DESIGN CONSIDERATIONS FOR SMALL-SCALE WIND ENERGY HARVESTERS DRIVEN BY BROADBAND VORTEX-INDUCED VIBRATIONS

Benjamin Paxson*[a] and Adam M. Wickenheiser[a]
[a]Department of Mechanical & Aerospace Engineering,
The George Washington University, Washington, District of Columbia, 20052, USA

ABSTRACT

In recent years, an increasing number of breakthroughs have been made in the field of small-scale wind energy harvesting, where specialized materials are utilized to convert flow energy into electric power. Several studies on this power extraction rely on a common energy harvester setup in which a stiff cantilever beam is attached to the trailing edge of a miniature bluff body. At these small scales where boundary layer effects are appreciable in the laminar flow regime, periodic vortex shedding can be used to drive transverse vibrations in the beam. Interestingly, the fluid dynamics involved in this unsteady process have been studied for decades not to exploit their characteristics, but instead to eliminate potentially destructive effects. As a result, there is still much room for improvement and expansion on recent design studies. A study of how subtle changes in bluff body trailing edge geometry effect power output of a model will be presented in this paper. The model under consideration consists of a miniature bluff body on the order of tens of millimeters in diameter, to which a piezoelectric cantilever is attached at the trailing edge. This model is specifically designed for laminar to transitional Reynolds Number flows (500−2800) where the periodicity of vortex shedding approaches the natural frequency of the beam. As the flow speed is further increased, the effect of lock-in occurs where the resonant beam motion resists a change in vortex shedding frequency. Vibration amplitudes of the beam reach a maximum under this condition, thus maximizing power generation efficiency of the system and providing an optimal condition to operate the harvester. In an effort to meaningfully compare the results, a number of dimensionless parameters are employed. The influence of parameters such as beam length and natural frequency, fluid flow speed, and trailing edge geometry are studied utilizing COMSOL Multiphysics laminar, fluid-structure interaction simulations in order to create design guidelines for an improved energy harvester.

Keywords: vortex-induced vibration, energy harvesting, von Kármán vortex streets

1. INTRODUCTION

Studies on small-scale energy harvesting have been steadily gaining traction over the past decade. As electrical nodes in urban settings become increasingly overcrowded and difficult to access, more effort has been made to find economical alternatives to wasteful circuit wiring and expensive battery replacements required for many low-power devices. Although several methods of energy harvesting exist, a majority of research in the field explores the potential of exploiting structural vibration energy driven by a steady-state base excitation [1-2]. Mechanical strains associated with these vibrations can generate meaningful levels of electric energy through the use of piezoelectric transducers.

Generally, these harvesters are tuned to vibrate at resonance under normal operating conditions. Therefore, any deviation in vibration input frequency results in a significant decrease in power production. For an environment that regularly experiences fluctuations in input frequencies, implementing a broadband energy harvester results in a higher average power output compared to a standard harvester design. Such devices require special design considerations as outlined by Wickenheiser, *et al.* [3], where a study is conducted on the optimization of power harvesters for use on broadband vibrations seen in motor vehicles and walking motions. Broadband energy harvesters have also proven useful in other unsteady environments such as those exposed to wind. Design considerations for these harvesters are inherently different than those exposed to purely mechanical vibrations though, as they rely on complex fluid-structure interactions to generate power. In a review of recent advancements of fluid flow energy harvesting, Sarpkaya notes that the nonlinear behaviors associated with these harvesters pose significant design challenges for broadband energy extraction [4]. The non-linear behavior of power harvesting in

Active and Passive Smart Structures and Integrated Systems 2014, edited
by Wei-Hsin Liao, Proc. of SPIE Vol. 9057, 90571K · © 2014 SPIE
CCC code: 0277-786X/14/$18 · doi: 10.1117/12.2046344