Influence of Buoy Size on Accelerated Wave Power Generation Device

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Abstract. This paper proposed a pulley-buoy accelerated wave energy linear power generation system, and the feasibility and effectiveness of this system were verified through experimental research. Compared with the traditional wave energy power generation system with three-stage energy conversion links, the pulley-buoy accelerated wave energy linear power generation system omits the intermediate energy transfer and conversion link, and realizes the direct gain of electric energy from the buoy movement caused by wave, and by introducing the pulley combination, the movement speed of the buoy is enlarged, the power generation of the linear power generation system is increased, thereby the wave energy conversion efficiency of the system is improved. Under laboratory conditions, a small-size pulley-buoy accelerated wave energy linear power generation system prototype and a swing-plate wave-making system were built to explore the effects of different buoy sizes on the power generation performance of the system. The test results show that within the research scope of this paper, increasing the size of the buoy can effectively increase the wave energy conversion efficiency of the system and improve the power generation performance of the accelerated wave energy power generation system. The research results in this paper provide useful experience for the practical application and efficient operation of wave energy power generation systems.

1 Introduction

As a sustainable energy source, wave energy has received widespread attention worldwide due to its high energy density, large reserves and wide distribution range [1-2]. In recent years, there have been many successful cases of wave energy technology in many foreign countries, such as the "PowerBuoy" in the United States, the "OE buoy" and "Wavebob" oscillating buoy type wave energy devices in Ireland, and the water column type wave energy device "Oceanlinx" oscillation in Australia, "Oyster" pendulum wave energy device and "Pelamis" raft type wave energy generator in British, "Penguin" floating boat type wave energy device and "WaveRoller" pendulum wave energy device in Finland, "Wave Star" multi-buoy wave energy device and "Wave Dragon" wave-over-wave energy device in Denmark, etc. [3-5]. With the support of relevant national plans and special funds, wave energy technology has developed rapidly in China, and related equipment has also undergone actual testing and operation, mainly including the duck-type and eagle-type wave energy devices developed by the Guangzhou Energy Research Institute, and the buoyant pendulum wave energy device developed by the National Ocean Technology Center, the combined oscillating buoy wave energy device developed by the Ocean University of China, and the raft, pendulum, hydraulic, and

pneumatic wave energy power generation devices developed by other colleges and universities[6-11]. However, in most wave energy power generation devices at home and abroad, problems such as low power generation efficiency, poor structural reliability, and unstable system operation are still not well resolved, which hinder the commercialization development of wave power technology to a certain extent.

The energy collection efficiency of the wave power generation system is closely related to the structural parameters of the float. Scholars at home and abroad have carried out a lot of research work on the optimization of the float. Shi et al. [12] optimized the design of a cylindrical buoy with a tapered bottom based on the RANS equation and CFD software, which improved the hydrodynamic performance and energy output of the system. Sheng et al. applied the separation variable method and the extended characteristic function matching method to optimize the design parameters of the cylindrical buoy to maximize the capture of wave energy [13]. The optimization content includes the buoy section radius and draft. Claudio A. Rodríguez et al. numerically optimized the buoy geometry of a point absorbing wave energy device (CECO) based on the exhaustive search method, and the obtained optimal geometry buoy can capture wave energy twice as much as before [14]. Zhang Yaqun et al. optimized the

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eagle-type wave energy power generation device and obtained the optimal buoy shape of the eagle-type device [15]. These optimization studies on the single-buoy structure have effectively improved the energy capture performance of the wave energy power generation system to a certain extent, and improved the wave energy collection efficiency, but the array research of the multi-buoy structure still needs to be further supplemented and strengthened.

Based on the above research work, different from the traditional three-stage energy conversion wave energy power generation system, this paper is based on a self-made linear power generation system and designed a pulley-buoy accelerated wave energy power generation system with only two-stage energy conversion links. The oscillating buoy in the system is directly connected to the mover in the linear power generation system, which can directly extract electrical energy from the buoy movement caused by waves, omitting the intermediate energy transfer and conversion link, and the introduction of the pulley combination can amplify the movement rate of the float. The rate at which the mover cuts the magnetic line of induction in the linear power generation system is increased by several times. According to the principle of electromagnetic induction, the power generation of the linear power generation system is increased, thereby finally achieving the purpose of improving the wave energy conversion efficiency of the system. To verify the feasibility and effectiveness of the pulley-buoy accelerated wave power generation system, a small-size pulley-buoy accelerated wave power generation system prototype and a swing-plate wave generating system were built under laboratory conditions. By simulating different wave conditions, the effects of different spherical buoy sizes on the power generation performance of the system were experimentally studied.

2 System introductions

2.1 Pulley-buoy accelerated wave energy linear power generation system

The two-stage energy conversion pulley-buoy accelerated wave energy linear power generation system proposed in this paper is shown in Figure 1. The system mainly consists of a set of linear power generation system, a set of pulleys and a portal frame. The pulley-buoy accelerated wave energy power generation system first converts the wave energy into the mechanical energy of the float. The buoy drives the mover of the linear power generation system to move, then the mover cuts the magnetic lines of force to directly convert the mechanical energy of the buoy into electrical energy. This system realizes the direct extraction of electric energy from the movement of the buoy caused by the wave, omits the transfer and conversion of intermediate energy, and can amplify the movement rate of the buoy through the combination of pulleys, thus the motion rate of the actuator in the linear power generation system is increased to several times that of the float. According to the electromagnetic

induction formula $E=BLV$ (E is the induced electromotive force; B is the magnetic induction intensity; L is the effective length; V is the cutting magnetic induction line speed), when other conditions remain unchanged, the increase in the speed of the coil cutting the magnetic induction line leads to the increase in the power generation of the linear power generation system, which ultimately improves the wave energy conversion efficiency of the system.

Figure 1. Pulley-buoy accelerated wave energy linear power generation system

The direct conversion from the movement of the buoy to the electric energy is realized by a linear power generation system. The self-made linear power generation system in this study is composed of a mover and a stator. The mover contains a ring magnet, a ring partition block and an aluminum main shaft, and the stator is a coil. When the buoy moves under the action of the waves, the pulley assembly directly drives the mover to move up and down, cutting the lines of magnetic force to generate electric current.

The pulley assembly includes a movable pulley, two fixed pulleys and a movable pulley motion guide. The fixed pulley is fixed on the door frame, the movable pulley can slide up and down along the moving guide rail, and a limit block that can be adjusted is arranged on the moving pulley guide rail to control the movement stroke of the movable pulley. One end of the cable is fixed on the gantry, and the other end sequentially bypasses the movable pulley and two fixed pulleys, and is connected to the upper end of the mover in the linear power generation system. The lower end of the movable pulley is connected with the float, and the buoy directly drives the mover of the linear power generation system to move through the movable pulley, cable and two sets of fixed pulleys. The introduction of the pulley combination makes the mover move several times the speed of the float, thereby realizing the function of speed increase. The increase of the mover speed increases the speed of the coil cutting the magnetic line of induction, thereby improving the power generation efficiency of the device.

2.2 Swing-plate wave making system

Figure 2. Swing-plate wave making system

To verify the effectiveness of the pulley-buoy accelerated wave energy linear power generation system, a swing-plate wave generation system was built under laboratory conditions, and the power generation performance of the system was evaluated by simulating wave motion. The swing-plate wave-making system is shown in Figure 2. The system is mainly composed of a motor drive control system, a motor drive system and a wave simulation system. The motor drive system mainly includes a crank connecting rod mechanism and an asynchronous AC motor, and the wave simulation system mainly includes a wave-making tank and a swing plate.

The basic parameters of the wave-making tank were set to $4\text{m} \times 1.2\text{m} \times 1.2\text{m}$, and the basic parameters of the swing plate were $1.5\text{m} \times 1.15\text{m} \times 0.03\text{m}$. The swing plate was set in the direction of the long side of the sink, 0.3m away from the side of the sink, and the lower end of the swing plate was hinged at the bottom of the water tank, which can swing back and forth around the fixed axis at the bottom. When the swing plate swings to the rear, it is perpendicular to the static water surface. A hinge point was arranged above the swing plate, which is connected with the crank connecting rod mechanism. The crank part of the crank connecting rod mechanism was fixedly connected with the rotating shaft of the driving motor. When the motor rotates, the crank is driven to make a circular motion, and the swing plate is driven to swing back and forth through the connecting rod to generate simulated waves. The length of the connecting rod connected with the swing plate can be changed by adjusting the bolt, as shown in Figure 2(a). There is long hole in the crank arm, and adjusting the fixed position of the connecting rod on the long hole on the crank arm can change the swing angle of the swing plate and generate simulated waves of different wave heights and wavelengths. When the connecting rod and the crank are

connected through the adjusting bolt in the hole A, the moving connecting rod has a longer length, the swing plate has a larger swing angle, and the generated waves have larger wavelengths and wave heights. When the connecting rod and the crank are connected through the adjusting bolt in the hole B, the swing plate has a smaller swing angle, and the generated wave has a smaller wavelength and wave height. The motor drive control system is equipped with a frequency converter. By adjusting the input frequency of the motor, the speed of the motor can be changed, and the motion cycle of the swing plate changes, then simulated waves of different cycles can be generated. A test point was set 2 m away from the swing plate along the long side of the water tank, and a wave height meter was installed at the middle of the short side of the water tank at the test point to measure the wave height. A transparent A_0 coordinate paper was posted on the front of the water tank at the test point, and a high-speed camera was set at a position parallel to the water surface directly in front of the water tank to capture the wave motion and measure the wave length and period.

3 Sink tests

During the test, the portal frame was moved to the top of the wave-making tank, and the buoy was connected to the movable pulley and placed in the tank. The main performance parameters such as voltage and current during the test were measured by a digital electrical parameter measuring instrument.

To explore the effects of different wave conditions and buoy sizes on the accelerated wave energy power generation system, three different wave conditions were simulated during the test, five spherical floats of different sizes were made and selected, and the power generation performance of the system was studied through comparative tests. The test steps are as follows:

1) Setting the number of ring magnets in the linear power generation system to 5, and the number of stator coils to 8;

2) Adjusting the bolt in the crank connecting rod mechanism to the position of hole B, and adjusting the inverter to make the motor speed 150rpm . In this case, the corresponding wave condition is recorded as the first wave condition (wavelet high wavelength, short wave period). Adjusting the adjusting bolt to the hole A, and still adjusting the motor speed to 150rpm . Thus, the corresponding wave condition is recorded as the second wave condition (large wave high wavelength, short wave period). The adjusting bolt is still in the hole A position. Adjusting the frequency converter to adjust the speed of the geared motor to 120 rpm . In this case, the corresponding wave condition is recorded as the third wave condition (large wave high wavelength, long wave period);

3) Putting spherical floats with diameters of 850 mm , 600 mm , 500 mm , 380 mm , and 310 mm (as shown in Figure 3) in the wave-making tank respectively, and conduct control tests of each buoy in three different wave conditions in turn, measuring and recording the current

and voltage of the linear power generation system after the system is operating stably, and calculating the power generation;

4) Comparing the power generation performance of the system under different test conditions, and exploring the influence of different wave conditions and buoy sizes on the power generation of the system.

Figure 3 Spherical floats of different sizes

In this experiment, under the condition that the number of ring magnets in the linear power generation system was 5 and the number of stator coils was 8, the comparative study of five spherical floats of different sizes under three different wave conditions has been completed. The diameters of the five different sizes of spherical floats were: 850 mm, 600 mm, 500 mm, 380 mm, and 310 mm. The three different wave conditions were-- Wave condition 1: small wave height and wavelength, short wave period; Wave condition 2: large wave height and wavelength, short wave period; Wave condition 3: large wave height and wavelength, long wave period. To qualitatively explain the influence of different wave conditions and buoy sizes on the power generation performance of the accelerated wave energy power generation system, the average power generation and peak value comparison of spherical floats of different sizes are shown in Figure 4. Comparing the power generation performance of spherical floats with diameters of 500 mm and 310 mm under optimal wave conditions (within the scope of this study, that is, wave conditions 2), it can be found that, under the conditions of large wave height and wavelength and short wave period, the peak power of a spherical buoy with a diameter of 500mm is increased by about 89.5% compared with a spherical buoy with a diameter of 300mm, and the average power is increased more obviously, about 130.6%. It shows that for the spherical buoy studied in this paper, under fixed wave conditions, increasing the buoy size to a certain extent can significantly improve the wave energy conversion efficiency and power generation performance of the accelerated wave energy power generation system.

Figure 4. Comparison of average power generation and peak value of spherical floats of different sizes

4 Conclusion

Aiming at the problem of low wave energy conversion efficiency of traditional direct-drive wave energy power generation systems, this paper proposed a new type of pulley-buoy accelerated wave energy linear power generation system. The oscillating buoy in the system was directly connected to the mover in the linear power generation system, which realized the direct extraction of electric energy from the movement of the buoy caused by the wave, omitting the intermediate energy transfer and conversion link, and the introduction of the pulley combination amplified the movement rate of the float. The rate at which the mover cuts the magnetic line of induction in the linear power generation system was increased several times, and the power generation of the linear power generation system was also increased, thereby achieving the purpose of improving the wave energy conversion efficiency of the system. To verify the feasibility and effectiveness of the pulley-buoy accelerated wave energy power generation system, a system prototype was made and a swing-plate wave-making system was built, and the system prototype was tested under laboratory conditions. The experimental results show that increasing the wave height, increasing the wavelength and shortening the wave period to a certain extent, and increasing the size of the buoy can effectively increase the wave energy conversion efficiency of the system and improve the power generation performance of the system. The experimental study verifies the feasibility and effectiveness of the pulley-buoy accelerated wave energy linear power generation system, and provides useful experience for the practical application and efficient operation of the wave energy power generation system.

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