Introduction to Electro-active Elastomers and Soft Robotics

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Electro-active Elastomers

Electro-active elastomers are materials that deform elastically in the presence of an electric field.

They are “smart materials” composed of a rubber-like basis matrix filled with electro-active particles. In the presence of an electric field, the particles are displaced and this induces a motion in the material.

Alternatively, they can be composed of a soft dielectric material between two flexible electrodes, which are linked to a generator.

Modelling Electro-active Elastomers

In order to model these materials, we must couple the theories of electromagnetism and elasticity. This involves the coupling of Maxwell's Equations and those of Continuum Mechanics.

The mathematical modelling of these solids is particularly difficult, due to the coupling of non-linear elastic deformation and electric fields. This coupling is strong and highly nonlinear. In addition, both Maxwell's Equations and the equations of Continuum Mechanics are complex.

Maxwell's Equations

We can look, for example, at the equations of electromagnetism. The complete set of Maxwell's equations consists of a system of four partial differential equations for the vector fields, **E**, the electric field, and **B**, the magnetic field.

$$\nabla \cdot \mathbf{E} = \frac{\rho_e}{\varepsilon_0} \qquad \nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Coupling these equations with those of Continuum mechanics will increase the complexity of the problem

Applications of Electro-active Elastomers

Electro-active elastomers are being used in a wide variety of applications including high-speed actuators and sensors, and biomedical applications such as artificial muscles.

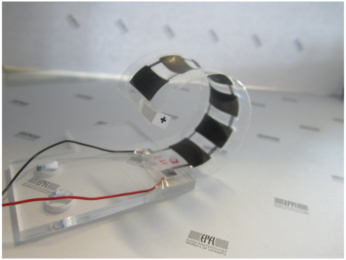

Figure: Bending a thin strip of electro-active polymer by applying a current (Ecole Polytechnique Fdrale de Lausanne)

We want to investigate the possibility of using electro-active elastomers to manufacture soft robots.

Soft Robotics

Soft Robotics is a new branch of robotics that has emerged in recent years to meet the type of challenges that hard-shell robots cannot address.

It takes its inspiration from natures many non-skeletal animals and organisms to design highly flexible and versatile robots with bodies made of very soft rubber.

Typically, the motion is caused by contracting their "muscles" using fluid pressure changes. This type of motion restricts their portability and range of action.

Aims of the Project

- Establish a robust formulation for the interactions of elasticity and electricity in order to model the deformations of electro-sensitive elastomers
- Implement the formulation into a finite element code
- Analyse, simulate and devise simple soft robots moving due to the application of electrical fields

Finite Element Simulations

Current finite element simulations make use of electro-thermal interactions. They are restricted to static phenomena, so that magnetic fields can be neglected, and to a very specialised type of energy potential, which does not allow for the large coupling of electricity and elasticity.

I hope to implement the the comprehensive models of Dorfman and Ogden into ABAQUS, to improve on current simulations.

References

- Dorfmann, L., Ogden, R.W., *Nonlinear Theory of Electroelastic and Magnetoelastic Interactions*, Springer, 2014.
- http://biodesign.seas.harvard.edu/soft-robotics