Prismatic Bifurcation Study of a Functionally Graded Dielectric Elastomeric Tube Using Linearized Incremental Theory of Deformations

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Abstract : In recent times, functionally graded dielectric elastomer (FGDE) has gained significant attention within the realm of soft actuation due to its dual capacity to exert highly localized stresses while maintaining its compliant characteristics on application of electro-mechanical loading. Nevertheless, the full potential of dielectric elastomer (DE) has not been fully explored due to their susceptibility to instabilities when subjected to electro-mechanical loads. As a result, study and analysis of such instabilities becomes crucial for the design and realization of dielectric actuators. Prismatic bifurcation is a type of instability that has been recognized in a DE tube. Though several studies have reported on the analysis for prismatic bifurcation in an isotropic DE tube, there is an insufficiency in studies related to prismatic bifurcation of FGDE tubes. Therefore, this paper aims to determine the onset of prismatic bifurcations on an incompressible FGDE tube when subjected to electrical loading across the thickness of the tube and internal pressurization. The analysis has been conducted by imposing two axial boundary conditions on the tube, specifically axially free ends and axially clamped ends. Additionally, the rigidity modulus of the tube has been linearly graded in the direction of thickness where the inner surface of the tube has a lower stiffness than the outer surface. The static equilibrium equations for deformation of the axisymmetric tube are derived and solved using numerical technique. The condition for prismatic bifurcation of the axisymmetric static equilibrium solutions has been obtained by using the linearized incremental constitutive equations. Two modes of bifurcations, corresponding to two different non-circular cross-sectional geometries, have been explored in this study. The outcomes reveal that the FGDE tubes experiences prismatic bifurcation before the Hessian criterion of failure is satisfied. It is observed that the lower mode of bifurcation can be triggered at a lower critical voltage as compared to the higher mode of bifurcation. Furthermore, the tubes with larger stiffness gradient require higher critical voltages for triggering the bifurcation. Moreover, with the increase in stiffness gradient, a linear variation of the critical voltage is observed with the thickness of the tube. It has been found that on applying internal pressure to a tube with low thickness, the tube becomes less susceptible to bifurcations. A thicker tube with axially free end is found to be more stable than the axially clamped end tube at higher mode of bifurcation.

Keywords : critical voltage, functionally graded dielectric elastomer, linearized incremental approach, modulus of rigidity, prismatic bifurcation
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