Non-linear Electromechanical Coupling: Large Deformation and Hysteresis

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ABSTRACT

Smart materials respond to external stimuli as, e.g., electric fields, which enables their usage as actuators and, possibly, also as sensors. The electromechanical coupling of the direct and converse piezoelectric effects, for instance, is used for both actuation and sensing in diverse engineering applications The response of piezoelectric materials depends on their state of (remanent) polarization and the presence of an external electric field. Typically, the polarization is assumed to be constant during operation of a device. To extend the operational range of sensors and actuators, however, an accurate understanding of the evolution of the material's state of polarization is required, which requires both physical and geometrical non-linearities to be taken into account. Moreover, polymeric materials as PVDF allow significantly larger deformation as compared to conventional piezoelectric ceramics. The electro-mechanical coupling in piezoelectric materials manifests in ferroelectric and ferroelastic hystereses, which are related to both reversible (e.g., domain-wall motion) and irreversible (i.e., domain switching) physical processes. Focusing on the latter, we transfer phenomenological models for domain switching [1] to the geometrically non-linear regime using the non-linear formulation for reversible electromechanical coupling [2] as a basis. For this purpose, we follow related concepts of geometrically non-linear elasto-plasticity [3], where the concept of a Lee-type multiplicative decomposition of the deformation gradient plays a key role. Therefore, an additional deformation path that describes the evolution of the poled state from the unpoled referential configuration is introduced. Within the phenomenological approach, micro-mechanically inspired internal variables related to the orientation of unit-cells [1] are introduced. Driving forces and evolution equations are derived within a thermodynamical framework.

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