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A curvilinear high order finite element framework for electromechanics: from linearised electro-elasticity to massively deformable dielectric elastomers

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Abstract

This paper presents a high order finite element implementation of the convex multi-variable electro-elasticity for large deformations large electric fields analyses and its particularisation to the case of small strains through a staggered scheme. With an emphasis on accurate geometrical representation, a high performance curvilinear finite element framework based on an a posteriori mesh deformation technique is developed to accurately discretise the underlying displacement-potential variational formulation. The performance of the method under near incompressibility and bending actuation scenarios is analysed with extremely thin and highly stretched components and compared to the performance of mixed variational principles recently reported by Gil and Ortigosa [1, 2, 3]. Although convex multi-variable constitutive models are elliptic hence, materially stable for the entire range of deformations and electric fields, other forms of physical instabilities are not precluded in these models. In particular, physical instabilities present in dielectric elastomers such as pull-in instability, snap-through and the formation, propagation and nucleation of wrinkles and folds are numerically studied with a detailed precision in this paper, verifying experimental findings. For the case of small strains, the essence of the approach taken lies in guaranteeing the objectivity of the resulting work conjugates, by starting from the underlying convex multi-variable internal energy, whence avoiding the need for further symmetrisation of the resulting Maxwell and Minkowski-type stresses at small strain regime. In this context, the nonlinearity with respect to electrostatic counterparts such as electric displacements is still retained, hence resulting in a formulation similar but more competitive with the existing linearised electro-elasticity approaches. Virtual prototyping of many application-oriented dielectric elastomers are carried out with an eye on pattern forming in soft robotics and other potential medical applications.

Keywords: Monolithic & staggered electro-elasticity, high order curvilinear meshes, dielectric elastomers, material instability, wrinkling

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