Study on hydrodynamic performance of the sealed-buoy wave energy converter

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Abstract. For investigating the wave energy converter working in low-energy flow density sea area, a novel sealed-buoy wave energy converter (SBWEC) was analysed by using the fluid simulation software ANSYS and AQWA according to Shandong Peninsula marine environment in this paper. For the SBWEC in the range of 5-20 m buoy diameter, the effect of mass on the response amplitude operator (RAO) and the motion response were analysed based on the frequency domain method and the time domain method. The wavelength range with higher wave energy was also investigated. Within the mass range of 8-12 t, the study found that the mass did not has a significant impact on the roll, yaw and pitch RAO and the pitch motion response except for the SBWEC with 5 m buoy diameter. The wavelength range with higher wave energy in Shandong Peninsula is 10-40 m, which is more suitable for operation of the SBWEC. These results can provide a reference for the design of related wave energy converters.

1. Introduction
Facing the fact that the depletion of fossil energy sources and environmental pollution are increasingly serious, the conversion of ocean wave energy into usable electrical energy is a great practical significance for alleviating the energy crisis of human society. Many experts have been continuously researching related types of the wave energy converters, hoping to improve the conversion efficiency and capture power. Among them, for a novel wave energy converter suitable for low-energy flow density sea area, the effect of mass and wavelength on the hydrodynamic performance and the choice of materials need to be studied and considered. Based on the marine environment of Shandong Peninsula, the effect of mass on the roll, yaw and pitch RAO and the pitch motion response of the sealed-buoy wave energy converter (SBWEC) were studied in this paper. Secondly, the wavelength ranges with higher wave energy was also studied. Through this research, on the one hand, relevant information on the structural design of the wave energy converter in low-energy flow density sea area can be consummated. On the other hand, it can promote the implementation of Replacing Old Growth Drivers with New Ones in Shandong Province under the new situation.

2. Sealed-buoy wave energy converter (SBWEC)
Figure 1 showed the mechanical structure diagram of the SBWEC. The magnetic levitation technique is firstly utilized between the magnetic mass slider and the circular magnetic guide, to reduce the frictional resistance when the magnetic mass slider moves around the circular magnetic guide. With the SBWEC operating, the buoy was produced a flip of angle θ under the act of wave motion. The balance was broke by the magnetic mass slider which gained the gravitational potential energy and then to rotate an angle of φ around the circular magnetic guide. The magnetic mass slider transmitted
the kinetic energy and mechanical energy to the gearbox. Then, the gearbox converted and passed them to the generator. The entire process completed the conversion of wave energy into electrical energy.

![Mechanical structure diagram of the SBWEC.](image)

3. Parameters setting

3.1. Marine and anchor chain parameters

To ensure the accuracy of the results, the calculation and selection of anchor chain parameters were strictly based on the hydrological parameters of Shandong Peninsula. The three-stage unstudded anchor chain is utilized according to the calculation. The marine and anchor chain parameters were shown in Table 1.

| Parameters                           | Value |
|--------------------------------------|-------|
| average wind speed \( V_{wi} \)/m·s\(^{-1} \) | 6.0   |
| period \( T \)/s                     | 5     |
| average height \( H \)/m             | 1.83  |
| average depth \( d_w \)/m            | 44    |
| wet water mass \( m_s \)/kg·m\(^{-1} \) | 13.00 |
| equivalent section area \( S_m \)/m\(^2 \) | 0.12×10\(^{-3} \) |
| equivalent diameter \( D_{md} \)/m    | 0.035 |
| the average surface residual flow velocity \( V_0 \)/m·s\(^{-1} \) | 0.1   |

3.2. Meshing and boundary conditions setting

According to the simulation requirements of the hydrodynamic calculation software AQWA, it is necessary to ensure that at least 7 diffraction units are covered in each wavelength range when meshing the SBWEC model. And the wave was assumed as an ideal fluid. The boundary conditions of the SBWEC were shown in Figure 2 and the motion equation of the SBWEC in the regular wave can be expressed as,

\[
-\omega^2MZ(\omega) = F_{FK}(\omega) + F_d(\omega) - (\omega^2M_a(\omega) + w\omega C(\omega))Z(\omega) - \rho gA Z(\omega) \tag{1}
\]

Where \( M, Z(\omega), F_{FK}(\omega), F_d(\omega), M_a(\omega), w, C(\omega), g, A \) are mass of the SBWEC, the vertical direction function, the Froude-Krylov force, the diffraction force, the additional mass, the imaginary unit, the radiation damping, the acceleration of gravity and the cross-sectional area of the wet surface, respectively. The expression of the response amplitude operator RAO is,

\[
RAO(\omega) = \frac{F_{FK}(\omega) + F_d(\omega)}{K - \omega^2(M + M_a(\omega)) + w\omega C(\omega)} \tag{2}
\]
4. Discussion

4.1. Effect of mass on SBWEC RAO
Keeping the buoy diameter constant, the effect of mass on SBWEC RAO was studied by adding the bob-weight. Since the roll and yaw RAO have a difference of $10^3$ orders magnitude with the pitch RAO, the sway, surge and heave of the SBWEC are only translational motion or up and down motion, no rotation of the magnetic mass slider is caused. Therefore, the effect of mass on the pitch RAO was analyzed as shown in Figure 3.

![Figure 3. The frequency domain response diagram of the SBWEC.](image)

In Figure 3, the pitch RAO changed in a parabolic manner with the increase of the wave frequency. In Figure 3 (a), (b), (c) and (d), the maximum relative variations are 27.68 %, 3.33 %, 0.5 % and 0.2 %, respectively. The maximum relative variations are decrease gradually. The relative variation of the SBWEC with 5 m buoy diameter is the biggest and exceeded 5 %. The main reason for this phenomenon is that the mass caused the center of gravity to be unstable. Further, the magnetic mass slider generated greater inertia, leading to the large response amplitude. But from the analysis of the
relative amount of the variations, in addition to the SBWEC with 5 m buoy diameter, the mass has no significant effect on the pitch RAO of the SBWEC with other buoy diameters.

4.2. Effect of mass on pitch motion response of the SBWEC RAO
The fluid simulation calculation software AQWA was used to obtain the pitch motion response of the SBWEC in different mass. The stable phases of the pitch motion response of the SBWEC were selected as the time domain analysis segment, as shown in Figure 4.

Figure 4. The pitch motion response diagram of the SBWEC.

In Figure 4, the pitch motion responses of the SBWEC under different masses are showed a certain period of sinusoidal variation. These are mainly due to the fact that the wave makes an approximately sinusoidal motion. But the pitch motion responses have not some certain regularity with the changing of mass. In Figure 4 (a), (b), (c) and (d), the maximum relative variations of motion response are about 100 %, 38 %, 7 % and 25 %, respectively. According to the maximum relative variations, the mass has a minimal impact for the SBWEC with 15 m buoy diameter. This is mainly due to the fact that the large-diameter SBWEC has a better self-stability and it can filter out the interference of low frequency wave to itself. But from the analysis of the response curves, except for the SBWEC with 5 m buoy diameter, the mass has no significant effect on the pitch RAO.

4.3. Effect of the wavelength on pitch RAO
The wave is composed of various wavelengths. It has great significance and value to design wave energy converter within the wavelength range which contains large wave energy. Figure 5 showed the pitch RAO response of the SBWEC under different masses. Comparing the size and concentration of the pitch RAO values, the wavelength range with higher wave energy was determined, which provides a certain basis for the design of the SBWEC.
Figure 5. The pitch RAO response diagram with the wavelength variation.

In Figure 5 (a), (b), (c) and (d), the wavelength range corresponding to a large pitch RAO value of the SBWEC are approximately 10-20 m, 10-30 m, 15-30 m and 20-40 m, respectively. Comparing the corresponding wavelength range, it can be determined that the wavelength range with higher wave energy is about 10-40 m.

5. Conclusion

Based on the marine environment of Shandong Peninsula, the frequency domain analysis method and the time domain response method were utilized to analysis the effect of mass and wavelength on the hydrodynamic performance. Some conclusion were obtained as flows,

(1) The pitch RAOs of the SBWEC under different masses were all increase and then decreases with the increase of the wave frequency, which showing a parabola change. In addition to a large fluctuation of the RAO value of the SBWEC with 5 m buoy diameter, the pitch RAO of the SBWEC with other buoy diameters were less affected by the mass.

(2) In addition to the SBWEC with 5 m buoy diameter, the mass had less impact on the pitch motion response. For different buoy diameters of the SBWEC, the pitch motion response curve had a certain degree of change under different masses, but the regularity of change was not obvious.

(3) The wavelength range with higher wave energy in Shandong Peninsula was about 10-40 m. The SBWEC all had large pitch RAO values and motion responses in this wavelength range, which was more suitable for the operating and capturing of the wave energy.

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