A NOVEL POSTBUCKLING-BASED MECHANICAL ENERGY TRANSDUCER AND ITS APPLICATIONS FOR STRUCTURAL HEALTH MONITORING

By
Pengcheng Jiao
Advisor: Dr. Nizar Lajnef
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3540 Engineering Building

ABSTRACT
In recent years, significant research efforts have been dedicated to developing self-powered wireless sensors without the limit of battery lifetime, such that those sensors can be deployed to continuously monitor structural conditions and detect potential failures for Structural Health Monitoring (SHM). In order to overcome the energy bound, a mechanism has recently been developed to harvest electrical power at very low frequency (< 1 Hz) using mechanical energy concentrators and triggers. This technique is based on the snap-through between different buckling mode transitions of bilaterally constrained beams subjected to quasi-static loads. Attaching piezoelectric transducers to the buckled beams, electrical power can be generated by converting the static excitations into localized dynamic motions. However, the efficiency of the energy solution, i.e., generating maximum electrical power at every buckling mode transition, significantly depends on tuning the post-buckling behavior of the beam systems. Inadequate controlling over the mechanical response critically impedes the application of the device. Therefore, it is of research and practice interests to effectively predict and tune the post-buckling performance of the bilaterally confined beam systems.

This study presents a well-tuned mechanism for energy harvesting and damage sensing under quasi-static excitations. To optimize the harvesting efficiency and sensing accuracy of the proposed technique, the post-buckling behavior of the structural instability-induced systems are
theoretically and experimentally predicted and controlled. The work conducted in this study can be drawn as follows:

- A theoretical model is developed using small deformation theory. Non-prismatic beam systems are investigated with respect to beam shape configuration and geometry property. Piezoelectric scavengers with different natural frequencies are then used to convert the high-rate motions at buckling transitions into electrical power. Experiments were conducted to inspect the generated electrical power using the non-uniform beams. Maximum energy, which cannot be obtained by using uniform beams, is obtained at each buckling mode transition based on the optimal design of non-prismatic beam systems.

- A theoretical model is developed to capture the buckling snap-through events using large deformation assumptions. The model examines the static and dynamic instabilities of bilaterally confined beams subjected to different types of axial loads. Experiments were carried out to compare the theoretical and experimental results with respect to force-displacement relationship and beam deflected configuration. Satisfactory agreements are obtained to demonstrate the accuracy of the presented model.

- A parametric study is carried out to identify the overlap and difference between the small and large deformation models. Bilateral constraints are then varied to examine the effect of confinements on the presented mechanism. Three types of side-walls are specifically investigated, i.e., irregular, movable and flexible. Experimental studies were proposed to validate the theoretical predictions. Finally, the large deformation model is deployed as an indicator in civil infrastructures for SHM. The electrical signals created at buckling snap-through events denote the corresponding strains/deformations that a structure undergoes and, therefore, the presented mechanism sufficiently indicate critical limit states.