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Modeling and simulation of the coupled mechanical–electrical response of soft solids

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ABSTRACT

Dielectric elastomer (DE) is one type of electro-active polymers (EAP) that responds to electrical stimulation with a significant shape and size change. As EAPs, dielectric elastomers are lightweight, inexpensive, pliable and can be fabricated into various shapes, all of which are attractive properties to justify the intense research in the field. This paper presents a nonlinear, electrical and mechanical coupled, large deformation finite element formulation for DEAs. Maxwell's equations for the electroquasistatic fields were solved simultaneously with equation of linear momentum. The hyperelastic Ogden model and total Maxwell stress method were combined to describe the material. The formulation was based on the weak forms of Maxwell's equation and linear momentum expressed in the reference configuration. The closed form consistent tangent moduli for dielectric elastomers were derived. The results of the simulation compared with the experiments have demonstrated the validity of the method from the computational aspect.

1. Introduction

Dielectric elastomers (DE) are one branch of electroactive polymers (EAP) that respond to electrical stimulation with significant shape and size changes. As EAPs, dielectric elastomers have many attractive properties, such as lightweight, low cost, pliability and potential to mimic complicated actuations or replace parts of animals and humans. Using dielectric elastomers as functional materials, dielectric elastomer actuators (DEA) transform electric energy directly into mechanical work and produce large strains. Since dielectric elastomers were identified and proposed as field-actuated polymeric actuators (Pelrine et al., 1998), research has been intense in this area. Some sophisticated designs of DE actuators have been demonstrated (Arora et al., 2007; Carpi et al., 2005, 2007; Kovacs et al., 2007; Kofod et al., 2006; Kornbluh et al., 2004).

Due to the large deformation usually involved with DE actuators, it is difficult to predict their actuated shape and stress state in many occasions. Effective design of DE actuated mechanisms with large strain necessitates adequate analytical and numerical tools for predicting the behavior and response. Several authors have addressed this issue. Kofod (2001) was the first to combine the model of hyperelasticity and Maxwell stress to explain the effect of pre-stretch on dielectric actuators. Based on constrained one-dimensional stretch tests on both silicone and VHB 4910 acrylic elastomers, four parameter Ogden model has shown to fit strain–stress curve better than Neo–Hookean, and Mooney–Rivlin model in high strain range. Kofod and Sommer-Larsen (2005) also concluded in their research on silicone elastomers that even for high strains, the actuation of dielectric elastomer actuators is well described by only considering the elasticity of the material and Maxwell stress due to the applied electric field. McMeeking and Landis (2005) formulated an energy balance for a system consisting of deformable

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