Design and research of hydraulic conversion system of wave energy generating device

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Abstract. Taking the hydraulic conversion system of the oscillating flapping-wing wave energy power generation device as the research object, a hydraulic conversion system is designed to convert wave energy into usable mechanical energy. Based on the principle of high-efficiency collection of wave energy and stable output of the hydraulic conversion system, the composition of the hydraulic conversion system and the parameters of each component are determined. According to different sea conditions, the pre-charge pressure of the accumulator is adjusted to keep the pressure of the high and low pipelines of the hydraulic system stable, and the mechanical energy is stably output through the hydraulic motor. The AMESim simulation platform is used to build the model of acquisition mechanism and hydraulic conversion system, simulate the motion response of acquisition mechanism under actual sea conditions as the system input, and analyze the effectiveness and output stability of hydraulic conversion system. The results verify that the designed hydraulic conversion system can achieve efficient collection of wave energy. The research results have laid a theoretical foundation for the development and research of wave energy power generation devices.

1. Introduction

The increasing problems of global climate change, energy shortage and environmental pollution have promoted the development of renewable energy to become a global consensus. As a clean, non-polluting renewable new energy, wave energy has abundant reserves and wide distribution, and has huge development potential. According to the International Energy Organization's forecast, the world's available wave energy reaches 2 to 3 billion kilowatts, which is equivalent to twice the total installed power generation capacity in the world. It is estimated that the global wave energy reserves can reach 2TW [1].

The research and development of wave energy in various countries is progressing rapidly, and a variety of wave energy power generation devices have been developed. KRAMER et al. [2] conducted a study on the Wavesta multi-floating array hydraulic power generation device in Denmark, and conducted experiments in the Hanstholm sea area. The research results showed that the key technology of wave power generation in the future is to ensure high energy efficiency and full power transmission to the grid. Blommaert et al. [3] studied the operating reliability of the Norwegian Seewec array float hydraulic wave power generation device under extreme wave conditions. Zhang Yaqun [4] took the hydraulic energy conversion system of the floating wave energy device as the research object and conducted experiments. The results showed that the greater the difference between the maximum
working pressure and the minimum working pressure of the accumulator, the greater the energy released by the energy storage system in a single cycle. More, the lower the cost of the energy storage system. Fang Zifan et al. [5] developed a multi-section floating mechanical wave energy power generation device and an experimental environment for a water tank, and conducted experimental research on the principle prototype. Davood Younesian et al. [6] proposed a nonlinear multi-stable energy harvesting system composed of a nonlinear recovery mechanism and a linear damper on the basis of a point absorption linear wave energy harvesting device. The steady-state system can broaden the collection frequency bandwidth of the wave energy collector. Liu Changhai et al. [7] took the raft-type wave energy power generation device as the research object, designed and manufactured a semi-physical simulation test platform, which can test the performance of the power generation system before the device is deployed in the sea without a laboratory pool or ocean test. Zhou Yahui et al. [8] considered the perforated damping plate on the basis of the existing double-floating point-absorption wave energy device, and proposed a new perforated double-floating structure with supporting columns.

In order to improve the efficiency and output stability of wave energy conversion, based on the existing research, the oscillating flapping-wing wave energy hydraulic conversion system is taken as the research object, and the wave energy hydraulic conversion system is designed to realize the collection of wave energy under different sea conditions.

2. Wave energy conversion mechanism
At present, the principles of wave energy power generation devices are roughly divided into the following two types: using the lifting and swaying motion of the floating body under the action of waves to convert wave energy into mechanical energy; using the climb of waves to convert wave energy into potential energy of water. The collection system captures wave energy, which is also called the primary energy conversion system. The Power Take-off (collective term for the original secondary and tertiary energy conversion systems) converts the collected wave energy into electrical energy. The power intake system generally includes a two-level energy conversion system and a three-level energy conversion system: the second-level energy conversion system converts the energy obtained from the first-level energy conversion into mechanical energy or hydraulic energy, etc.; the third-level energy conversion uses a generator to convert mechanical energy into Electrical energy.

![Figure 1. Schematic diagram of the structure of oscillating flapping wave power generation device](image)

As shown in figure 1, the support platform is a vertical marine fixed platform. The top of the rocker arm is connected with the support platform, and the bottom of the rocker arm is connected with the float to form a wave energy collection system; a hydraulic cylinder and the hydraulic system constitutes a wave energy conversion system.

3. Design of hydraulic conversion system

3.1. Basic system composition
In order to adapt the oscillating flapping-wing wave energy generating device to different sea conditions, a hydraulic conversion system is designed. As shown in figure 2, the hydraulic conversion system is mainly composed of hydraulic cylinders, accumulators, hydraulic motors, generators and so on. Under
the excitation of waves, the flapping wings swing to generate kinetic energy by the collecting mechanism. The collecting mechanism converts random mechanical energy into hydraulic energy, which is transmitted by the hydraulic system and converted into rotary motion by a hydraulic motor, driving the generator to generate electric.

3.2. System Mathematical Model

3.2.1 Wave model Assuming.
that the wave acting on the floating body is a regular wave, the regular wave can be defined as a plane sine wave, where the incident wave is defined as:

\[ \eta(x, y, t) = H \cos(\omega t - k(x \cos \theta + y \sin \theta) + \phi) \]  

(1)

\( H \) is the wave height, \( \omega \) is the frequency of the wave, \( k \) is the wave number, \( \theta \) is the direction of the wave, and \( \phi \) is the phase of the wave.

3.2.2 Flapping wing float motion model.
The law of the heave motion displacement of the flapping-wing float under the wave motion and the law of its angle change during the swing process can be expressed as:

\[ \begin{align*}
  z(t) &= z_0 \cos(\omega t - \sigma_z) \\
  \theta(t) &= \theta_0 \cos(\omega t - \sigma_z + \psi)
\end{align*} \]  

(2)

\( z(t) \) is the heave movement displacement of the floating body in the vertical direction, reflecting the movement of the floating body under wave motion; \( \theta(t) \) is the angle change of the floating body relative to the coordinate axis when the floating body rotates with the flapping wings; \( z_0 \) means the floating body rises in the vertical direction. The amplitude of the sinking motion; \( \theta_0 \) represents the amplitude of the angle change when the floating body is moving, which is limited by the length of the rocker arm; \( \psi \) represents the phase difference between the heaving motion and pitching motion of the floating body.

3.2.3 Hydraulic cylinder model.

\[ p_A = \frac{\beta_e}{V_0 - A_p \dot{z}} (A_p \dot{z} - \dot{V}_1 + \dot{V}_4) \]  

(3)

\[ p_B = \frac{\beta_e}{V_0 - A_p \dot{z}} (-A_p \dot{z} - \dot{V}_2 + \dot{V}_3) \]  

(4)

\( p_A, p_B \) represents the pressure of the hydraulic cylinder chamber, \( \beta_e \) represents the bulk modulus of the hydraulic fluid, \( V_0 \) represents the volume of the hydraulic cylinder, \( A_p \) represents the area of the piston, \( \dot{V}_1, \dot{V}_2, \dot{V}_3, \dot{V}_4 \) represent the volume flow through the four check valves, \( z \) represents the displacement of the piston, and \( \dot{z} \) represents the speed of the piston.
3.2.4 Accumulator model.
The accumulator is mainly used as the energy storage element in the hydraulic conversion system of the oscillating flapping-wing wave energy power generation device. Analysis of the wave action period shows that the charging and discharging time of the accumulator is less than 1 minute. When the accumulator is used as the accumulator of the auxiliary power source, in order for the hydraulic system to work continuously, the minimum working pressure of the accumulator is required to meet:

\[ P_1 = P_m + (\sum \Delta P)_{max} \]  

Where \( P_m \) is the maximum working pressure of the farthest energy-consuming element; \( \sum \Delta P \) is the sum of the pressure loss from the accumulator to the farthest energy-consuming element.

Considering the bearing capacity, use conditions and working conditions of each component in the system, it is generally necessary to meet:

\[ P_1 = (0.6 \sim 0.85)P_2 \]  

Where \( P_1 \) is the lowest working pressure of the accumulator; \( P_2 \) is the lowest working pressure of the accumulator. Flow into the accumulator:

\[ V_c = -aDn + \dot{V}_1 + \dot{V}_2 \]  

Where \( \alpha \) is the swash plate angle ratio, that is, the instantaneous hydraulic motor divided by the hydraulic motor displacement; it is used to control the volume flow through the motor; \( D \) is the nominal displacement of the hydraulic motor; \( n \) is the generator speed; for this hydraulic system, the swash plate angle ratio is fixed for the simulated sea state.

3.2.5 Hydraulic motor model.
Since the output shaft of the hydraulic motor and the generator shaft are rigidly connected, they have the same torque and opposite rotation directions, the speed of the hydraulic motor can be known:

\[ \dot{n} = \frac{1}{J} (aD(P_c - P_D) - b_g n - b_f n) \]  

In the formula, \( b_g n \) represents the generator torque, \( b_f n \) represents the friction damping, and \( J \) is the total moment of inertia of the generator drive system.

4. System modeling and simulation
In order to study the working conditions of the hydraulic conversion system under specific sea conditions, the multi-energy domain bond graph modeling theory is used, combined with the AMESim simulation platform to build the acquisition mechanism and the hydraulic conversion system simulation model, and the parameters of the system components are set to the movement of the flapping wings in real sea conditions is used as the system input to simulate the hydraulic conversion system.

![Simulation model of hydraulic conversion system](image)
AQWA simulates the movement of the flapping wing in real sea conditions as the input of the hydraulic conversion system. According to the angular displacement of the flapping wing, it can be known that the flapping wing can stably output simple harmonic motion under the action of regular waves, and the angular displacement of the flapping wing is used as the hydraulic conversion. The input of the system, the simulation analysis of the system.

![Angular displacement curve of flapping wing](image1)

**Figure 4. Angular displacement curve of flapping wing**

Determine the relevant parameters of the system, simulate the movement of the acquisition mechanism under real sea conditions, and perform simulation analysis on the hydraulic conversion system. The pressure changes of high and low pressure pipelines are shown in Figure 5.

![High and low pressure pipeline pressure](image2)

**Figure 5. High and low pressure pipeline pressure**

![Hydraulic motor speed](image3)

**Figure 6. Hydraulic motor speed**

According to the results, it can be seen that the oil pressure in the high-pressure pipeline is basically stable around 25Mpa, and the low-pressure pipeline is stable around 15Mpa. This is due to the working characteristics of the accumulator on the high and low pressure pipelines, which keep the pressure of the hydraulic pipeline relatively stable. It can effectively improve the working stability of the hydraulic motor, so that the hydraulic conversion system can maintain stable work under different sea conditions.

The hydraulic motor acts as an executive element in the energy conversion system, converting hydraulic energy into rotational mechanical energy. According to the pipeline oil characteristics, it can be known that the pressure of the high and low pressure pipelines can basically be kept relatively stable, so that the hydraulic motor can maintain good rotation characteristics. As shown in figure 6, the speed and torque of the hydraulic motor maintain an increasing trend within 0-20s, and enter a stable phase after 20s, maintaining around 300r/min.

5. Conclusion

By studying the hydraulic conversion system of the oscillating flapping-wing wave energy power generation device, a hydraulic conversion system is designed. The composition of the system and the
specific parameters of each component are determined, and the simulation model of the system is built using AMESim simulation software, and the working characteristics of the hydraulic conversion system under real sea conditions. The working characteristics of accumulator and pipeline pressure and the motion characteristics of hydraulic motor are analyzed. And the efficiency and stability of the designed hydraulic conversion system are studied. The research results show that the use of the accumulator can effectively stabilize the oil pressure in the high-pressure pipeline around 25Mpa and the low-pressure pipeline around 15Mpa, so that the hydraulic motor can achieve stable output characteristics.

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