Research on Wave Energy Equipment Based on Gyro Effect

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Keywords: Wave power generation device, Gyro principle, Model test, Dynamic.

Abstract. A new type of wave power generator based on gyro stability was derived. Compared to other wave power generators, gyro-type power device has higher sensitivity and wider marine adaptability. This paper describes the structure and function of the device, the dynamics model is established, and the influence of the motor torque constant on the power generation is analyzed. The relationship between the change of the different parameters and the power is obtained. The simulation results show that the first order energy conversion efficiency of the device is higher than that of the direct drive type.

Introduction

Finding a clean and renewable new energy source has become the main way for all countries in the world to solve the energy crisis at this stage. As the ocean accounts for 70.8% of the Earth's surface area, and the waves in the ocean can have great development value, according to statistics, the global available wave energy can reach 20-25 billion kW, which has the advantages of large energy density and small energy propagation loss [5-7].

Wave power generation is the process of converting the wave energy into a wave energy capture device of mechanical energy of a carrier, and then converting the obtained mechanical energy into electricity through a certain medium [1]. Wave energy devices can usually be divided according to the installation location: onshore, near shore and offshore. According to capturing energy: Oscillation Water Column(OWC), Float, Tapchan and Clam. According to convert energy: Hydraulics, Pneumatics, Gearbox and Direct drive system. According to the fixed way: Fixed and Floating.

Wave Energy Theory

At present, the linear wave theory is relatively mature in the field of describing wave energy, and the power density of the wave can be expressed as [4]:

\[ P_{wf} = \frac{\rho g H^3 L}{16 T_w} \left[1 + \frac{4 \pi h}{L} \right] \frac{1}{\sinh(4 \pi h / L)} \]  

(1)

\[ L = \frac{g T_w^2}{2 \pi} \tanh(4 \pi h / L) \]  

(2)

where: \( P_{wf} \) is wave energy density, \( \rho \) is sea water density, \( g \) is gravitational acceleration, \( H \) is effective wave height, \( L \) is wavelength, \( T_w \); is wave period, \( h \) is water depth. In view of this complex equation, Eq. 1 also can be approximated by:

\[ P_{wf} = \frac{\rho g H^2 T_w^2}{64 \pi} \]  

(3)

Most wave energy devices usually have three stages of energy conversion. The first step is to convert wave energy into mechanical energy of a certain carrier. The second is to convert
mechanical energy into rotational mechanical energy and finally to electrical energy. The conversion efficiency has been a central issue in judging power devices. The energy conversion efficiency of each mode is shown in Table 1 [2-3].

Table 1. Energy conversion efficiency of different devices.

<table>
<thead>
<tr>
<th>Conversion efficiency</th>
<th>first stage</th>
<th>Second stage</th>
<th>Third stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pneumatics</td>
<td>about 60%</td>
<td>0-20%</td>
<td>0-90%</td>
</tr>
<tr>
<td>Hydraulics</td>
<td>20-80%</td>
<td>60-80%</td>
<td>60-90%</td>
</tr>
<tr>
<td>Direct drive system</td>
<td>30-40%</td>
<td>50-60%</td>
<td></td>
</tr>
</tbody>
</table>

However, most current wave power devices need careful selection of installation locations, usually in areas with higher energy density and without extreme weather conditions, which increases the difficulty of wave power generation. Since 2000, Professor Kami Kobo of Kobe University has applied the achievements of gyro research to wave power generation. The principle is to convert the tilting motion of waves to the same direction of gyroscopic rotation [8], which provides a new thinking.

Model Establishment and Simulation Analysis

Figure 1 shows the wave power device, which performance indicators: the structure size of 3 * 1.5 * 1.5m, rated power 1Kw. It is mainly composed of inertial gyroscope, mechanical hydraulic mechanism, variable motor, generator and the corresponding parts of the control system. Among them, the inertial gyroscope is used to sense the movement of waves, transform the wave of the waves into the rotation of the gyroscope's rotating axis, and then convert it into hydraulic energy through the mechanical hydraulic mechanism, which is the first energy conversion. The second energy conversion is driven by a hydraulic variable motor generator; which convert hydraulic energy into electrical energy output.

![Wave power generation device structure diagram.](image)

In this paper, the torque generated by the fixed-axis of high-speed gyroscope is used to drive the external mechanism to generate electricity. However, the fixed-axis gyroscope rotor rotates at high speed without any external moment acting on the gyroscope. Shaft in inertial space points to maintain a stable character. According to this characteristic, the angular momentum equation of gyro rotor, the torque equation of precession, the torque equation of motor and the dynamic balance equation of inner rotor ring can be obtained:
\[
\frac{H^1}{J_g, \omega_g} \right.
\begin{align*}
M_g &= -H^1 \times \omega \\
M_L &= k\dot{\theta} \\
M_g - M_L - Gd \sin \theta &= J\ddot{\theta}
\end{align*}
\] (4)

In the formula, the moment of gyration of the gyro rotor about the rotating shaft is \( J_g \), \( \omega_g \) is the gyro rotor speed, \( \omega \) is the angular velocity of the wave motion and \( M_L \) is the load torque of the gyro inner ring shaft driving power generation device, the gravity of the ring frame is \( G \), \( d \) is the distance between the center of gravity of the inner ring of the gyroscope and the axis of the inner ring frame, \( J \) is the moment of inertia of the inner ring around the inner ring in the whole gyro, \( k \) is the torque constant of the motor and \( \theta \) is the angle of oscillation after the inner ring receives the gyro torque.

In this paper, taking the sea conditions in the South China Sea as an example, the wave period of most sea areas is more than 5.5s [9]. Taking the wave period as 6s and the wave swing angle as 10\(^\circ\), the length of the device in the wave motion direction \( l=3m \), the effective wave height is \( H = l \times \sin 10^\circ \), the power generation efficiency is:

\[
\eta = \frac{M_L \omega}{P_i} = \frac{k \times \omega^2}{\frac{\rho g^2 H^2 T_w^2}{64\pi} \times l} = 51.6\%
\] (5)

According to the actual parameters, gyroscopic rotor moment of inertia of \( 16kg \cdot m^2 \), rated speed of 6000rpm, wave amplitude of 10\(^\circ\), the cycle of 6s, the motor torque constant of 1000, the simulation analysis with Matlab model, the correlation curve between motor torque constant and wave power can be obtained.

![Figure 2. Relationship between motor torque constant and power generation.](image)

It can be seen from Fig. 2 that the torque constant of the motor is not linearly related to the generated power, but the average generated power reaches the maximum near 350. In order to meet the rated power generation power, it is best to choose \( k \) in the 150-1000 range.
As can be seen from Fig. 3, the peak value of angular displacement of gyro rotor precession is about 70 ° and the instantaneous power of load instantaneous power is about 3300w, with an average of 1138w. While keeping the original parameters unchanged, the parameters of wave period, gyro rotor speed and rotor moment of inertia are individually changed to simulate and analyze the influence of different parameters on the power generation device. The results are shown in Fig. 4.

It was shown that increasing the moment of inertia can increase the power generation by increasing rotor inertia from 16 to 20 in Fig. a. The maximum power generation increased to 7500w by period reducing to 4 in Fig. b. With the rotor speed raising to 10000rpm, the maximum power is 9000w in Fig. c.

**Summary**

In this paper, a novel kilowatt-class wave power generation device based on the gyro principle is creatively proposed. The theoretical calculation and simulation results show that the first-level energy conversion efficiency of this device is 51.6%, which exceeds the current mainstream secondary energy conversion wave power generation The conversion efficiency of the device and the optimum range of the torque constant of the motor are obtained through the simulation and analysis under the action of a wave amplitude of 10 ° and a period of 6 seconds when the gyroscope rotor speed is 6000 r / The results show that the shorter the wave period and the larger the rotor speed and moment of inertia, the greater the power generation will be.

**References**


