DYNAMIC RESPONSE OF THREE-DIMENSIONAL MULTI-DOMAIN PIEZOELECTRIC STRUCTURES VIA BEM

L.A. Igumnov, I.P. Markov, A.K. Lyubimov, V.V. Novikov
Research Institute for Mechanics, National Research Lobachevsky State University of Nizhni Novgorod, 23, bldg. 6, Prospekt Gagarina (Gagarin Avenue), Nizhny Novgorod, 603950, Russia
E-mail: teanku@gmail.com

Piezoelectric materials can convert energy between electrical and mechanical and that makes them very common in many engineering fields. They are widely used in smart devices, sensors, actuators, transducers, etc. Due to coupled multiphysics nature of piezoelectric materials accurate and versatile analysis methods are required for modelling the behaviour of piezoelectric structures. For three-dimensional (3D) piezoelectric solids with arbitrary degree of anisotropy analytical or semi-analytical solutions are available only for limited number of structural configurations and loading conditions, especially if the problem involves material inhomogeneities or subregions. The Boundary Element Method (BEM) is a frequently applied numerical approach in many areas of engineering mechanics. We present a direct BEM formulation in Laplace domain for the transient analysis of three-dimensional piecewise homogeneous piezoelectric solids.

Consider a 3D homogeneous linear piezoelectric solid under the quasi-electrostatic assumption, in the absence of body forces and in the absence of free electrical charges. In order to combine the mechanical and electric variables together the coupled fields are described through the generalized quantities. Initial conditions are assumed to be zero. Initial boundary value problem is reformulated as a system of boundary integral equations for generalized displacements in Laplace domain

$$\int_{\Gamma}\left[\bar{U}_k(\mathbf{y},s)\bar{h}_{jk}(\mathbf{y},\mathbf{x},s)-\bar{U}_k(\mathbf{x},s)h^S_{jk}(\mathbf{y},\mathbf{x},s)\right]\mathrm{d}\Gamma(\mathbf{y})-\int_{\Gamma}\bar{T}_k(\mathbf{y},s)\bar{g}_{jk}(\mathbf{y},\mathbf{x},s)\mathrm{d}\Gamma(\mathbf{y})=0,$$

where the integral containing the Laplace domain piezoelectric dynamic generalized traction fundamental solution $\bar{h}_{jk}$ is regularized by its static part h^S_{jk}, therefore no strongly singular integrals are present; s is the Laplace parameter; $\mathbf{y}$ is the observation point; $\mathbf{x}$ is the source (collocation) point and $\bar{g}_{jk}$ is the displacement fundamental solution. The full-space fundamental solutions are expressed in integral form.

Considering piecewise homogeneous piezoelectric solid, we apply standard discretization BEM procedure for each homogeneous subregion and enforce equilibrium of generalized tractions a continuity of generalized displacements on each interface. Geometry of boundary elements and boundary variables over each element are represented according to the idea of mixed elements. After spatial discretization is done and the boundary conditions are applied, a complex-valued linear system is obtained for a particular value of the Laplace transform parameter. Time-domain solutions are obtained after solving the problem on a set of Laplace transform parameters and subsequently employing Convolution Quadrature Method as a numerical inversion technique.

To test the presented multi-domain BEM a numerical example of nonhomogeneous piezoelectric solid under dynamic impact loading is considered. A column made of two dissimilar piezoelectric materials is subjected to a Heaviside-type traction at one side and grounded and fixed at the opposite side. The rest of the surface is free from the generalized tractions. A mesh convergence study is conducted on a four boundary element meshes. The obtained boundary element results agree well with the finite element solutions.

The reported study was funded by the Russian Foundation for Basic Research, according to the research project No. 16-38-60097 mol_a_dk.