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Mathematical Modelling of Dielectric Elastomer Transducers

Abstract

Dielectric elastomers (DEs) are smart materials. The DE material itself is simply a soft dielectric polymer material. Both large surfaces of a DE film are coated by compliant electrodes in order to make the film electro-active. If a voltage is applied across the electrodes, the DE material contracts in the direction of the film thickness and it expands in the plane in parallel with the electrodes due to oppositely charged electrodes attracting each other. Electrical input energy has been converted into mechanical energy. The effect works in the reverse direction as well, i.e. mechanical input energy can be converted into electrical energy. In either mode of operation, actuation or generation of electrical energy, the conversion between electrical and mechanical energy is based on the deformation-dependent capacity of the electrode-coated DE film.

Because of this functioning principle and the properties of the DE material and the compliant electrodes, electromechanical transducers based on DEs are supposed to provide large strains, a high energy density, a high efficiency, a fast response, and a long lifetime while being light weight and, in most cases, inexpensive and operating noise-free. Despite the vast potential of the DE technology, only very few commercial applications exist where a DE transducer either provides a unique feature or outcompetes another already established technology. Additional research is needed in order to bring DE transducers closer to the market. Therefore, the company Danfoss PolyPower A/S initiated a large research project (ATF project) on the development of DE materials, DE transducers, and high-voltage electrical drives for DE transducers involving four companies and three universities in 2011. This Ph.D. project has been a part of a work package of that ATF project. The final goal of the work package is the development of an engineering tool which facilitates the fast simulation of electromechanical systems consisting of several DE transducers.

An electromechanically coupled visco-hyperelastic model is needed in order to characterize a DE material at large strains. Such a three-dimensional continuum model is presented. Continuum and lumped parameter models of two DE transducers, a tubular DE transducer and a linear DE transducer, are developed. The effective material parameters of the lumped parameter models depend on the DE material, the transducer geometry, and the electromechanical boundary conditions the transducer is subjected to. They are identified by proper finite element (FE) simulations of the continuum models. The lumped parameter models have been implemented in Simulink. These Simulink implementations are the core of the desired engineering tool. The static models for a tubular DE transducer are validated against electromechanical experiments. FE simulations show that the effective elastic material parameters and the static electromechanical performance of a tubular DE transducer depend markedly on the anisotropic stiffening, induced by the anisotropic metal electrodes characteristic to the DE film supplied by Danfoss PolyPower A/S, and the transducer's geometric dimensions.

Beside the work on the mathematical models for the engineering tool, the electromechanical efficiency of a loaded tubular DE actuator is investigated theoretically and dynamic models for a bubble-like hydrostatically coupled DE (HCDE) actuator are developed. The latter models enable to study the impact of the DE's and the fluid's material properties, the actuator's geometric dimensions, and the prestretch ratio of the DE membranes on the actuator's resonance frequency and the actuator's viscous behaviour. That is important in view of the intended application of bubble-like HCDE actuators as Braille-like tactile displays and high frequency cutaneous stimulators.