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Experimental Study on Operation Performance of Two-Body Wave Energy Generator

S WU[1] and Y J LIU
Institute of Marine Science and Technology, Shandong University, Qingdao 266237, Shandong, China

Abstract. The two-body oscillating type wave energy converter (WEC) is a hot research topic at present. A two-body device with damping disc was taken as the test model in this paper. The two bodies were connected by a hydraulic piston cylinder to realize the relative motion energy conversion. Physical experiments were carried out in a wave-making flume to study the operation performance. The effects of wave elements and load on the hydrodynamic characteristics and capture width ratio (CWR) of the model were analysed respectively. The results showed that wave frequency and external load were the main factors affecting the motion response and energy conversion of the device. With the increase of wave frequency and external load, the response amplitude operator (RAO) and the capture width ratio both increase first and then decrease. Wave height has little effect on system characteristics. There exists a best-matching wave period condition, and the optimal motion response and energy conversion are obtained.

Keywords. Wave energy converter, energy conversion, response amplitude operator

1. Introduction

Ocean wave energy comes from solar energy and exists in the form of kinetic energy and potential energy on the ocean surface. As a renewable energy source, it has the characteristics of clean, pollution-free and inexhaustible. The use of wave energy has been studied for a long time. The first documented device was a patent designed by the French Girard and his son in 1799 [1]. It is not until recent decades that wave power generation devices have entered a stage of rapid development. According to the working principle and structure form, the wave energy conversion device is mainly divided into three categories: oscillating type, oscillating water column and overtopping [2-5]. Compared with the other two types, the oscillation device has the advantages of small size, low construction and maintenance cost, easy construction, easy mooring, and convenient application in offshore devices, so it is the mainstream form of wave energy conversion device. Oscillating type is divided into single-body, two-body and multi-body and other different forms. The two-body wave energy conversion device studied in this paper is composed of a buoy, a float and a hydraulic

[1] Corresponding Author, S WU, Institute of Marine Science and Technology, Shandong University, Qingdao 266237, Shandong, China; Email: wushuangsdu@163.com.

power take-off (PTO) system. The device uses the relative heave motion between the buoy and the float to drive the PTO system to realize energy conversion.

The experimental research on the operation characteristics of WEC is mainly conducted on the single floating body [6-10]. For two-body converters in most cases, large-amplitude relative motion will bring significant nonlinearity, which enlarges the difficulty of understanding and analyzing the system. Therefore, it is very necessary to carry out systematic flume test research on the two-body WEC device. Yang [11] studied the operation characteristics of the wave energy converter with vertical arrangement of two floats (simplified as two cylinders), and preliminarily discussed the influence of wave elements and external load on the dynamic response of the float. Scott J. Beatty et al. [12] studied the influence of different shapes of underwater bodies on the hydrodynamic performance of two-body WECs in the case of regular and irregular waves, and verified the effectiveness of boundary element method (BEM) by testing the additional mass and excitation force, the test did not analyze the effect of the PTO load. Kim et al. [13] experimental study on a hemispheric point-absorber-type wave energy converter with a hydraulic power take-off system, the experimental model is that the buoy and the fixed platform are connected by triangular arms, and the double-acting hydraulic cylinder is installed at one third of the arm length.

To sum up, further experimental studies are needed to analyze the operation performance of the two-body wave energy conversion device. The main factors affecting the hydrodynamic characteristics and energy conversion rate were explored considering the wave element and load pressure.

2. Experimental Design

The experiment was carried out in the underwater equipment laboratory of the Qingdao Haijian Group. The flume is 30 m long and 4 m wide, and the experimental water depth is 2 m. The overall layout of the experiment is shown in figure 1. The model device is composed of a buoy and a float, which are respectively connected with the tube and piston rod of the hydraulic cylinder. The wave energy is extracted and converted into hydraulic energy by the relative movement of the two body. The model parameters of the buoy and the float are listed in Table 1. This test conducted under the regular wave conditions (wave height H, wave period T, wave length λ, wave number k. A voltage regulator was used to apply different load conditions; A constant pressure flowmeter with a window was used to record the change of load pressure P and flow Q at the outlet. A displacement sensor and wave height meter were used to record the relative motion and wave surface changes of the two bodies. Figure 2 shows the test scenario. Further details can be found in [14].

Table 1. Model parameters of the buoy and the float.

	Buoy	Float
Diameter	0.80 m	0.17 m (damping disc 0.8 m)
Height	0.25 m	1.30 m (damping disc 0.1 m)
Draft	0.12 m	0.90 m
Mass	28.57 kg	51.79 kg

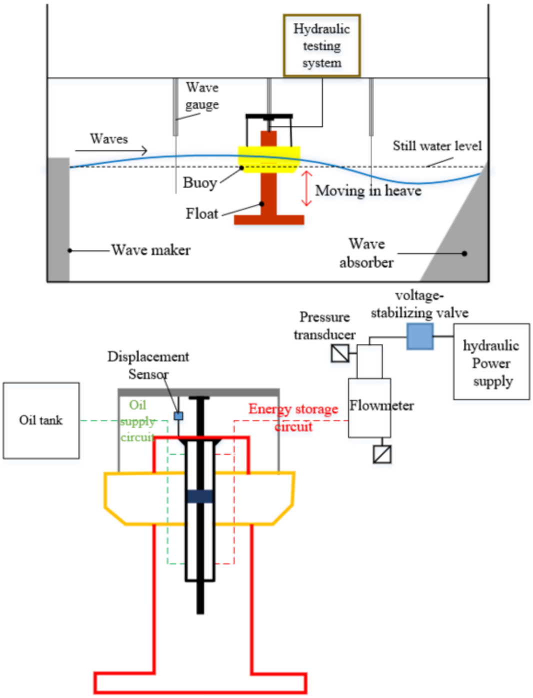

Figure 1. Sketch of the experimental setup in the wave flume.

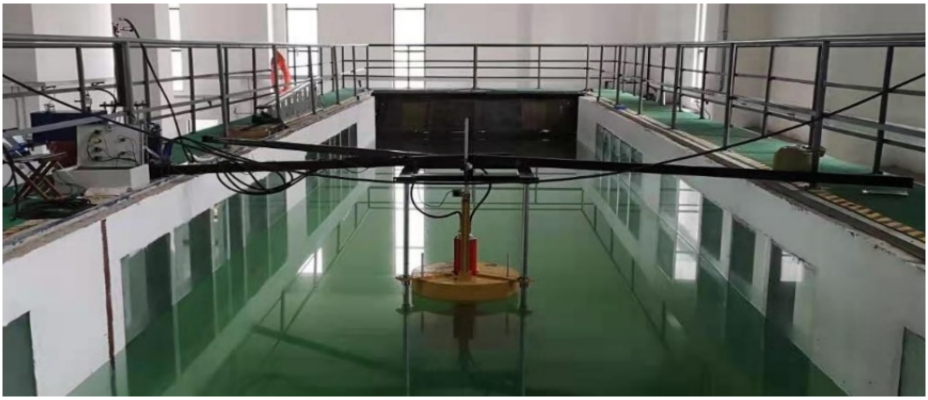

Figure 2. Device in the flume.

3. Parameter Calculation

3.1. Parametric Representation

The Response Amplitude Operator (RAO), which can be defined as a ratio between the heave motion amplitude and the incident wave amplitude. The energy provided by the incident wave in a unit wave period E_0:

$$E_0 = \frac{1}{8}\rho g H^2 \lambda D \cdot \frac{1}{2}\left(1 + \frac{2kH_w}{\sinh\left(2kH_w\right)}\right) \tag{1}$$

The hydraulic energy converted by the wave energy converter in a unit wave period E_h,

$$E_h = PQT \tag{2}$$

The capture width ratio (that is, the efficiency of wave energy into hydraulic energy):

$$\eta = E_h / E_0 \times 100\% \tag{3}$$

3.2. Nondimensionalization

According to the principle of dimensionless harmony, the physical quantities such as wave height, wave frequency and load pressure involved in the test are all dimensionless quantities. In flume experiments, the water depth is kept constant, and the effects of H/B, ω / ω_n, and p on Z/H and η are quantitatively analyzed. where $p = P / P_{\max}$, $P_{\max}$ is the maximum external load that can be applied by the experimental system, here is 10MPa. The wave frequency variable is expressed as ω / ω_n, ω is the wave frequency and ω_n is the natural frequency of the experimental model, which is measured by the hydrostatic attenuation test.

4. Experiment Results and Analysis

4.1. Influence of Wave Elements on Operating Performance

4.1.1. Impact on Hydrodynamic Characteristics

The influence of wave elements on the hydrodynamic characteristics is analyzed without considering the external load, i.e., p=0. As can be seen from figure 3, RAO values have little change under different wave height parameters. This is because within the range of experimental conditions, the hydrodynamic characteristics meet the linear boundary conditions, so it is independent of the wave height. The RAO value increases first and then decreases with the change of wave frequency, and reaches the maximum value at about 0.6. At this point, the wave frequency is close to the natural heave frequency of the device and the relative heave displacement reaches the maximum.

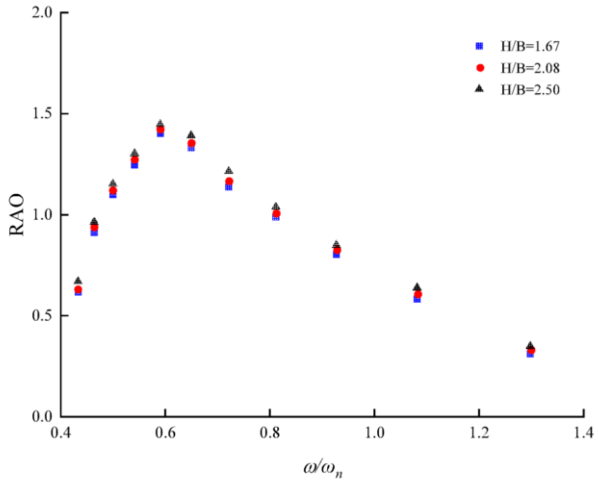

Figure 3. Variations of RAO with ω / ω_n in regular waves.

4.1.2. Impact on Capture Width Ratio

Figure 4 shows the variation of the with wave frequency of the device converting wave energy into hydraulic energy under different wave elements. As can be seen from the figure, with the increase of frequency, the conversion efficiency also presents a change rule of first increase and then decrease, and reaches a maximum value at 0.6. Under the same load condition, the change of wave height has little effect on the efficiency.

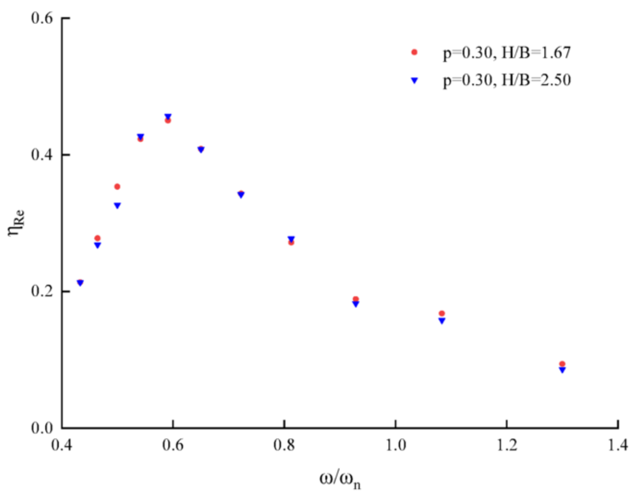

Figure 4. Variations of η with ω / ω_n in regular waves.

4.2. Load Influence on Operation Performance

4.2.1. Impact on Hydrodynamic Characteristics

Figure 5 shows the test results of relative motion response under different load conditions. As can be seen from the figure, under the same wave element condition, with the increase of load pressure, the resistance to be overcome increases, and the relative motion response decreases.

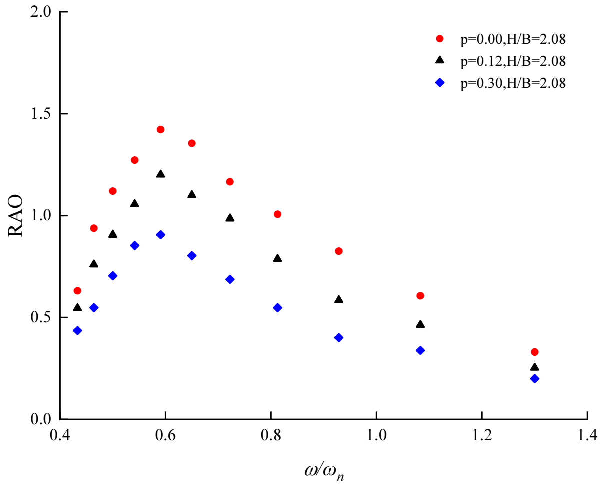

Figure 5. Variations of RAO with ω / ω_n in regular waves.

4.2.2. Impact on Capture Width Ratio

Figure 6 shows the experimental results of conversion efficiency under different load pressures. The results show that with the increase of load pressure, the efficiency increases first and then decreases, and the maximum value is reached when p=0.2.Under the same wave conditions, the wave forces acting on the model are the same, and when the load pressure is 0 or the resistance generated by the load pressure is greater than the wave force, the hydraulic energy cannot be output, that is, CWR is 0.Therefore, for a wave energy device of a fixed size, there is an optimal load value corresponding to which the wave energy conversion efficiency reaches the maximum.

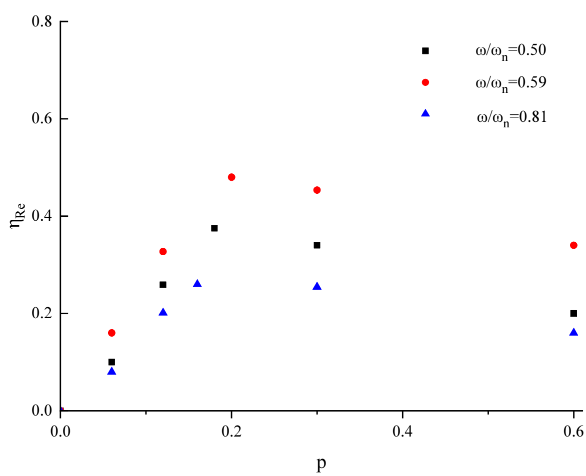

Figure 6. Variations of η with p in regular waves.

5. Conclusion

In this paper, the operating performance of a two-body oscillating type wave energy conversion device are experimentally studied. The results show that for a given size device, there exists a best-matching wave period condition, and the optimal motion response and energy conversion are obtained. Wave height has little effect on system characteristics, RAO and CWR are mainly affected by wave frequency and external load. With the increase of wave frequency and external load, RAO and CWR both first increased and then decreased.

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