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SMALL-SCALE WIND ENERGY HARVESTING FROM FLOW-INDUCED VIBRATIONS

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ABSTRACT

Significant wind energy exists in the boundary layers around naturally occurring and manmade structures. This energy source has remained largely untapped, even though it presents a significant source of energy for powering wireless devices in built-up areas. This paper discusses a study on harnessing energy from piezoelectric transducers by using bluff body and vortex-induced vibration phenomena induced by low-speed flows. The proposed devices are miniature, scalable, aeroelastic wind harvesters designed for extracting turbulent, low-speed wind energy from the boundary layers around structures. The design configuration consists of a bluff body with a flexible piezoelectric cantilever attached to the trailing edge. In this design, transverse vibrations are induced in the piezoelectric members by alternating vortex shedding. The multi-physics software package COMSOL is used for coupled simulation of the fluid and structural domains, and Matlab is used to couple the structural deformations to the attached power harvesting circuitry. The design and environmental parameters are varied to optimize the configuration and to identify the significant parameters in the design. The lock-in phenomenon, in which the vortex shedding frequency is entrained to the fundamental structural frequency, is exploited to achieve resonance over a range of flow velocities, thus increasing the velocity "bandwidth" of the devices. Simulations are run for different characteristic dimensions or shapes for the bluff body to study the strength and nature of vortex shedding in the presence of vibrating beam sections. The results of parameter variation for the design configuration is presented and discussed with regard to broadband wind energy harvesting.

INTRODUCTION

Cylindrical bluff-bodies, triangular bluff-bodies etc. shed vortices in a subsonic flow. The vortex street wakes tend to be very similar with the same periodicity regardless of the geometry of the structure [1]. The earliest discovery of Vortex-Induced Vibration (VIV) was when Leonardo da Vinci first observed wind-induced vibrations in 1504 AD in the form of "Aeolian Tones" from the taut wires of an Aeolian harp. The vibrations induced in elastic structures by vortex shedding are of practical importance because of their potentially destructive effect on bridges, stacks, towers, offshore pipelines, and heat exchangers. This paper discusses how these non-linear vibrations can be used to harness energy by mounting piezoelectric bimorphs on the vibrating structures. This stored energy can be used to power densely populated wireless sensor nodes in urban environments.

Vortex-induced vibration phenomena have been studied extensively by various researchers since the collapse of the historical Tacoma Narrows Bridge. The phenomenon of periodic vortex shedding occurs when a flowing fluid is unable to negotiate its way smoothly around a bluff object [2]. Hall studied this VIV phenomenon using a semi-empirical modeling approach that includes extensive study of harmonically forced cylinders, spring-mounted cylinders, and taut elastic cables. Sarpkaya and Blevins studied vortex-induced oscillations in a few specific fundamental cases such as vortex shedding from a stationary bluff body; furthermore, they investigated the consequences of the lock-in phenomena, added mass, damping, and dynamic response measurements [1-3]. All these factors together are salient to studying our model. Lock-in occurs when the vibrating structure oscillates at the same frequency as the undistributed wake behind the bluff-body. This phenomenon helps in understanding the range of maximum amplitude for our design. The added mass factor is used to measure the susceptibility of lightweight structures to flow-induced vibrations. Dynamic response measurements help us understand the change in the motion of the beam to changes in a fluid flow. The displacement amplitude, frequency response etc. helps us in defining whether the system changes with respect to fluid flow changes.

Whenever a stationary bluff object is immersed in a flowing medium, driving oscillating forces called the von Kármán vortex streets are generated on either ends of the bluff-body. These oscillating forces can mechanically strain piezoelectric cantilever beams attached to the bluff-body and produce electricity. Out of the three basic vibration-to-electric energy conversion mechanisms, namely electromagnetic, electrostatic and piezoelectric transductions, the latter has gained importance in the past decade for its high energy density,

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