Multiscale Modelling and Design of Magnetoelastic Materials and Structures

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ABSTRACT

In this talk, we will present the ongoing work in “Mechanics of Materials” laboratory in the Department of Aerospace Engineering at IISc, Bangalore. One of our the main themes in our work is to design magneto-elastic materials and structures which can be remotely actuated and undergo large deformations with moderate external magnetic field. To achieve this we have two different strategies.

The first strategy involves using slender ferromagnetic structures. We analyse the deformation of ferromagnetic slender structures by minimizing the sum of elastic and magnetic energy for slender structures. The magnetic energy (∼ demag. energy) strongly depends on the shape of the body and is computed by solving Maxwell’s equations of magnetostatics. The demag. energy is computationally expensive and is difficult to calculate for general 3D bodies but takes simpler forms for slender structures. This gives us an opportunity to explore these problems (semi) analytically. We have been able to use this simplification to obtain closed form analytical expressions of the energy in certain scenarios. Equilibrium equations, their solutions and stability analysis of some ferromagnetic slender structures will be presented. Furthermore, a novel loading device for verifying our predictions has been designed.

The second strategy involves the use of magneto-active polymers (MAPs). MAPs are essentially multi-scale materials - at the micro-scale they consists of a periodic distribution of ferromagnetic inclusions in an elastomer matrix. At the macro-scale it behaves as a large effective ferromagnet which can undergo large deformation. We have developed a homogenised model for MAPs based on material physics rather than constitutive assumptions. In our model, the total energy of a MAP is given by the sum of the elastic and magnetic energy. One of the main achievements of our model is that it captures the magnetostatic energy correctly. Our model accounts for the magnetostatic interactions between the particles at the micro-scale and also accounts for the magnetostatic energy due to the overall shape or geometry of the body. The latter is well known in the classical theory of micromagnetics as the “demag factors” or shape factor of the specimen. For the elastic energy, we use the standard Saint Venant−Kirchhoff model. We use an appropriate convex combination of the elastic moduli of the magnetic particles and the polymeric matrix as the effective moduli of the MAPs. The magnetization and magnetostriction curves for ellipsoidal specimens with different unit cells highlight the importance of microstructure at the micro-scale in these materials.