Research on a new wave energy absorption device

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Abstract. To reduce impact of global warming and the energy crisis problems caused by pollution of energy combustion, the research on renewable and clean energies becomes more and more important. This paper designed a new wave absorption device, and also gave an introduction on its mechanical structure. The flow tube model is analyzed, and presented the formulation of the proposed method. To verify the principle of wave absorbing device, an experiment was carried out in a laboratory environment, and the results of the experiment can be applied for optimizing the structure design of output power.

1. Introduction

With the countries all around world are now making great efforts to reducing their pollution from energy supplies derived from fossil fuels [1, 2], the development of renewable energy take-off technologies becomes excessively important. Among various forms of ocean energy such as, solar energy, thermal energy, wind energy [11] and wave energy [14], the energy from ocean waves has the biggest density of power and most applicable in offshore areas [10]. Systems for taking-off wave energy to converting to electricity [15, 16] are in development, some of which have been utilized to generate electrical power [12, 13]. There are various technologies in wave energy conversion [3, 4, 7].

The device presented in this paper belongs to the near shore category. It will be better if the working area is in sea state 3, as it presents a lot of advantages. Because the energy levels are higher in water locations of sea state 3, and the device is protected from the extreme forces developed in storms by the natural process, and installation and maintenance costs may be reduced.

2. Model description

Learn from Wave Glider [5] and change the glider’s parallel blades into Circular array [6]. In this way, buoy’s heaving motion directly changed into continuous rotary motion, which is more suitable for generating electricity, as shown in figure 1(a).

The principle diagram of the new wave energy device is shown in figure 1, absorber (A) and absorber (B) are configured in the opposite direction, as shown in figure 1(b) and figure 1(c). In a long running process:
Figure 1. The principle diagram of the new wave energy device

(1) When the buoy rise, the tether drag the PTO rising, the bionic fin downward swing, as shown in figure 1(d) and generate a forward thrust on the fin, as shown in figure 1(f). By the forward thrust, absorber A rotate anticlockwise as shown in figure 1(b), absorber B rotate clockwise as shown in figure 1(c).

(2) When the buoy sink, By the water resistance on the bellow of the bionic fin, the bionic fin upward swing, as shown in figure 1(d) and figure 1(e). By the forward thrust, absorber A still rotate anticlockwise and absorber B still rotate clockwise. As a conclusion, no matter the buoy rise or sink, by the water resistance, the bionic fin will adaptively downward or upward swing and then generate the same forward thrust on the fin. Because absorber A and absorber B rotate in opposite direction, torque automatically balanced. Also, in theory, the device can automatically adjust to changes to the ocean’s wave height.

3. Model analysis of the absorber
If the angular velocity of absorber is $\omega$, the absorber is chosen as reference object [8, 9], the water flow rotate at angular velocity $\omega$ relative to absorber as shown in figure 2. Because of the induction of blades and water flow, the angular velocity of water flow behind the absorber is $(\omega + \sigma)$, the induction angular velocity is $\sigma$, the flow tube $(r, r + dr)$ is selected as research object. Based on the momentum theory, the torque at radius $r$ is calculated as:

Figure 2. The tube flow model
The power on this flow tube is calculated as:

\[ dP = \omega dM = 4\pi \rho \omega V_i (1-a) br^3 \, dr \]  

(2)

\( a \) is the axial interference coefficient and \( b \) is the tangential interference coefficient.

The power coefficient on this flow tube is calculated as:

\[ dC_p = \frac{dP}{\frac{1}{2} \rho V_i^3 S} = \frac{4\pi \rho \omega V_i (1-a) br^3 \, dr}{\frac{1}{2} \rho V_i^3 \pi R^2} \]

(3)

The tip speed ratio is \( \lambda_m = \frac{\omega R}{V_i} \), the speed ratio at radius \( r \) is \( \lambda = \frac{\omega r}{V_i} \).

Then it can be work out as:

\[ dC_p = \frac{8}{\lambda_m^2} b(1-a) \lambda^3 \, d\lambda \]

(4)

And, \( C_p = \int_0^{\lambda_m} \frac{1}{2} \rho \pi R^2 V_i \, \frac{dP}{\rho \pi R^2 V_i^3} = \frac{8}{2} \int_0^{\lambda_m} b(1-a) \lambda^3 \, d\lambda \)

4. Results and discussion

![Figure 3. The system structure](image-url)
To verify device in theory and experiment need to be done first in primary stage. Build experiment platform under the laboratory environment as shown in figure 3. The system contains PC, differential wave energy power generation device, DAQ card (Data Acquisition Card), linear heaving type electric cylinder, and water pool, etc.

According to the formula $P = \frac{U^2}{R}$, if keep the electrical load $R$ is constant, it can obtain more power when the voltage $U$ increased. But the electrical load also influences the output power significantly, and this experiment is to verify the electrical load's influence to the output power. Set the amplitude of linear heaving electrical cylinder is 150mm, the period is 1.5s according to the parameters of sea state 3, and set the maximum blade angle is $\pm 15^\circ$. The experiment result is shown in figure 4.

- (a) The electrical load is $10\Omega$
- (b) The electrical load is $15\Omega$
- (c) The electrical load is $20\Omega$
(d) The electrical load is 25Ω

(e) The electrical load is 30Ω

Figure 4. The output power corresponding to different load

Table 1. The electrical load and the output power

| Load /Ω | Average power/ W | Maximum power/ W |
|---------|------------------|------------------|
| 10      | 2.89             | 7                |
| 15      | 2.92             | 7                |
| 20      | 3.24             | 8                |
| 25      | 3.87             | 9                |
| 30      | 3.62             | 9                |

As shown in table 1, when the electrical load is about 25Ω, the average output power reach the maximum (3.78W), so that can determine 25Ω is the optimal electrical load of this system.

5. Conclusion

This paper introduces a new wave absorbing equipment, and the model is analyzed. And on this basis, carried out a test under laboratory environment, verified the feasibility of this device in principle. When the wave period is around 1.5s, which is same to sea condition of sea state 3, the average maximum output power can reach 3.87 W. The relationship between the output power and electrical load can be seen in the experiment. The paper provides the experimental basis for optimization design of this device in next stage. Electrical system is indispensable part of the wave energy power generation device. The experiment declares that, load change’s impact on the output power, which provides experiment basis for system optimization.
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