Research on the dynamic characteristics of the acquisition mechanism of the oscillating flapping wing wave energy power generation device based on the bond graph

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Abstract. Taking the acquisition mechanism of the oscillating flapping-wing wave energy power generation device as the research object, the design of the acquisition mechanism, the bond graph model of the acquisition mechanism and the dynamic characteristics are studied. According to the working principle of the acquisition mechanism of the oscillating flapping wing wave energy power generation device, the bond graph model and the state space equation of the acquisition mechanism are established. Based on the bond graph theory, the AMESim software is used for simulation analysis to verify the correctness of the bond graph model of the acquisition mechanism. The research results show that the designed oscillating flapping wing wave energy generation device acquisition mechanism responds quickly and stably, and the bond graph model basically matches the real system. The research process provides an effective reference for the development of the acquisition mechanism of the oscillating flapping wing wave energy power generation device.

1. Introduction
The severe consumption of traditional energy, the impact of fossil fuels on the environment and the scarcity of habitable land are promoting the development of renewable energy projects in the marine environment [1]. As a clean, pollution-free renewable new energy, wave energy has abundant reserves and wide distribution, and has huge development potential. According to the prediction of the International Energy Organization, 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 [2-4]. Compared with other renewable energy sources, wave energy has a higher energy density, has less environmental impact when used, and has a long average available time. Therefore, it has very important practical significance for wave energy development.

European and American countries have a strong interest in the use of wave energy, and actively develop a variety of new wave energy power generation technologies, and have developed sea test devices for wave energy power generation as typical representatives of Pelamis, Oyster, PowerBuoy, WaveDragon, Wave Roller and WaveStar [5]. The wave energy power generation device is mainly composed of three parts: an energy harvesting mechanism, an energy conversion device and an electric energy storage device. Taking the oscillating flapping-wing wave energy power generation device as the research object, its acquisition mechanism is in direct contact with waves, and there is a conversion
process of wave energy-mechanical energy-hydraulic energy. The stability, conversion efficiency and reliability of energy output are closely related to the design of the acquisition mechanism.

In the 1950s, H.M. Paynter proposed the bond graph theory [6] to solve the problem of dynamic analysis of multi-energy domain electromechanical systems. Taking the oscillating flapping-wing wave energy power generation device as an example, the structure characteristics and working principle of the acquisition mechanism are analyzed, and the acquisition mechanism model is innovatively established based on the power bond graph theory, and the bond graph model is used to express the energy transfer in the acquisition mechanism. The power bond graph theory is an important theoretical support behind the AMESim software. The use of AMESim software to establish a simulation model of the acquisition mechanism for verification and analysis is not only of profound significance for the in-depth understanding of the energy flow and power flow direction of the wave energy generation device, but the development of wave energy devices provides a theoretical basis.

2. Basic composition of oscillating flapping wave energy acquisition mechanism

As a key component of the wave energy device, the acquisition mechanism has the function of transferring motion and energy, and is an important link in the realization of wave energy acquisition and conversion. In order to absorb the energy in the horizontal and vertical directions of waves at the same time, according to the principle of energy acquisition of ups and downs and pitch-coupling vibration-type oscillating flapping wing [7], based on the crank and swing slider mechanism, a crank and swing slider acquisition mechanism for an oscillating flapping wing wave energy power generation device is designed, as shown in figure 1. It is similar to the lifting mechanism of a loading dump truck. The lifting mechanism converts hydraulic energy into mechanical energy, while the working principle of the flapping wing wave energy acquisition mechanism is the opposite.

The oscillating flapping wing wave energy acquisition mechanism is composed of a supporting platform, a float, a rocker arm, and an oil cylinder. The supporting platform is a vertical marine fixed platform, which connects the positional relationship between the wave acquisition system and the energy conversion system. The supporting platform is divided into two parts: the top of the rocker is hinged with the supporting platform, and the bottom of the rocker is fixedly connected with the float; on the vertical supporting platform and the rocker There are oil cylinders between them to form an oscillating flapping wing energy-capturing mechanism. The piston rod of the hydraulic cylinder is hinged with the rocker arm, and the cylinder body of the hydraulic cylinder is hinged with the supporting platform; the hydraulic system, hydraulic motor and other equipment are installed in the sealed cabin of the supporting platform.

From the perspective of energy transmission, the flapping wings swing up and down under wave excitation to generate kinetic energy, which makes the rocker arm compression cylinder piston of the energy capture mechanism produce reciprocating mechanical motion, and converts the random mechanical energy of the flapping wings into high-pressure hydraulic energy. Energy conversion. The energy harvesting mechanism is designed as a rotating structure, which can make the float and the wave better coupled motion response. When the rocker arm is parallel to the forward direction of the wave, the instantaneous velocity of the float under the wave force is no longer only in the vertical direction,
but at a certain angle to the horizontal plane. The flapping-wing oscillating motion turns part of the resistance existing in the original heave motion into the power of the floating body movement, which is beneficial to increase the displacement amplitude of the floating body in the vertical direction and improve the energy conversion efficiency.

3. Model of oscillating flapping wave energy acquisition mechanism

The energy conversion, transmission, and distribution links and interfaces of the oscillating flapping wing wave energy acquisition and conversion system are diverse. The dynamic changes of energy flow are closely related to the evolution of multi-physical processes, and multi-energy domain system dynamics modeling and analysis are required. The theory of power key combined graphs provides an effective way.

In the acquisition mechanism of the oscillating flapping wing wave energy power generation device, the hydraulic cylinder is selected as a single-rod piston hydraulic cylinder, and its structure diagram is shown in the figure 2. It is necessary to consider the quality of the piston rod of the hydraulic motor, the capacity of the hydraulic oil, the leakage and the friction during movement when establishing the power bond graph model of the hydraulic motor. The power bond graph is shown in the figure 3.

\[ \text{Figure 2. Schematic diagram of the structure of a double-rod piston hydraulic cylinder.} \]

\[ \text{Figure 3. Power bond graph model of hydraulic cylinder.} \]

If friction is neglected, according to the principle of power bond graph, the state equations of the hydraulic cylinder can be derived as follows:

\[
\begin{align*}
\dot{V}_1 &= Q_1 - A_2 \frac{A_1}{I_h} P_3 - \frac{V_1}{C_{p1}} - \frac{V_2}{C_{p2}} - \frac{1}{R_f} \\
\dot{V}_2 &= \frac{V_1}{C_{p1}} - \frac{V_2}{C_{p2}} + \frac{A_2}{I_h} \frac{A_1}{I_h} P_3 - Q_2 \\
\dot{p}_3 &= \frac{A_1}{C_{p1}} V_1 - \frac{R_f}{I_h} P_3 - \frac{A_2}{C_{p2}} V_2 - S_e 
\end{align*}
\]

Where: \( V_1 \) and \( V_2 \) are the volume of hydraulic oil in the rodless cavity and the rod cavity respectively; \( Q_1 \) and \( Q_2 \) are the flow rates of the rodless cavity and the rod cavity respectively; \( A_1 \) and \( A_2 \) are the piston action area of the rodless cavity and the rod cavity respectively; \( C_{p1} \) and \( C_{p2} \) are the fluid volume of the rodless cavity and the rod cavity respectively; \( R_f \) is the leakage resistance of the hydraulic cylinder; \( I_h \) is the mass of the piston rod of the hydraulic cylinder; \( P_3 \) is the momentum of the piston rod.

According to the working principle of the acquisition mechanism of the oscillating flapping wing wave energy power generation device and the modeling rules of the bond graph, the power bond graph model is established as shown in the figure 4. The following assumptions are made when establishing the power bond diagram: consider the mass of the float and the rocker arm with the equivalent concentrated mass; the coupled motion of the float and the wave has radiation damping to the system.
Figure 4. The power bond graph model of the oscillating flapping-wing wave energy acquisition mechanism.

In the figure: $S_e$ is the potential source; $F_w$ is the wave force; $v_w$ is the wave speed; $C_{\text{hyd}}$ is the wave radiation damping; $F_r$ is the float input force; $v_f$ is the float speed; $T_r$ is the rocker torque; $w_r$ is the rocker angular velocity; $F_p$ is the input force of the hydraulic cylinder; $v_p$ is the speed of the piston rod of the hydraulic cylinder; $I_p$ is the quality of the piston rod of the hydraulic cylinder; $R_f$ is the hydraulic cylinder friction fluid resistance; $C_p$ is the hydraulic cylinder fluid capacity; $R_{l}$ is the hydraulic cylinder leakage fluid resistance; $C_l$ is the hydraulic cylinder leakage fluid Rong; $S_f$ is the source of flow.

It can be seen from figure 4 that the power bond diagram of the acquisition mechanism of the oscillating flapping-wing wave energy power generation device has a power input terminal, wave energy $S_e$. The float converts the energy in the seawater into its own kinetic energy, and converts it into the torque and angular velocity of the rocker arm through the linkage mechanism. The rocker arm rocker mechanism converts the torque and angular velocity of the rocker arm into the input force and the hydraulic cylinder through the converter. Speed, the piston rod moves back and forth, the two chambers of the hydraulic cylinder respectively output pressure and flow into the hydraulic conversion system, convert the mechanical energy of the mechanism into hydraulic energy, and complete the energy conversion.

4. Acquisition mechanism simulation analysis

4.1. Simulation parameter definition

The power bond graph theory is an important theoretical support behind AMESim. Compared with the bond graph, it has an intuitive graphical interface, which can realize schematic-oriented modeling. During the entire simulation process, the simulation system is displayed through an intuitive graphical interface. The AMESim software is used to simulate and analyze the dynamic characteristics of the oscillating flapping wing wave energy acquisition mechanism. The simulation parameters of each part are shown in the table 1.

| Parameter                        | Unit | Value |
|----------------------------------|------|-------|
| Float weight                     | kg   | 18    |
| Rocker arm length                | mm   | 800   |
| Piston rod diameter              | mm   | 28    |
| Piston rod stroke                | mm   | 200   |
| Inner diameter of hydraulic cylinder | mm  | 50    |
| Hydraulic oil density           | kg/m³ | 850   |
4.2. Simulation analysis
In AMESim, the components of mechanical library and hydraulic library are used to build the simulation model of acquisition mechanism, as shown in figure 5.

![Simulation model of oscillating flapping-wing wave energy acquisition mechanism.](image)

ANSYS is used to simulate the motion characteristics of the float under the action of waves under the condition of three-stage waves, and the angular displacement of the rocker arm is used as the input signal of the simulation model, as shown in figure 6. The displacement of the piston rod of the hydraulic cylinder and the pressure at the port in the acquisition mechanism are shown in figure 7 and figure 8 respectively.

![The angular velocity of the rocker arm of the acquisition mechanism.](image)
The movement of the piston rod of the hydraulic cylinder is driven by the rocker float under the force of waves, so the range of movement of the piston rod is related to the angle of rotation of the rocker arm. It can be seen from figure. 6 and figure. 7 that the movement range of the piston rod is 0.1m, reaching half of the design stroke of the piston rod, and its movement coincides with the rotation angle of the rocker arm. It can be seen from figure 8 that the two ports of the hydraulic cylinder alternately enter and exit oil, with fast response and stable pressure.

5. Conclusion
Taking the acquisition mechanism of the oscillating flapping-wing wave energy power generation device as the research object, based on the crank and swing slider mechanism, a flapping-wing wave energy acquisition mechanism is designed, the power bond graph model is established, and the mechanical structure and hydraulic system are analyzed. Co-simulation analysis. Concluded as follow:

1) The designed oscillating flapping-wing wave energy power generation device acquisition mechanism is mainly composed of floats, rocker arms and hydraulic cylinders, and the shape is similar to the flapping wings of birds. According to the energy acquisition principle of the oscillating flapping wing, the acquisition mechanism can absorb the energy in the horizontal and vertical directions of the wave, convert the wave energy into hydraulic energy, and improve the energy absorption efficiency.

2) According to the power bond graph theory, the bond graph model of oscillating flapping wing wave energy acquisition mechanism is established, which clearly shows the transmission of energy in the acquisition mechanism.

3) The wave energy acquisition mechanism of oscillating flapping wing is simulated by AMESim software. With sinusoidal signal as the system input, the rocker arm mechanism and hydraulic system can respond quickly and output energy stably. The analysis results show that the bond graph model and the simulation model have high matching degree, and can truly reflect the dynamic characteristics of the system.

The bond graph theory can provide a theoretical basis for the development of the acquisition mechanism of an oscillating flapping-wing wave energy power generation device, reflecting the dynamic characteristics of the system, and the research process has promoted the progress of wave energy conversion technology.

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