beak perpendicular to the first line. The intersection of the second line to the eagle beak and the base is the position of the hydraulic cylinder connecting to the base and eagle beak, respectively.

The work process of the device in a wave period can be described as follows: the device floats in the sea at the quiescent state. When the waves change from troughs to crests, the waves drive the eagle beak to rotate upwards, and the hydraulic cylinder synchronously moves upward. Then, the hydraulic fluid of the hydraulic cylinder is squeezed into the accumulator to generate electricity or do other forms of work. When the waves change from crests to troughs, the eagle beak rotates down under gravity, the piston rod of the hydraulic cylinder is reset and hydraulic oil is added to the rod cavity to prepare for the next wave period.

Four types of motion of the device under the action of the forward waves are shown in Fig. 1: the heave motion, the surge motion, the pitching motion of the eagle beak and the pitching motion of the underwater base.

To establish the right-hand coordinate system, the origin of the coordinate system is defined on a still water surface, and the positive of the x-axis is horizontal right and the positive of the z-axis is vertical upward. Assuming that the wave is an ideal fluid, which is incompressible and flows without spin, the fluid state can be described by the velocity potential function $\Phi(x,y,z,t)$. The velocity potential function $\Phi(x,y,z,t)$ can be decomposed as follows:

$$\Phi = \mathrm{Re}\left[\phi(x,y,z)\exp^{-i\omega t}\right] \tag{1}$$

Here, Re represents the real part; $\phi(x,y,z)$ is the potential function of the fluid space velocity with independent of time t; exp is the natural exponent; i is the imaginary unit, $i=\sqrt{-1}$; ω is the incident wave angular frequency; and $\omega=\frac{2\pi}{T}$, T is the wave period.

The device movement under the actions of the wave is periodic, and its frequency is the same as the incident wave frequency, while its displacement x_j can be set to

$$x_j(x,y,z,t) = \mathrm{Re}\left[\xi_j(x,y,z)\exp^{-i\omega t}\right] \tag{2}$$

Here, ξ_j is the device displacement in the frequency domain, and the subscript j represents the four motion modes of the device meeting the constraint condition, $j=1,2,3,4$.

The space velocity potential $\phi(x,y,z)$ is the linear velocity potential, so ϕ can be decomposed (Yu and Falnes, 1995) into

$$\phi(x,y,z) = \phi_I + \phi_D - i\omega\sum_{j=1}^{4}\xi_j\phi_j \tag{3}$$

Here, ϕ_I, ϕ_D and ϕ_j are, respectively, the incident wave velocity potential, the wave diffraction velocity potential, and the radiation velocity potential that occurs when the device oscillates at unit speed.

The incident wave velocity potential $\phi_I(x,y,z)$ under a limited water depth is as follows:

$$\phi_I(x,y,z) = \frac{-igA}{\omega}\frac{\cosh[k(z+h)]}{\cosh(kh)}e^{ikx} \tag{4}$$

Here, g is the acceleration of gravity; A is the incident wave amplitude; h is the water depth; k is the wave number, and the wave number k meets the dispersion relationship $\omega^2 = gk\tanh(kh)$ under the limited water depth.

The diffraction velocity potential $\phi_D(x,y,z)$ and the radiation velocity potential $\phi_j(x,y,z)$ are expressed by $\phi_l(x,y,z)$, which satisfies the following definite conditions:

In the calculation domain,

$$\nabla^2\phi_l = 0 \tag{5}$$

Free surface boundary condition

$$\left.\frac{\partial\phi_l}{\partial z}\right|_{z=0} - \frac{\omega^2}{g}\phi_l = 0 \tag{6}$$

Seabed surface boundary conditions

$$\left.\frac{\partial\phi_l}{\partial n}\right|_{z=-h} = 0 \tag{7}$$

Infinity surface boundary conditions

$$\lim_{r\to\infty}\sqrt{r}\left(\frac{\partial\phi_l}{\partial r} - ik\phi_l\right) = 0 \tag{8}$$

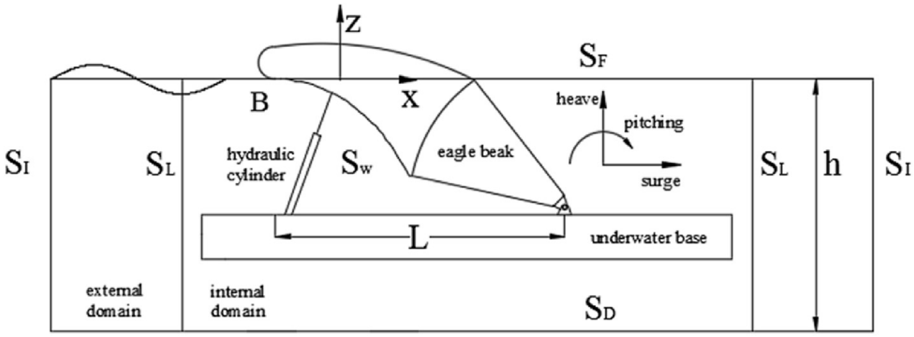

Fig. 1. Schematic diagram of the device.