Finite Strain Formulation of Electro-Visco-Hyperelastic Nematic Elastomers

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Abstract

Nematic liquid crystal elastomers (NLCE) form a important class of highly responsive multifunctional materials combining the anisotropy and self-organisation of liquid crystal mesogens with the flexibility of cross-linked polymeric networks. They also display significant programmable and rapid shape changes in reaction to different stimuli, light, heat, or electric fields, where effects of soft-elasticity and rate dependence play an important role. This work is dedicated to computational implementation of finite strain model of electro-visco-elastic interactions that occur in dielectric NLCE, with including key phenomena such as Maxwell's stress, director rotation, nonlinear deformations, electric Fréedericksz transition and energy dissipation. By integrating the framework of continuum mechanics, Maxwell's equations, and the principle of virtual power, the governing equations for dielectric NLCEs are systematically derived. This approach ensures the formulation of thermodynamically consistent constitutive relations, capturing the coupled electro-mechanical behavior and time-dependent viscoelastic response while adhering to the physical plausibility. The presented model involves two dissipation mechanisms: viscous dissipation of the director rotation and viscoelastic dissipation within the polymer matrix introduced as internal variables, both of which play critical roles in governing the material's electro-mechanical response. Special attention will be given to the finite element implementation in the FEniCSx software, focusing on two electro-viscoelastic instabilities: pull-in and wrinkling. The study will explore various deformation modes that may emerge during these phenomena. Finally, the implemented numerical simulations will include the hysteresis response and a validation study comparing the obtained numerical results with analytical solutions from the literature.

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