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Numerical simulation of the pendulum system in a buoy-pendulum wave energy converter

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Abstract

Sea conditions have a significant impact on the efficiency of wave energy converters (WECs). Based on the buoy-pendulum WEC presented in the paper, the energy-collection principle of the pendulum system is described, and the motion response of the pendulums under three wave conditions is simulated. It is shown that the optimal wave direction for pendulum system’s operation is 45°; the pendulum is apt to reach balance when wave height is less than 0.6m. In addition, a method to estimate the average conversion efficiency of the pendulum system is proposed based on the fitting function software, and the efficiencies under five ideal wave conditions are calculated. The results show that the greater the wave period and the wave height, the lower the collection efficiency of the pendulum.

1. Introduction

In recent years, wave power generation technology has attracted many countries’ attention for its unique advantages. Britain is committed to on-shore fixed WEC and prototype wave power generator group. Japan has focused on buoy and pendulum wave power device. Norway has proposed many wave power generation technology theories, such as phase control, point absorber, multi-resonance and poly wave. Portugal has built a large ocean experimental zone in the Atlantic Ocean, and so on. For a long time, China has also devoted to pendulum, oscillating water column, buoy and small wave power

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generation converter \cite{1, 2}. With reference to the worldwide wave power generation technologies, the authors' team proposed a new buoy-pendulum wave power device, as shown in Fig.1. This device includes the main body frame and four collection systems, the former composed of external frame and pontoon, while the latter of pendulums and buoys. From Fig.2 we can see, the pendulum can collect wave energy no matter how its swinging state is. In this work, the motion response of pendulum system is simulated and analyzed using AQWA hydrodynamic software. And the collection efficiency of the pendulum is estimated based on some fitting function software. The results can provide a theoretical reference and guidance for conceptual design and real sea experiments.

2. Modeling and simulation

It is noted that the pendulum is mainly used to absorb the wave energy in horizontal direction, while the middle pontoon plays a role in providing buoyancy and protecting conversion devices inside it. After some necessary simplifications, the pendulum system is modeled as shown in Fig. 3. The pontoon is named structure 1; the four pendulums are named structure 2, structure 3, structure 4 and structure 5, respectively.

During the simulation, taking density of seawater as 1025kg/m³, taking torque of pendulum shaft as 230N.m, assuming that the wave is regular wave (here taking Stokes wave as the standard), taking the sea state level 3 as the standard. Wave direction is defined as the angle of the wave propagation direction in relation to x-axis counterclockwise. There need to be three wave condition parameters including wave height, wave period and wave direction for simulation. Here we fix two parameters and simulate the third’s effect on the pendulum. Wave parameter selections are shown in Tab. 1.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
NO. & Wave height/m & Wave period/s & Wave direction/° \\
\hline
1   & 0.5           & 3.0           & 0°;15°;30°;45°     \\
2   & 0.5           & 2.0;2.5;3.0;3.5 & 45°              \\
3   & 0.4;0.5;0.6;0.7 & 3.0           & 45°              \\
\hline
\end{tabular}
\caption{Wave condition parameters}
\end{table}
3. Results and discussion

3.1. Analysis of the added mass and wave excitation forces

The simulation results show that the added mass increases with the increasing of the wave frequency, but the increase of the magnitude is small. The horizontal wave excitation forces on pendulum and pontoon also increase with wave frequency: the wave excitation force on pontoon is much greater than that on pendulum; while the relative pendulums’ wave force are substantially equal.

3.2. Swing angle of the pendulum in different wave direction

It is shown that pendulums can achieve very good acting when wave directions are 0°, 30° and 45°. When wave direction is 15°, only structure 2 and structure 4 can achieve very good acting, but structure 3 and structure 5 are in a no-swing state, as shown in Fig. 4. Furthermore, the results shows that the pendulums need to undergo a longer time to reach balance when wave direction are 0° and 30°, and they have to withstand greater impact before balancing, which is disadvantageous for the pendulum itself and the stability of the entire power generation device. Therefore, wave direction of 45° is the preferred operation angle for the pendulums.

3.3. Swing angle of the pendulum under different wave period

Fig. 5 illustrates the swing angles of structure 2 when wave periods are 3s and 3.5s. It is shown that the swing angle range under wave period of 3.5s is larger than that under period of 3s; but the swing angle curve experiences more cycles of swing under the latter. Obviously, the acting ability of the pendulum is stronger when the swing frequency and angle range are both larger. Due to the opposite effect of wave period on the swing angle range and the swing frequency, the period has less obvious effect on the acting ability of the pendulum.

3.4. Swing angle of the pendulum with different wave height

Fig. 6 shows the swing angles of structure 2 when the wave heights are 0.4m and 0.5m. It is shown that a larger wave height will cause a larger swing angle range and a longer time for the pendulum to reach balance. Also, longer time results in greater impact on the pendulum, which is undesired.

3.5. The wave-energy-collection efficiency of the pendulum

Based on the characteristics of the buoy-pendulum WEC presented in this paper, we define the conversion efficiency of pendulum as the ratio of pendulum shaft output power to the wave energy power.
With the help of MATLAB software, speed curve of the swing angle for pendulums within regular time segment can be fitted so as to work out the output power of pendulum shaft, and then the conversion efficiency can be calculated. The conversion efficiency of structure 2 under 5 kinds of ideal wave conditions is shown in Tab. 2.

<table>
<thead>
<tr>
<th>Items</th>
<th>Wave condition 1</th>
<th>Wave condition 2</th>
<th>Wave condition 3</th>
<th>Wave condition 4</th>
<th>Wave condition 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave height/m</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Wave period/s</td>
<td>3</td>
<td>2</td>
<td>2.5</td>
<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>Wave direction/°</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Conversion efficiency</td>
<td>7.5%</td>
<td>14.8%</td>
<td>8.6%</td>
<td>7.0%</td>
<td>14.0%</td>
</tr>
</tbody>
</table>

4. Conclusions

The motion response of the pendulum in a novel buoy-pendulum WEC is simulated and analyzed. The conclusions are as follows:

(1) Wave direction is the main factor that affects the four pendulums whether to work simultaneously. The optimal operating angle between wave direction and relative pendulum connection line is 45°.

(2) Wave period has an opposite effect on the swing angle range and the frequency of the swing, so it has less obvious effect on the acting ability of the pendulum.

(3) The higher the wave height, the greater the swing angle range of pendulum. But the excessive wave height is not good for the strength of the pendulum or the stability of the power generation device.

(4) Drawn from the efficiency calculation, the greater the wave period and the wave height, the lower the collection efficiency. The incident wave energy increases to a greater extent than the pendulum work with the increase of the wave parameters.

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References


Biography

He Hong-zhou, born in 1967, Professor, Ph.D.He works as dean of college of Mechanical and energy Engineering in Jimei University. His major research field is development and utilization of renewable energy including wave energy and solar.