EFFICIENT PIEZOELECTRIC BEAM FINITE ELEMENT FORMULATIONS BASED ON COUPLED POLYNOMIAL INTERPOLATIONS

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by

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ABSTRACT

The performance of the conventional two-noded Equivalent Single Layer (ESL) extension mode piezoelectric beam finite elements is affected by ‘locking’ phenomena. The conventional formulations available in the literature employ independent polynomials for the interpolation of mechanical displacements and transverse electric potential. ‘Material locking’ due to bending-extension coupling and ‘shear locking’ due to bending-shear coupling hamper the finite element convergence, while ‘piezolocking’ due to induced potential coupling affects the accuracy. Hence, the conventional formulations demand a refined mesh in the axial direction, to overcome shear and material locking effects and a sublayered modelling of the electric potential in the transverse direction, to overcome piezolocking effects. However, these measures to circumvent locking effects are inefficient because they lead to increase in number of nodal degrees of freedom and computational effort. In this thesis, accurate and efficient ESL piezoelectric beam finite elements are developed using coupled polynomials for field interpolations, without increasing the number of nodal degrees of freedom. The formulations are developed for Euler-Bernoulli theory (EBT), first-order (FSDT) and higher-order (HSDT) shear deformation theories.

The higher-order through-thickness distribution of electric potential in a physical piezoelectric layer, consistent with the respective ESL theory, is derived from an electrostatic equilibrium equation to eliminate piezolocking. This consistent potential contains, in addition to conventional linear terms, higher-order coupled term(s) which depends only on the bending strain and hence does not bring in any additional nodal electric potential degree of freedom in the formulation. The governing equilibrium equations derived from a variational formulation are used to establish the relationship between field variables involved in the ESL theory based formulations with respective consistent potential. These relationships lead to a set of coupled polynomials for their interpolations. A set of coupled shape functions obtained from these polynomials incorporate the bending-extension, bending-shear and induced potential couplings in a variationally consistent manner.

The proposed coupled polynomial based piezoelectric beam finite element formulations are validated by benchmark solutions from ANSYS 2D simulations. Comparison of results for numerous test problems proves improved accuracy and efficiency of the proposed formulations over their conventional counterparts.