Nonlinear Electromechanical Conversion and Sensory Response of Multi-Stable Piezoelectric Shallow Shells with Piezoelectric Films

Varelis D.*, and Saravanos D. A.†

* Department of Aeronautical Sciences
Hellenic Air Force Academy (HAFA)
Dekelia Air Force Base, Dekelia-Attiki 1010, Greece
e-mail: dimitrios.varelis@hafa.haf.gr

† Department of Mechanical Engineering & Aeronautics (MEAD)
University of Patras
Patras 26500, Greece
e-mail: dsaravanos@upatras.gr

ABSTRACT

Shallow shell structures under external transverse loads, exhibit a complex nonlinear multi-stable behavior, manifested as instantaneous snap through instability, which transitions the shell between two stable equilibrium configurations via an unstable equilibrium state, that is associated with large deflections and shape changes.

While the multi-stable response of shallow shells with piezoelectric actuators has been received reasonable attention, the nonlinear electromechanical conversion and the associated electric charge generation and free electrical response of attached piezoelectric films has not been studied. In fact, it seems that efficient electromechanical energy conversion may be achieved during the transition between equilibrium states of a piezoelectric shallow shell, making over the latter promising subsystems for energy harvesting and or dissipation applications. Moreover, it is highly desirable to detect the onset of snap-through instability through the monitoring on sensory voltages. The sensor signals describing the local response of piezoelectric sensor patch and eventually the global structural multi-stable response of smart shallow shells must be thoroughly modelled and understood.

The present work revisits and extends a previous theoretical and computational framework developed the authors to addresses the previous open research issues by focusing on the nonlinear electromechanical response of shallow cylindrical laminated shells encompassing piezoelectric films subject to free electrical conditions, undergoing elastic instability and a transition between at least two stable equilibrium paths. The computational framework is based on nonlinear mechanics, incorporating full coupling between mechanical and electric fields and encompassing geometric nonlinearity effects due to large displacements and rotations. The governing equations are formulated explicitly in orthogonal curvilinear coordinates and are combined with the kinematic assumptions of a multi-field shear-layerwise shell laminate theory. A finite element methodology is adopted to represent the nonlinear governing equations in discrete coupled equations of motion which are incrementally/iteratively solved, using the Cylindrical Arc Length Method in combination with the Newton-Raphson iterative technique.

Validation and evaluation cases on laminated cylindrical strips and panels subject to transverse mechanical loads, demonstrate the robust capability of the method to predict the complex sensory electromechanical response of shallow cylindrical shells that transit between two stable equilibrium states. At the same time the generated electrical charge and the stored electric energy in the piezoelectric film during the nonlinear bistable loading and unloading paths is predicted. The feasibility to detect and monitor the onset of snap-trough instability, and to enhance the electromechanical energy conversion efficiency of the system for improved energy dissipation/harvesting systems, is also investigated. The influence of shell thickness, curvature and laminate configuration on the electromechanical conversion is finally investigated.