Challenges Facing MEMS Analysis

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The evergrowing complexity of MEMS designs and the large-scale integration of MEM components with electronic components on a chip pose many challenges that are very unique to MEMS field. Till a few years ago, MEM designs relied primarily on integration of mechanical and electrical principles. However, many recent applications and designs rely not only on integration of mechanical and electrical principles but also on integration of fluidic, optical, chemical and biological principles. It is the integration of all the analysis functions on a single chip that makes MEMS a promising technology, but, it is just that level of integration which makes designing MEMS very challenging and complex. Because of the diverse and disparate nature of MEMS applications, the development of computer-aided design tools for microsystem technology hasn’t been easy. We identify four areas of critical importance to the development of MEMS analysis tools - The four areas are: mixed-domain simulation, multi-scale analysis, mixed-regime simulation and model-order reduction. Advances in these four areas could lead to breakthrough developments in MEMS analysis and design.

1 Mixed-Domain Simulation

Mixed-domain simulation refers to the coupled analysis of the many energy domains describing the behavior of a single MEM device. Typically the interaction between the energy domains is strong and highly sophisticated approaches are needed to accurately perform the coupled analysis. To investigate design alternatives and design optimization issues, mixed-domain simulation tools need to be very fast, accurate, efficient and robust. Advances in fast algorithms, higher-order accurate numerical methods, flexible approaches such as meshless techniques for seamless integration of various energy domains and algorithms to efficiently combine various energy domains can lead to cutting-edge simulation tools for MEMS analysis.

2 Multi-Scale Simulation

A critical issue with MEMS analysis is the validity of continuum theories for the prediction of device behavior. In certain situations, the use of continuum theories can lead to inaccurate results. An alternative is to use molecular theories, but the simulation times with such techniques are prohibitive. Since the continuum theories breakdown only over a small, but critical, region of the device, molecular techniques can be used to simulate just the small regions with continuum theories applied elsewhere. Such approaches where continuum methods are combined with molecular techniques are referred to as multi-scale approaches. For MEM designs where fluidics or thermal phenomena is one of the energy domains, the breakdown of continuum theories can be an issue. The use of multi-scale approaches for such situations can lead to accurate, reliable and robust simulation tools.

3 Mixed-Regime Simulation

The response of a MEM device to an input can be linear over a large portion and nonlinear over a small portion. In such situations, the combination of linear and nonlinear theories with appropriate domain decomposition can be an efficient approach. Similarly, a significant portion of the micromechanical structure can be rigid with only a small elastic part. The use of mixed rigid/elastic theories can be a much faster approach. Depending on the specific problem, the use of mixed-regime techniques can lead to fast and accurate simulation tools.

4 Model-order Reduction

The development of reduced-order models for MEMS is of significant interest for systems-on-a-chip concept. Large scale integration of MEM components with electronic components is currently hampered by the lack of reliable compact models. The development of model-order reduction techniques for linear phenomena in microdevices is tractable. However, the development of reliable and robust model-order reduction techniques for nonlinear MEMS is currently a greatest challenge.