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EXPERIMENTAL VALIDATION OF MODELS FOR GAS DAMPING FROM CONTINUUM TO FREE MOLECULAR FLOW

Attilio Frangi, Aldo Ghisi

Dipartimento di Ingegneria Strutturale, Politecnico di Milano,
Piazza Leonardo da Vinci 32, Milano, 20133 (ITALY).
attilio.frangi@polimi.it, aldo.ghisi@polimi.it

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ABSTRACT

The correct evaluation of gas damping in MEMS structures vibrating at low-to-moderate frequency must consider the transition from a continuum-based theory at ambient pressure, when slip boundary conditions are applied, to rarefaction effects when pressure decreases and to a free molecular flow regime when the pressure reaches $10^{-3} \div 10^{-5}$ bar. By descending to even lower pressures, solid damping becomes comparable with fluid effects. MEMS devices, in fact, can work in these different pressure environments, and the knowledge of device quality factor is essential to calibrate sensor operation.

This contribution presents numerical methods able to estimate the damping coefficient for complex MEMS structures when pressures range from the atmospheric value to the free molecular flow. Fully three dimensional codes have been developed and, since MEMS typically exhibit repetitive geometries, a representative fluid cell is analyzed; then, the results are transferred with engineering confidence to the overall structure. At (or near) ambient pressures, methods based on integral equations [2] are considered; in the free molecular flow regime ($p \sim 10^{-3} \div 10^{-5}$ bar), instead, three different approaches are proposed and compared: a) a classical molecular dynamics calculation; b) a method based on an integral formulation [3]; c) a method based on the linearized Boltzmann equation. Even if method c) can be used to explore the transition regime at intermediate pressures [4], it is shown that, for the class of applications here studied, a single analysis at low pressure combined with a very limited number of analyses at near-ambient pressure can furnish enough data to identify (through a nonlinear fitting of numerical results) the complete damping coefficient curve in between. All the calculations are verified with experimental data at varying pressure on existing industrial MEMS, showing very good agreement.

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