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Experimental energy harvesting from fluid flow by using two vibrating masses

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A B S T R A C T

In this study, an experiment was performed to determine how the addition of a second degree of freedom to a vibratory system affects its energy extraction from a surrounding fluid flow. A circular cylinder was submerged underwater and subjected to flow, and another cylinder mounted on springs was inserted between the submerged cylinder and a generator. The experiment results demonstrated that vortex-induced vibration occurred at frequencies that were locked-in to the first and second natural modes for reduced velocity ranges of 5.0–9.0 and greater than 12.0, respectively. The output voltages were particularly high when the vibration frequency was locked-in to that of the second natural mode. It was found that application of energy extraction using a system with two degrees of freedom can widen the range of reduced velocity within which power extraction is effective.

1. Introduction

Harnessing of renewable energy from fluid flow has been widely examined by researchers in the past. Most of these studies considered extracting flow energy by using a turbine rotated by fluid forces acting on its blades. Another mechanism for extracting fluid flow energy is flow-induced vibration of a slender body (e.g., [1–5]), which is generated by periodic vortex-induced forces acting on the body. Vibratory extraction is now attracting less attention from researchers than is extraction using turbines, because the technology of generators well-suited to vibratory devices is immature. The rotation of a turbine directly drives the rotation of a generator (rotation–rotation transmission), which results in the generation of electrical energy through electromagnetic induction. This type of power transmission has already been established, and it is widely employed in generators in thermal, nuclear, and wind power plants. In contrast, the body motion produced by flow-induced vibration is essentially translational, but no method has yet been developed for combining it with a rotational generator, because this would require transduction of motion from translation to rotation, which would make the structure complicated.

A power transmission device that is installed in very severe environments such as underwater and that is expected to serve as an energy harvester in such conditions for long periods should have a simple structure to prevent problems during operation. In this regard, an approach of combining the translational motion of the body with the translational motion of a linear-type generator has sufficient potential to provide renewable energy continuously. Nevertheless, this topic has rarely

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been studied to date, and there is considerable scope for research in this direction. To develop a renewable energy system using flow-induced vibration that exploits these advantages, we must address the technical issue of how to connect the vibration of a body to a generator.

With the aim of offering a solution to this issue, the present study attempts to insert a moving body between a submerged body experiencing vortex-induced vibration (VIV) and a generator. The typical VIV response of a vibratory system with one degree of freedom (1DOF), such as a rigid circular cylinder mounted on springs, is observed in the form of large amplitudes that are close to the diameter of the cylinder at reduced velocities of 5.0–9.0 (e.g., [6–9]). The VIV response disappears at higher reduced velocities because the vortex shedding frequency is no longer locked-in to the natural frequency of the system.

According to vibration mechanics, a vibratory system with two degrees of freedom (2DOF) has two natural frequencies [10]. The natural frequency of the first mode is lower, and that of the second mode is higher. Thus, we infer that the presence of the second-mode natural frequency forces the vortex shedding frequency to be locked-in to it at reduced velocities exceeding 9.0. Frequency lock-in to both the first and the second natural modes can result in widening of the flow velocity range within which remarkable VIV occurs. Zhu et al. [11], Tang and Zuo [12], Nishi [13], and Xiao et al. [14] analytically investigated the performance of a vibratory system with 2DOF for energy harvesting, and they reported that the 2DOF system has high potential to offer more energy than do 1DOF systems. However, most of these works did not consider the systems that were excited by flow. The potential of a 2DOF system for harnessing renewable energy has scarcely been confirmed experimentally.

The higher frequency of the second natural mode seems to produce a higher frequency of vibration, which would possibly yield larger outputs of harnessed energy. The purpose of this study is to experimentally confirm this possibility.

2. Experimental method

2.1. Experimental setup

In the experimental setup used in this study, two movable circular cylinders were mounted on springs (Fig. 1). One of them (cylinder A) was positioned underwater so that it would be subjected to fluid flows, and it was supported by a spring

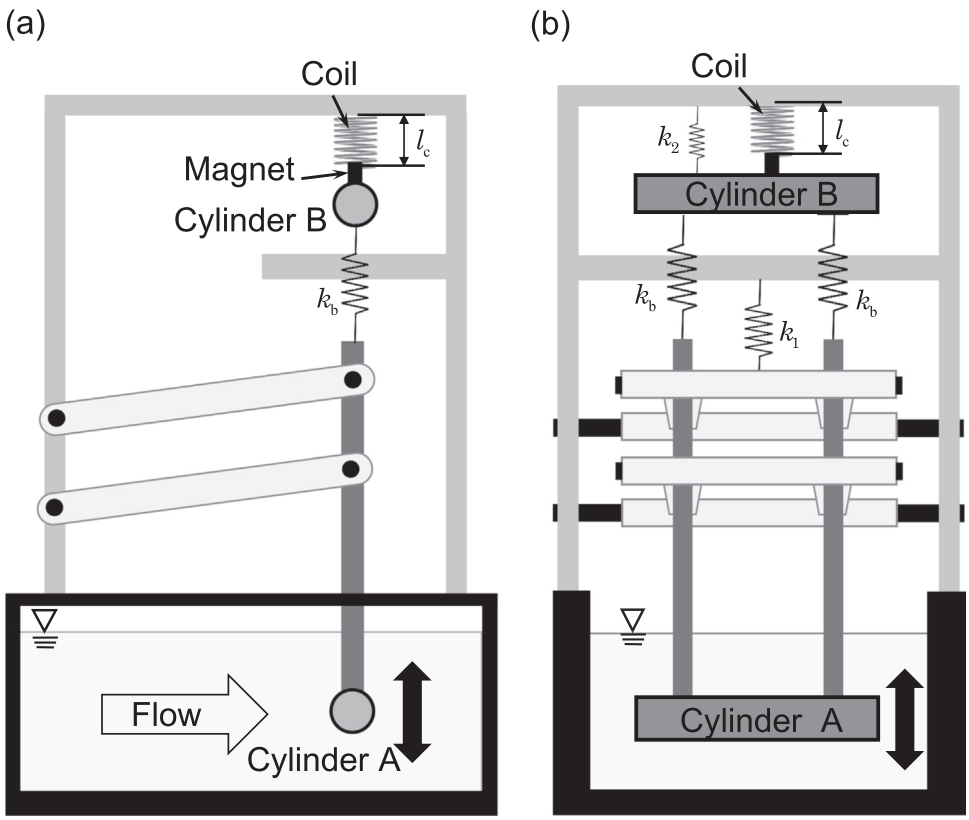

Fig. 1. Schematic illustrations of experimental setup installed in circulating water channel. Spring stiffness and coil length are indicated in the figure. (a) Side view; (b) front view.

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