MODELING ELECTRO-ACTIVE DIELECTRIC AND ELECTROSTRICTIVE ELASTOMER PLATES IN THE FRAMEWORK OF NONLINEAR STRUCTURAL ELECTRO-MECHANICS

Elisabeth Staudigl, Michael Krommer, Yury Vetyukov

E325 - Institute of Mechanics and Mechatronics

INTRODUCTION

One of the major innovations in the context of future smart materials is the expansion from current ceramic based materials to the usage of soft materials, e.g in view of building bioinspired soft robots. One group of smart materials, which has gained attention because of their muscular evoking behavior when subjected to an electric field, are dielectric/electrostrictive elastomer actuators. Because of their simple design- sandwiching the elastomer between two electrodes (see Figure 1), the inexpensive and easy manufacturing process and their superior performance when it comes to voltage induced deformations, these actuators are also termed artificial muscles.

Yet, practical applications suffer from a variety of failure and instability mechanisms, motivating a theoretical study on these elastomer actuators in order to help circumventing some obstacles. In this contribution, the modeling framework for electro-active dielectric and electrostricitve elastomer actuators is presented.

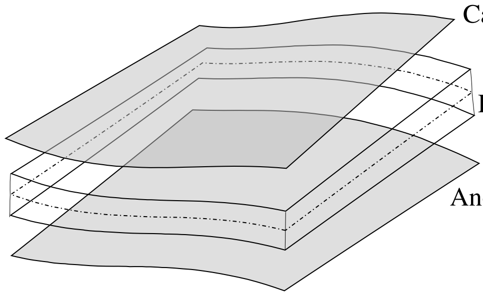

Figure 1: Construction of an electro-active elastomer actuator.

MODELING FRAMEWORK

The starting point of our derivation is a continuum mechanics framework, which allows to write the balance equations as function of electric and mechanic field quantities with regard to the whole three dimensional set-up. From the 1st law of thermodynamics, a free energy function additively decomposes of a pure mechanical, and an electrostatic energy $\Psi = \Psi_{me} + \Psi_{el}$, rendering the basis of the model. This allows for a modular incorporation of any nonlinear phenomenon crucial to the electro-elastic coupling of an electro-active elastomer actuator or sensor. The mechanical part Ψ_{me} takes the (hyper-)elastic energy of the polymer chain-network microstructure into account, while the electrostatic part Ψ_{el} features the re-orientation of dipoles upon application of an external electric field, causing a polarization and hence Coulomb-type electrostatic force- and moment couples within the elastomer.

Because of the large deformations, a geometric nonlinear formulation, where field quantities in the current configuration are referred to a reference configuration, using the deformation gradient tensor $\mathbf{F}$, is crucial. Some actuators exhibit even larger deformations because of crystalline particles embedded in the polymer network matrix. These crystalline dipoles rotate, when an external electric field is applied, and cause, independently of the applied field direction, an additional effect through the thickness of the dielectric. This so called *electrostrictive* effect, is accounted for by means of a multiplicative decomposition of the deformation gradient tensor $\mathbf{F} = \mathbf{F}_{me} \cdot \mathbf{F}_{el}$. Once all the crystal units have aligned, further deformation relies on the polymer network matrix, and polarization saturation takes place. We account for this effect by incorporating a proper saturation function to the electrostatic energy Ψ_{el}, featuring relevant material properties known from experiments.

Solving for the whole set of three dimensional equations numerically might be computationally intensive and for most of the applications even unnecessary, as typical applications feature very thin designs. This encourages us to seek for solutions within the structural mechanics framework, considering plates as a material surface.

RESULTS AND DISCUSSION

To this end, the resulting three dimensional constitutive law is reduced to the structural level by applying a plane stress condition. Incompressibility of the elastomer is ensured by introducing a Lagrange multiplier, where by an appropriate decomposition of the Green-Lagrangian strain tensor a complete decomposition into a membrane free energy, and a bending energy is accomplished. This completely two dimensional energy comprises the bases for the finite element implementation into our in-house finite element code ShellFE.

Figure 2 shows the finite element results of a circular ring plate actuator, where the outer radius is clamped. Upon application of a voltage between the two electrodes on top and bottom of the circular ring, the inner circle gradually shrinks as the voltage is ramped up. A possible application might be a circular valve actuator, with the possible objective to build a biocompatible unit. Another possibility builds on a combination of multiple actuators into a matrix such that an electrically driven sieve or separator can be realized. However, yet, these ideas remain part of the future, because electro-active elastomer actuators still suffer from their downside that very large electric fields are necessary for actuation.

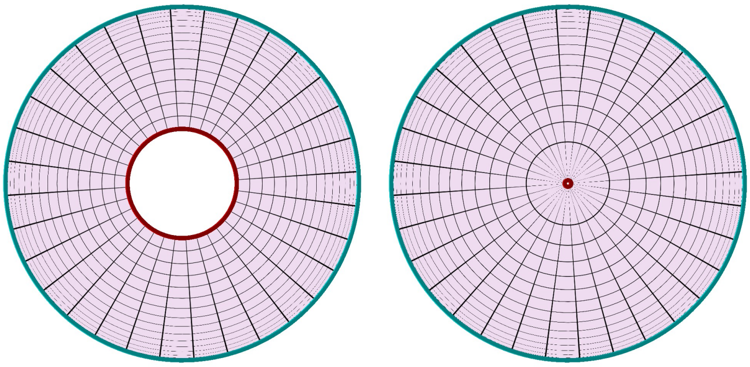

Figure 2: Example of a valve actuator, left: open valve, no voltage applied, right: closed valve upon actuation.

CONCLUSION

Modeling electro-active dielectric and electrostrictive elastomer actuators comprise some difficulties, as not only the large deformations necessitate a geometric nonlinear formulation, but also the material itself along with the inherent electric coupling constitute additional nonlinearities. The presented approach resolves some of the prominent issues and allows to easily incorporate, or drop, any effect relevant for the specific material under investigation. Another strength comes with the computation efficiency, which is of special interest if a control strategy for a collaborative of multiple electro-active elastomer actuators, integrated on a carrier structure, has to be designed. This can be used to trigger a desired motion of the carrier structure, e.g. a wing structure in order to mimic the motion of a bird.

REFERENCES

[1] E. Staudigl, M. Krommer, Y. Vetyukov.: *"'Finite deformations of thin plates made of dielectric elastomers: Modeling, numerics and stability"'*, Journal of Intelligent Material Systems and Structures, 2017.