Modeling MEMS Gyroscopes With COMSOL Multiphysics®

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Abstract

MEMS gyroscopes are typically challenging to model due to the variable length scales present in the device (typically 1000:1) and because the devices themselves are highly sensitive to both environmental and manufacturing process induced deviations from the ideal geometry. In this paper we look at various techniques to model MEMS gyroscopes, using as an example a simple 1 axis device based loosely on the early Draper gyroscope design [1].

To model the electrostatic actuation of the gyroscope's comb drives, we employ an equation based, non-linear force that depends on the relative positions of the comb stators and rotors. We use COMSOL Multiphysics®'s genext() operator in combination with the structural mechanics interface to implement these forces in a manner that has been shown to be scalable with larger devices. For this case study we use a relatively crude model for the comb forces, but we discuss potential improvements. We then look at the use of COMSOL Multiphysics®'s deformed geometry interface to model the effect of various manufacturing defects on the device: focusing on the effect of sidewall angle. The deformed geometry interface allows for complex manufacturing variations to be captured in the model (for example, variations which vary spatially), and importantly the use of the same mesh for an ideal device and a device with the defect of interest allows for an accurate assessment of the effect of tiny variations on performance. Finally we consider the effect of external environmental factors on the device performance: taking as an example the deformation of the substrate into a cylindrical shape (this is intended as a proxy for thermal or mechanical stresses which result in substrate deformation).

The examples presented in this paper are available for further review in the COMSOL Multiphysics® 5.6 Model library [2].
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Reference

[1] J. Bernstein, S. Cho, A. T. King, A. Kourepenis, P. Maciel and M. Weinberg, "A micromachined comb-drive tuning fork rate gyroscope," Proceedings IEEE Micro Electro Mechanical Systems, Fort Lauderdale, FL, USA, 1993, pp. 143-148.
[2] “A Micromachined Comb-Drive Tuning Fork Rate Gyroscope” and “Manufacturing Variation Effects in a Micromachined Comb-Drive Tuning Fork Rate Gyroscope” COMSOL 5.6 MEMS Module Model Library.

Figures used in the abstract

Figure 1 : Figure 1. Gyroscope drive mode, showing the velocity of the two proof masses in the x direction (du/dt) in red and the direction of the Coriolis force (Fcor) in blue. The rotation direction sensed ( ) is indicated in green.

Figure 2 : Figure 2. Gyroscope sense mode, showing the direction of the proof mass acceleration along the z-axis in blue.