Magnetostriction of fractionally viscoelastic MREs

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Abstract

Magnetorheological elastomers (MREs) are composite materials consisting of non-magnetic elastomer matrix combined with powder-like magnetic particles dispersed throughout it. Such materials exhibit magnetostriction, i.e. they deform when exposed to an acting magnetic field, and due to this property they have found numerous practical applications ranging from soft robotics and biomedical engineering devices to soft actuators and sensors and magneto-active vibration absorbers and pumps. Theoretical modelling of MREs has been rapidly developing over the past decade, gradually including more and more complex effects such as viscosity of the elastomeric matrix, ferromagnetic hysteresis of the magnetic particles, and influence of the magnetic fields in the surrounding air on the MREs' response. However, these models usually account for the viscoelastic dissipation by introducing several internal variables in the form of discrete relaxation times and material constants, and increasing the model accuracy is achieved by increasing the number of these variables, thus making the model computationally more demanding. In this contribution, an MRE model is proposed where viscoelastic properties are modelled with fractional-order derivatives, and the derived model is then applied to analyse a soft magneto-active actuator in the form of a tri-layer MRE beam exposed to a variable exterior magnetic field. Fractional-order damping model assumes power-law relaxation spectrum, thus enabling formulation of the model by using only two parameters - fractional derivative order and one relaxation time, which provides more efficient numerical simulation possibilities. The governing equations describing the large nonlinear deformations of MREs are derived by using thermodynamically consistent framework, and the free energy (i.e. magnetic enthalpy) is obtained by considering continuum mechanics constitutive theory in combination with magnetostatic Maxwell's equations. The weak form of the problem is then derived and the obtained system is numerically implemented in the open-source finite element software FEniCSx, providing a robust solution code for the analysed case of magneto-active fractionally viscoelastic tri-layer beam actuator. This study shows an example of a successful application of fractional viscoelasticity in conjunction with magnetorheological elastomeric materials and provides a solid base for further extension by including thermal effects or electric field effects for even broader application spectrum.

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