Finite element analysis on the nonlinear oscillation of dielectric elastomer actuator under parametric excitation

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Abstract

Recently, dielectric elastomer based actuators have received considerable interest not only in the adaptive structures requiring large shape conformability but also in the dynamic fields, such as loud speakers, energy harvesting and active noise control systems. Although systematic theory has been built to explain various quasi-static behaviors of dielectric elastomer actuators (large deformation, wrinkle and crease), dynamic analysis is still limited to several simple structures. Powerful but convenient computational tool is anticipated to investigate the resonance frequencies and optimize the electrically induced response. This study presents a numerical method with commercial finite element package to analysis the vibration characteristics of dielectric elastomer actuator. When subject to alternating voltage, electrostatic force reduces dielectric's size along the electric field direction and expands the area in the orthogonal plane. For modeling the other electroactive polymer, piezoelectric material, the applied electric field is not influenced by deformation due to the small size change. However, the deformation of dielectric elastomer leads to the increase of electric field and correspondingly strengthens the force, which in turn affects the mechanical deformation until a stable equilibrium is reached. Here, an electro-mechanical fully coupled dynamic model is derived according to the non-linear field theory of dielectric elastomer. The influence of compliant electrodes on the deformation is neglected and the material is treated as electrically linear. Accordingly, the electric excitation appears as the inhomogeneous item of the motion equations, which is different from piezoelectric one only with homogeneous item. Moreover, due to the quadratic dependence of electric stimuli and the hyperelastic constitution, the dynamic model shows strong non-linearity, hard to be analytically solved. With the weak form of motion equation, numerical analysis of the oscillating dielectric elastomer actuator, a parametrically excited system, is implemented in COMSOL. Based on the proposed finite element method, the resonance and time response of an edge-clamped planar dielectric elastomer is calculated. Besides the fundamental response and super harmonic, it is interesting to find sub-harmonic response appears. The response time and frequency response function is derived. And the influence of system parameters including the damping coefficient and excitation voltage on the oscillation is investigated. The proposed finite element method is very convenient and user-friendly, especially for the potential users without computation background. It is expected that the approach may promote the application of DEAs by helping design more complex DEAs.

Keywords: finite element method, dielectric elastomer actuator, hyperelasticity, nonlinear oscillation, parametric excitation