Effective Mass Calculations Using COMSOL Multiphysics® for Thermomechanical Calibration

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Abstract

Over the past few decades, nano/micro-mechanical resonators have experienced tremendous improvements in measurement sensitivity, achieving sub-attometer displacement transduction [1], yoctogram mass resolution [2], and force measurements on the order of attonewtons [3]. In order to ensure this level of accuracy, it is crucial that each nano/micro-mechanical device is properly calibrated. As technology moves to smaller and smaller devices, however, this proves to be an increasingly challenging task. Thermomechanical calibration, in which the equipartition theorem is used to relate a device's displacement to its thermal energy, provides a noninvasive calibration method by which scaling issues can be circumvented. In this approach, each resonator is modeled as a damped harmonic oscillator, while accounting for its extended structure by introducing a single, mode-dependent quantity known as its effective mass. In order to perform thermomechanical calibration accurately, it is important to properly calculate a resonator's effective mass. Though the effective mass can be calculated analytically for a number of simple cases, the finite element method (FEM) capabilities in COMSOL Multiphysics® were used for modeling more complex geometries. Utilizing user-defined functions, the mode shape and effective mass for any structure can be correctly determined. I will present the results of these calculations, which when combined with thermomechanical calibration, provide a recipe by which any nano/micro-mechanical resonator can be calibrated using COMSOL, as discussed in detail in our recent manuscript [4].

Reference

1. Olivier Arcizet et al., High-sensitivity optical monitoring of a micromechanical resonator with a quantum-limited optomechanical sensor, Phys. Rev. Lett., 97, 133601 (2006).

2. Julien Chaste et al., A nanomechanical mass sensor with yoctogram resolution, Nature Nanotech., 7, 301-304 (2012).

3. Emanuel Gavertin et al., A hybrid on-chip optomechanical transducer for ultrasensitive force measurements, Nature Nanotech., 7, 509-514 (2012).

4. Bradley Hauer et al., A general procedure for thermomechanical calibration of nano/micro-mechanical resonators, arXiv:1305.0557 (2013).

Figures used in the abstract

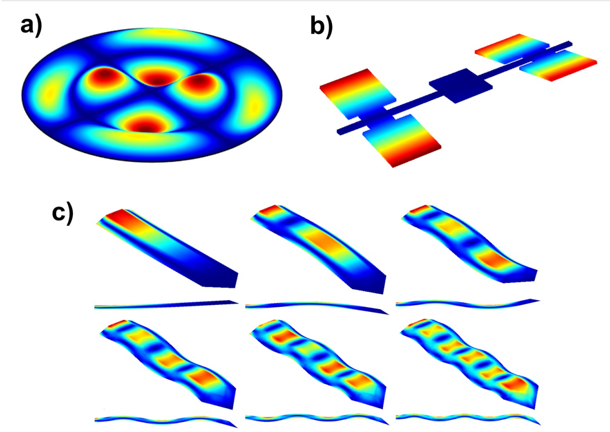

Figure 1: Mode shape simulations using COMSOL for (a) a circular membrane, (b) a triple paddle torsional resonator and (c) the first six modes of an AFM cantilever.