A Computational Multiscale Framework for Coupled Transient Electromagnetic-Mechanical Phenomena for Antenna and Sensors

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Abstract

Multi-functional devices that integrate electromagnetic and mechanical fields are gaining importance in a wide variety of applications. The combined mechanical and electromagnetic regimes, encompassed in these structures, make it necessary to develop effective multi-physics analysis tools at a range of temporal scales. This work develops a framework for coupling transient electromagnetic (EM) and dynamic mechanical (ME) fields to predict the evolution of electrical and magnetic fields and their fluxes in a vibrating substrate undergoing finite deformation [1]. To achieve coupling between fields the governing equations are solved in the time domain. A Lagrangian description is invoked, in which the coupling scheme maps Maxwell's equations from spatial to material coordinates in the reference configuration.

An important consideration is that the different fields governing multi-physics response may have large frequency discrepancies, e.g. the ultra-high electromagnetic frequencies and moderate vibration frequencies. Computational analyses of these discrepant frequency problems using conventional time integration schemes can become intractable. This work addresses the issue of time integration with large frequency ratios, by introducing a novel wavelet transformation induced multi-time scaling (WATMUS) method in the finite element framework [2], [3]. The method significantly enhances the computational efficiency in comparison with conventional single time-scale integration methods. An adaptive enhancement of WATMUS scheme allows for the optimal wavelet bases in the transformation and integration step sizes. The accuracy and efficiency of the proposed WATMUS scheme is verified by comparing the results with the single time-scale simulations of the coupled transient electromagnetic nonlinear vibration problems.

Finally, a coupled electric and mechanical model with evolving damage is developed for piezoelectric materials, to develop a damage sensor. Piezoelectric constitutive relations coupled with phenomenological damage in a finite deformation setting will be used for developing a formulation for the damage sensor.

References

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