Energy Harvesting from Fluttering Membranes

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ABSTRACT

Vibration energy harvesting using piezoelectric generators have been preferred due to the higher power output. Such low power generated can be successfully used to power wireless sensors nodes while extracting energy from environmental sources. Machine vibrations have been typically chosen for this endeavor, but recently fluid flow energy harvesting induced are being investigated. This research focuses on study of the self-sustained oscillations (panel flutter) for energy generation with the use of flexible piezoelectric materials (MFC) with a thickness of 9 µm attached to a thin Mylar. Wind speeds a low as 7 mph can produce an open-circuit of 0.85 volt.

Keywords: Fluttering Membranes, Energy Harvesting, Piezoelectric Generation

1. INTRODUCTION

In the past decade studies have been focused on small energy harvesting devices using ambient vibrations and piezoelectric energy. These energy generators have a number of military and civil applications since they are self-powered, can be used in remote locations, and require almost no maintenance. From all available ambient energy harvesting sources, vibration-based power generation is found to produce the higher power output (Roundy, 2005). When considering applications for energy vibrating sources, several transduction technologies can be employed, such as electrostatic, electromagnetic, and piezoelectric generation. Among all these methods, piezoelectric conversion is preferred considering the higher power density (Erturk, 2009).

Most researchers have considered ambient structural vibrations for this task, but lately continuous source of energy from flowing fluids using different mechanisms. A number of investigators have used the aeroelastic flutter vibrations and the self-sustained oscillations due to the unsteady pressure field created by the Karman Vortices shed behind a bluff body. Piezoelectric strips oscillating, due to the Karman vortices shed behind a bluff body is used to harvest energy by Taylor et al. (2001). They use bimorphs to extract energy from flowing water. Allen and Smith (2001) and Pobering et al. (2009) using flexible piezoelectric membranes excited by the Karman vortices behind a bluff body has investigated the possibility for power generation using a water tunnel. Robbins et al. have used thin membranes composed of piezoelectric elements flapping in wind. Generation of energy using bending-torsion flutter in a cantilever beam using piezoelectric material is demonstrated by Erturk et. al.(2010). Kwon (2010) has used a T-shaped cantilever with attached piezoceramic patched under air flow for generating electric powder. An aeroelastic flutter energy harvester using a cantilevered piezoelectric beam connected to a flap at the free end is proposed by Brtant and Garcia (2011) Flutter of a thin membrane for wind energy extraction using flexible piezoelectric films is discussed in this work.

The surface of a thin membrane in fluid flow is subjected to in-plane tension and aerodynamic forces normal to the membrane. When the flow velocity is increased beyond a critical value, called the onset flutter speed, the membrane exhibits self-sustained oscillations (panel flutter). At velocities below this critical speed a membrane does not undulate. Heavy waving on thin membranes is related to high strains for piezoelectric materials. Since piezoelectric materials require being under strain in order to generate a charge, it is desirable that the critical wind velocity is as low as possible for energy generation.

2. EXPERIMENTAL SETUP

Experimental investigation was conducted to determine the effect of onset and higher flutter speed with (i) the aspect ratio (length/width) of the membrane, (ii) the effect of fins attached at the downstream end of the membrane, and (iii) to determine the relation between the output voltage and the flow speed. The experiments were performed in a low speed suction type wind tunnel with a test section of 8” x 8” and with a length of 24”. The tunnel has a maximum speed of 29 mph. Modifications were made in the tunnel to test the effect of diverging channels on flutter speed and the cut-in speed. Mylar membranes with a thickness 9 µm (0.004”) and aspect ratios of 1.5, and 2 were tested. Thin 7.5”x5” piezoelectric film with a thickness of 9µm was used. In a typical experiment, the tunnel speed was increased gradually till it reaches the onset flutter speed at which the membrane starts to flutter. Subsequently the tunnel velocity was increased till a measurable voltage was obtained.

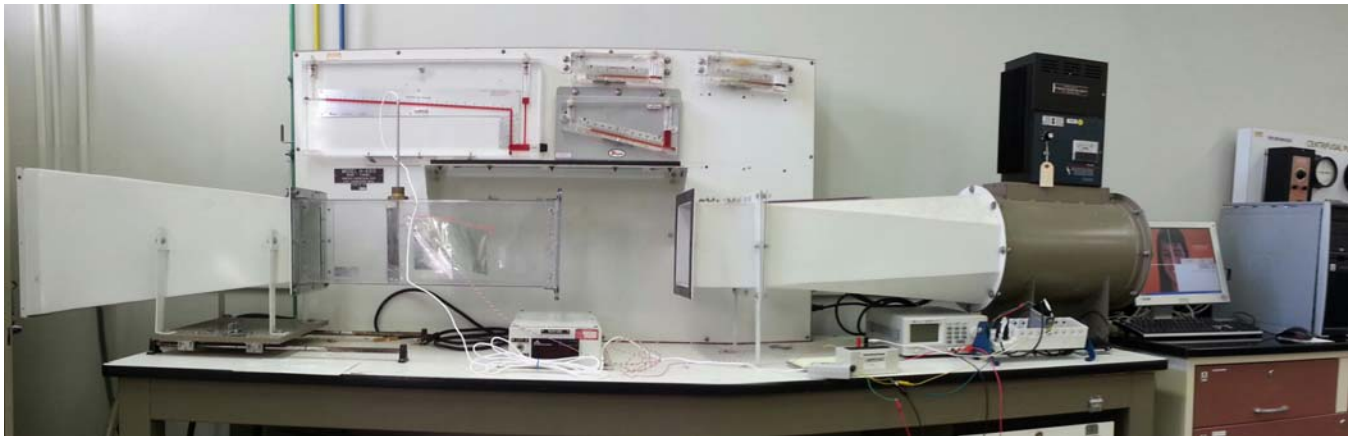

Figure 1. Wind Tunnel Setup

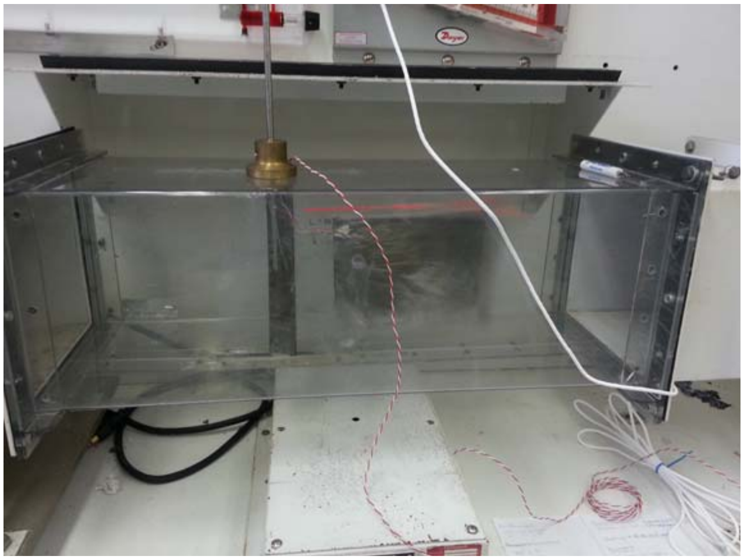

Figure 2. Test Section

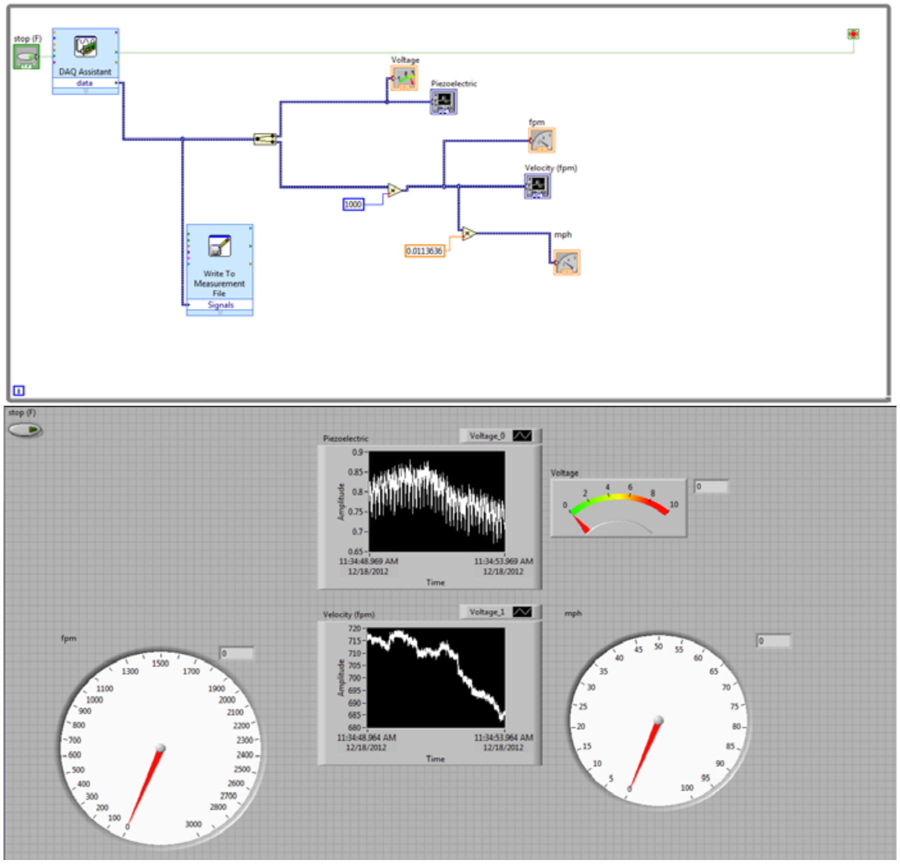

Figure 3. LabVIEW Program

3. EXPERIMENTAL RESULTS

Figure 2 shows the open-circuit voltage variation with wind tunnel speed for an aspect ratio of 1.5. The membrane flutter starts at 3 mph and the voltage increases with the flow velocity. The maximum open- circuit voltage is reached at the tunnel speed of 5 mph. The effect of fins attached at the downstream end of the membrane is shown in fig 3. The fins with 1-inch width have no effect in the open- circuit voltage. Increasing the aspect ratio also has no effect on the measured open-circuit voltage.(fig 4). The experiment shows the effectiveness of thin piezoelectric membranes in harvesting energy for fluttering membranes.

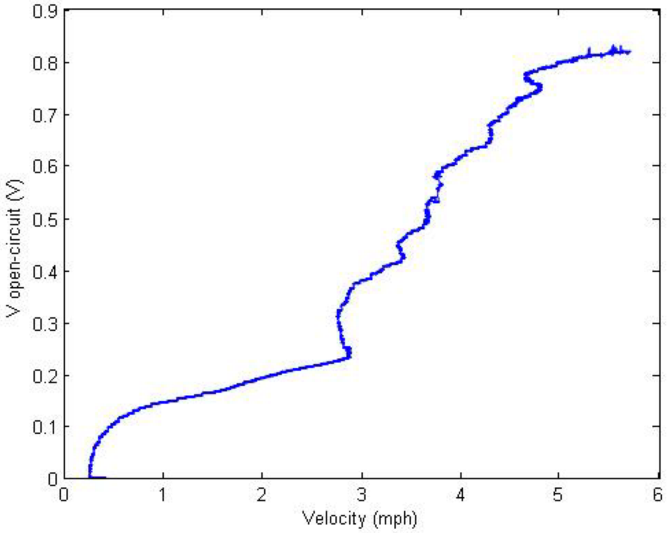

Figure 4. The variation of Open-circuit voltage with flow velocity (for aspect ratio 1)

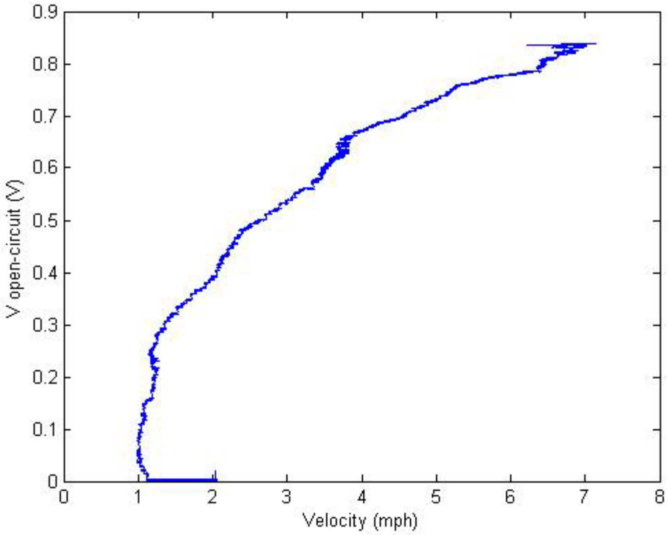

Figure 5. The variation of open-circuit voltage with flow velocity with fins

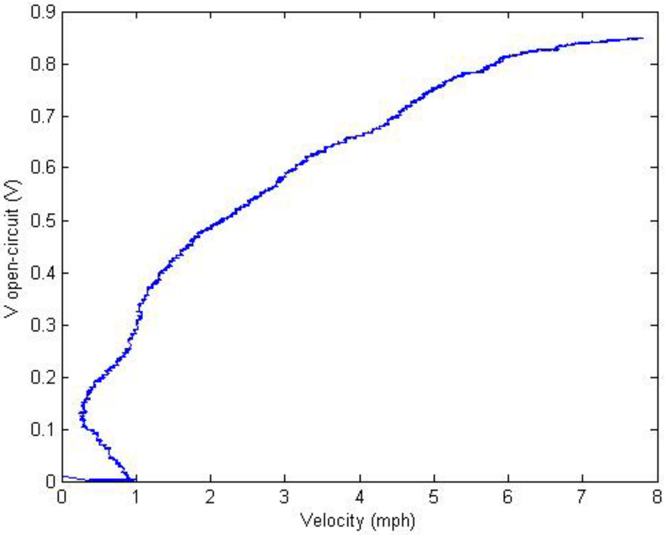

Figure 6. Variation of open-circuit voltage with flow velocity (for aspect ratio 2)

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