論　文　の　要　旨

題　目　　Study on Energy Harvesting from Wave and Flow Energy Using Triboelectric Generator and Piezoelectric Generator

（摩擦発電と圧電発電を用いた波・流れエネルギーによるエネルギーハーベスティング技術に関する研究）

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The energy crisis has a significant impact on the economy, politics, and environment of both developed and developing countries. Therefore, utilization of renewable energy is one of the most promising methods to deal with the energy crisis. Considering the reliable, robust, and desirable characteristics of ocean energy, utilizing of it is one promising method. Among it, ocean wave and flow energy are ubiquitous. The aim of the thesis is to propose suitable wave and flow energy harvesting devices for isolated islands, sensors on fish aggregating device (FAD), and wave information monitoring for various weather environment and low-frequency wave conditions. This means structure of devices based on piezoelectric nanogenerators (PENGs)/triboelectric nanogenerators (TENGs), which are suitable medium for energy harvesting, should be designed to perform both sensing wave parameters and powering other sensors. To test and improve the efficiency of wave energy harvesting based on PENGs/TENGs, indoor and real-sea test experiments for optimization should be conducted and complete experimental process of optimization should be clarified. Simultaneously, when coupling wave with devices in numerical simulation, traditional grid methods often suffer from distortions due to the large motion. Therefore, suitable numerical algorithm needs to be selected to meet the challenges of the fluid-structure interaction. These can help us to predict the power generation of the developed devices. For flow energy harvesting with PENGs/TENGs, there are few numerical algorithms and mechanism about exploring the turbulent energy and flow control with local polymer coating. At the same time, previous numerical algorithms always choose the DNS method, demanding high spatial and temporal resolution. This approach proves computationally intensive, time-consuming, and heavily reliant on computer memory. Therefore, alternatives are needed when dealing with high Reynolds cases.

In the Chapter 2, to facilitate continuous and stable energy supply based on PENGs/TENGs for both FAD equipment and islands, we design a flexible piezoelectric device (FPED) based on PENGs used for ocean energy harvesting. Our approach involves the development of FPEDs coated with piezoelectric paint spray technology. Simultaneously, hemi-spherically spring origami triboelectric nanogenerators (HSO-TENGs) designed for self-powered ocean wave monitoring are developed based on TENGs technology.

In the Chapter 3, FPEDs are attached to the frame of a FAD to assess their performance characteristics in varying submerged depths and support types. Through examination under various wave conditions, we've identified the key parameters significantly impacting electrical performance. The maximum output voltage

can be increased obviously with cantilever support, fully submerged depths, thickness 50 μm, and aspect ratio 1:2. Utilizing the experimental setup as a basis, we construct a theoretical model and further refine a computational model employing the immersed boundary method to analyze FPED-wave interactions. The latter is found to be a better predictor of power generation from FPEDs than the former. In addition, a field test conducted in real sea conditions, supported by a remote data monitoring system for the painted FPEDs, demonstrate exceptional performance even under extreme bending, weathering, and fatigue.

In the Chapter 4, HSO-TENGs are designed for self-powered ocean wave monitoring, driven by two optimization approaches. (1) Swing machine experiments are employed to assess the HSO-TENGs' monitoring capabilities concerning wave height and period, showing satisfactory accuracy. Three structural parameters, the weight of magnet mass, the height of the hammer, and the length of the external swing arm, are found to increase average voltage generation by 33%, 62%, and 50%. (2) Numerical simulations utilizing the smoothed particle hydrodynamics (SPH) method can find the most suitable fixed condition for HSO-TENGs to effectively sense wave changes. Then, no-submergence that can fully compress and stretch SO-TENGs is selected from three fixed conditions. Subsequent wave tank experiments aim to evaluate their proficiency in detecting wave height, period, frequency, and direction. The maximum voltage can reach 15v. When the four spring origami triboelectric nanogenerators (SO-TENGs) are connected in parallel, the output voltage can supply the temperature and humidity sensor continually. Finally, we investigate the HSO-TENG's ability to monitor wave direction and spreading parameters through numerical SPH circular wave tank simulations. And the SPH method is found to simulate the motion of HSO-TENG and similar energy harvesting devices in waves well, thereby guiding device design and predicting device performance.

In the Chapter 5, we develop a novel numerical model to control turbulent flow filed and drag reduction performance with polymer coating. This model merges mesoscopic methods with computational fluid dynamics (CFD) techniques, addressing the underexplored area of non-uniform polymer drag reduction in external flows. This model integrates direct numerical simulation (DNS) and large eddy simulation (LES) methods within the CFD framework. Both of them are in good agreement with the previous reference results, which proves the reliability of the model, Our approach initially couples the mesoscopic dissipative particle dynamics (DPD) method with DNS and LES methods, validating the results through the finitely extensible nonlinear elastic approach. Subsequently, we utilize the model to discuss the impact of varying polymer region heights on non-uniform polymer drag reduction. Particularly noteworthy is the efficiency highlighted by the LES method, offering computational efficiency, especially at higher Reynolds numbers. Then, the mean velocity, the root-mean-square velocity fluctuations and the Reynolds shear stress presents a monotonous trend to the particle energy density. Furthermore, releasing polymer particles close to the wall is also found to achieve drag reduction, and the drag reduction efficiency of releasing polymer particles in half of the region is very high. The new vortex grows again above the polymer region. Our model illuminates that significant polymer drag reduction efficiency persists even when the polymer region doesn't span the entire fluid area, as observed in conditions like the application of polymer coatings. And high energy dissipation gradually changes from dispersion to concentration during the process of the drag reduction. Lastly, for different Reynolds numbers, the model can be widely used and has a good prospect.