A coupled FEM-BEM formulation to solve electroelastic problems including free space effects

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Abstract

In this work, we have developed a coupled FEM-BEM computational framework for arbitrary 3D solids as well as slender rod-like bodies to obtain the nonlinear behavior of an electro-elastic body incorporating also the impact of free space surrounding it. As the body deforms, the boundary of the free space changes too. Therefore, it is a two-way coupled problem which requires simultaneous solution of electromechanical problem of the body as well as free space electric problem outside the body. The free space problem can be neglected if the electric field remains contained in the body or outside electric field is strong enough to be modulated by body's deformation. Otherwise, one needs to also solve a Laplace equation for electric free space (1). The high computational expense to solve the Laplace equation in 3D free space domain has motivated us to work with the boundary integral equation(BIE) which simply sits on the boundary of the body (1). However, the BIE has singular integrand terms and this study also proposes a mixed analytical-numerical approach to evaluate these integrations. In addition to usual electromechanical variables for the body such as displacements and electric potential, an electric flux-like variable acting on the boundary of the body accounts for the influence of free space. A comparison of 3D FEM-BEM with axisymmetric formulation and the formulation by Barreto et.al.(2) for slender structures of different slenderness ratios verifies each of these theories. A 3D non-isotropic electroelastic stored energy density suitable for piezoelectric and dielectric material is taken for both 3D FEM-BEM and slender bodies. The numerical results show that free space has a substantial influence on the electric and mechanical response of the body. Moreover, both analytical and numerical results suggest that the free space effect is dominant when the electric field is applied across the length of rod-like slender structures. This analysis also demonstrates a fascinating change in stiffness, moments and forces due to interaction between mechanical and electrical variables. The proposed study will help in enhancing the design of soft electroelastic robots, actuators and sensors.

References :
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