Study on oscillation characteristics of a spar-buoy under Mathieu instability

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博士学位論文内容要旨
Abstract

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論文題目 Title	**Study on oscillation characteristics of a spar-buoy under Mathieu instability** マシュー不安定性におけるスパー型ブイの動揺特性に関する研究		

With the rapid development of human society, the demand for energy is growing rapidly. Energy is the foundation of economic development and a material guarantee for improving the quality of human life. Since the industrial revolution, the transitional consumption of traditional fossil energy has brought about energy shortages and environmental pollution. Since the first oil crisis in 1973, people have paid more and more attention to the development of renewable resources. For the sustainable development of human beings, it is of importance to adjust the energy structure and discovery of renewable energy. In recent years, renewable energy sources, such as wind energy and solar energy, have been put into much attention, and related applications have also been promoted. Although wave energy is another form of renewable and clean energy, it has not been widely promoted like wind and solar energy. Wave energy is potential energy with the advantages of no pollution and wide distribution. As an excellent renewable energy, ocean energy is inexhaustible. Marine energy accounts for about 70% of the global total energy. If fully utilized, it will greatly alleviate current energy shortages.

Due to its advantages, the high energy flux density, rarely limited by time, available to implement wave power for power generation and supply with smaller volume, wave energy has attracted more and more interest from scholars and researchers around the world. Waves energy extraction is achieved by using the device called Wave Energy Converters (WECs), which convert wave power into electricity. Over the last few decades, large number of WECs have been developed, tested and presented in publications. According to the working principle, the technologies could be classified into three main types: the oscillating water column, the over-topping and the oscillating bodies. One of the most typical oscillating bodies is point absorbers, which can harness incoming wave-energy from all directions with the normal function in most of the time and keep relatively small size and simple functional principles with relative lower cost.

WECs technologies are still in its infant stage, which naturally confronts this renewable energy converters with lots of challenges, problems and barriers during its maturation. To maximize the waves energy, the oscillation characteristics of the floating device, such as point absorbers, should be optimized to the most frequent waves at the local site. However, the bandwidth of the frequency response is relatively narrow, and the natural frequency is much higher than the typical ocean wave frequencies. Therefore, several methods of phase-control have been proposed and carried out. Meanwhile, it is well known that the spar-type platform shows extreme heave motion at resonance. Moreover, parametric resonance of the pitch motion has been confirmed. When the frequency of the heave motion is approximately twice the pitch natural frequency, the very large amplitude oscillatory motion will occur.

By changing the viewpoint, a new concept was proposed to utilize the Mathieu-type instability for WECs. A subject was carried out and limited to pure heave motion of a spar-buoy type point absorber and utilized the Mathieu-type instability by the dynamic buoyancy control system. However, it was also revealed that the efficiency was far from practical applications. As the improvement of the study, the subject was focused on a coupled motion of heave and pitch.

The research work of this thesis mainly consists of four parts, one part includes the experimental work and other three parts are the analysis work based on the experimental results. And the contents

are organized as follows:

In the first part, the experimental devices were designed and made. A ballast controlling system into the buoy was installed to change the natural frequency of the pitch motion. The free decay of buoy damping motion was carried out to make the buoy model satisfy the Mathieu instability condition (the natural frequency of heave is double the natural frequency of pitch motion). After that, the experiment was carried out with regular wave. Based on the experiment results, it is indicated that the large pitch motions occur suddenly and the heave amplitude shrinks just after the occurrence of larger pitch motion.

In the second part, it aims to investigate existence of the energy transform of the buoy motions. The signals of the heave acceleration were integrated with high pass filtering in the frequency domain and the vertical velocities and displacements of the buoy were calculated. Base on the integrated data and the original measured data, the kinetic and potential energy of heave and pitch motions were calculated. The energy transform of the buoy motions is discussed in time domain. The total energy takes the maximum value around 16s and the first half of the peak is dominated by the heave energy and the latter half is replaced by the pitch energy. Therefore, this can be concluded that the energy was transferred from the heave mode to the pitch mode and shrunken by the pitch damping. On the other hand, the power to be taken off is closely related to the total energy.

In the third part, in order to find some conditions in which the large pitch motion occurs suddenly by considering the theoretical condition of the Mathieu-type instability. The righting lever of the buoy model is calculated with assuming the free board is infinite. The relationship between the pitch angle and the righting lever under the Mathieu-type instability was theoretically discussed in the time domain. It was indicated that the experimental relationship between the pitch angle and the righting lever during the large pitching motions is similar to the theoretical characteristic of the Mathieu-type instability. The large pitch motion disappears just after the theoretical characteristic of the Mathieu-type instability is lost.

In the last Part, the occurrence of the large pitch motion is investigated by the stability chart of the Mathieu equation. The stability chart of Mathieu equation was plotted for the experiment with the method of the harmonic balance. It could be found that all the experimental results were in the unstable region before the large pitch motion disappeared, which inducing the Mathieu-type instability of pitch motion. Before the large pitch motion decayed, the stability results were in the stable region of the stability chart of Mathieu equation. It was shown that the large pitch motions disappeared (decayed) at the timing when the condition of the Mathieu-type instability is lost. It has been shown stability results returned to the unstable region, and large pitch motion occurred again after large pitch motion disappeared, which is induced by the condition of Mathieu instability.