論 文 要 旨

Study on Power Generating System for Dielectric Elastomers driven by Karman Vortex Street

カルマン渦列により駆動する誘電エラストマーを用いた発電システムに関する研究

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While the demand for electric energy has been growing due to population increase and improvement in living standards, power generations utilizing renewable energy are in the spotlight nowadays because of their impacts to global warming and considerations of nuclear accidents and so forth. Hydropower generation is the conventional method of producing electricity from renewable energy sources. Since large-scale hydroelectricity requires the construction of dams that cause environmental damages, the development of smaller-scale hydroelectricity has recently been anticipated. Conventional electric generators using electromagnetic induction, however, may not be suitable to down-scaling. These electric generators tend to operate most efficiently in a narrow range of high frequencies. Accordingly, electricity generation systems by electric generators using electromagnetic induction include a mechanical or hydraulic transmission, resulting in more complex and larger systems.

Dielectric elastomers (DEs) are one of the most promising artificial muscles and a new transducer technology that is capable of converting mechanical energy into electrical energy. Compared to conventional power generators using electromagnetic induction or piezoelectric effect, generators using dielectric elastomers have high energy density and can efficiently produce electricity at low frequency.

In this study, we proposed a small-scale power generating system for dielectric elastomers driven by Karman vortex street which are present in the wake of a cylinder. This system extracts mechanical energy from fluid energy using the vibration of a wing which is set in the Karman vortex street in response to hydrodynamic force. The mechanical energy is transmitted to a DE generator through a shaft and subsequently converted into electrical energy. In order to investigate the power generating performance and feasibility of the proposed system, the experimental model was fabricated and tested in a small circulating water channel. Furthermore, CFD analysis on the model of the present hydropower system was conducted to estimate the power generation performance in a wide range of parameters.

As the first step, we fabricated and tested an experimental model of the proposed system to investigate its feasibility and power generating performance. From the experimental results, we obtained the following conclusions: The power generating system for the generators using dielectric elastomers with 8 cm diameter can be driven well by the Karman vortices in a water flow; we have to select the diameter of the cylinder and the size of the wing corresponding to the fluid velocity in order to obtain high efficiency of this system; the maximum energy efficiency is about 43% in the present system, when the water velocity is 0.4 m/s, the cylinder diameter is 48 mm and the distance between the cylinder and the wing is 170 mm; the maximum average electric power of approximately 16 mW is verified with a generation efficiency of about 36%, when the span and chord length of the wing are 120 mm and 30 mm, respectively, the diameter of the cylinder is 60 mm, the distance between the cylinder and the wing is 170 mm, and the velocity of the water flow is 0.5 m/s.

Secondly, we focused on the oscillation of the wing that is directly associated with the generation performance in the proposed system. The drive characteristics of the wing and the flow fields around the wing were measured in a small circulating water channel. The measuring results show that the wing vibration frequency agrees very well with the vortex shedding frequency, the wing oscillation amplitude becomes largest, i.e., the resonance amplitude, at a reduced velocity of approximately 5, and vortices which drive the wing are not fully developed near the cylinder owing to a dead water region.

Two-dimensional CFD analysis was carried out for the small hydropower generation system proposed in this study to evaluate its generation performance in a wide range of parameters. The wing oscillations behind a circular cylinder which generates Karman vortices were simulated and the results were compared with the experimental data. Although the computational results show that the frequency of wing oscillation tends to be approximately 15% larger than the experimental results, the simulation result of a flow pattern corresponds well to the experiment when the oscillation amplitude of the CFD result is close to the resonance amplitude of the experiment. Therefore, by improving the accuracy of simulation (such as three-dimensional simulation), we can expect that the power generation performance of the system is predicted well by CFD.

We presented the characteristics of the power generating system for dielectric elastomers driven by Karman vortex street and estimated its electric power generation in this study. The proposed system consists of a simple structure and can be expected to be used at various locations in the future.