Opinion

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A Finite Element Framework for Coupled Electromechanics that is both Resilient and Computationally Efficient

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Abstract

EAPs (electro-active polymers) are becoming increasingly used as actuators, sensors, and energy harvesters. Finite element simulations are proven to be an indispensable tool for simulating the complicated behaviour of actuators under coupled loads, especially in the fields of soft robotics, biomedical engineering, and energy harvesting. We provide a new finite element framework for simulating coupled static and dynamic electromechanical interactions in electro active polymeric materials in this paper. A two-field mixed displacement-pressure formulation is used to mimic the incompressible character of EAPs, which, unlike the commonly used mixed three-field and F-bar formulas, is applicable for both virtually and fully incompressible materials. Innovative quadratic Bezier triangular and tetrahedral elements are employed for spatial discretization. A monolithic scheme is used to solve the governing equations for the coupled electromechanical issue; for electrodynamics simulations, a state-of-the-art implicit time integration is adapted. Several benchmark examples in computational electro mechanics, such as simulations of a spherical gripper in electrostatics and a dielectric pump in electrodynamics, are used to show the accuracy and computing efficiency of the proposed framework.

Keywords: EAPs; Framework; Computational

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Introduction

EAPs (electro-active polymers) are a novel type of functional or active material that can be activated by electric fields or potential differences. A dielectric elastomer (DE), a type of EAP, is made up of two compliant electrodes sandwiched between two thin polymeric films. When a voltage difference is supplied across a film thickness, the material contracts in the direction of the applied voltage and expands in the transverse plane direction; this is known as the mechanical output of an electric input. As a result of these activation mechanisms, EAPs are one of the most promising active materials for a wide range of engineering applications, including artificial muscles in soft robotic mechanisms, optical membranes for shape correction in lenses, and energy harvesting from ambient motions like human walking and ocean waves.

The set of governing equations must be solved in coupled forms due to the interaction of the mechanical and electric fields; see, for example, [1] for a range of extensive evaluations on the potential uses for EAPs. The mathematical basis of electromagnetic field coupling in finite strains has been thoroughly described in previous papers. The most prevalent EAPs are acrylic type VHB, polyurethanes, and silicone polymers, all of which are commercially accessible. Due to the restricted actuation of unfilled polymers, high permittivity particle-filled polymeric composites are increasingly being investigated for EAPs, resulting in comprehensive reviews on the state-of-the-art of EAP materials. There is a scarcity of experimental work on pure or composite EAPs in the literature [2].

While studying the electromechanical properties of synthesised polyurethane elastomer film-based polyester, conducted experiments on an acrylic type polymer under uncoupled electromechanical loading. Extensive experimental experiments were conducted to demonstrate the time-dependent viscoelastic behaviour of VHB 4910 polymer under pure mechanical loading. Furthermore, an experimental investigation on the dielectric properties of a poly acrylate dielectric elastomer was presented, as well as a comparison of silicone and acrylic elastomers that could be used as dielectric materials in electro-active polymer actuators. The limited actuation of commonly used commercially available acrylic-based VHB polymers encourages the development of novel acrylic type polymers that can be actuated at very low electric voltages [3].

The following are some of the key features of the proposed finite element framework: The proposed framework's computational efficiency is due to a combination of (a) a two-field mixed formulation for the mechanical problem, (b) quadratic polynomials for the displacement and electric potential, and a linear approximation for the pressure, (c) the ability to compute accurate numerical solutions using coarse meshes, and (d) the ability to complete the simulation using fewer load steps in electrostatic problems and fewer time steps in electrodynamics problem. The suggested framework is resilient because it uses in fsup stable elements rather than the inf-sup unstable Q1/P0 element [4].

Furthermore, unlike the Q1/P0element, the suggested element's iteration convergence is unaffected by changes in the bulk modulus value [5]. Geometries with a lot of detail: The suggested framework's usage of triangular and tetrahedral elements makes mesh generation much easier, compared to schemes based on quadrilateral and hexahedral elements, which make mesh generation for complex geometries extremely difficult.

Conclusion

The suggested framework demonstrates that it is an excellent finite element framework for simulating complicated coupled interactions in electro-active polymers. The fundamental computational advantages of this novel framework can be extended to develop robust, accurate, and computationally efficient computational tools for the simulation of complex multi-physics thermo-electro-mechanical interactions as well as coupled fluid-structure interactions in electromechanical systems 37 for biomedical engineering and energy harvesting applications. We will extend this paradigm in future contributions to capture viscos-anisotropic and coupled thermo-electro-mechanical behaviour of electro-active polymers.

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