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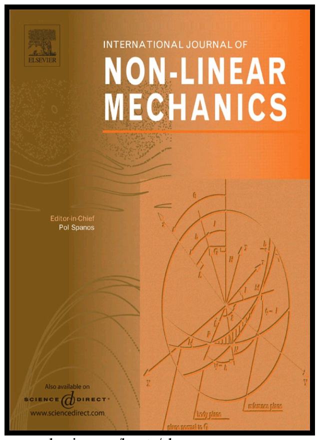

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Self-Induced Parametric Amplification in Ring Resonating Gyroscopes

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Abstract

We investigate self-induced parametric amplification that arises from dispersive nonlinear coupling between degenerate modes in systems with circular symmetry that rotate about the axis of symmetry. This phenomenon was first observed in micro-electromechanical ring/disk gyroscopes, where it provided enhanced readout gain using purely passive nonlinear effects [Nitzan et al., 2015]. The goal of this investigation is to provide a fundamental description of this phenomenon, which is an example where nonlinear dynamics can improve the performance of a practical device. To describe this behavior, we consider the in-plane vibrations of a thin ring surrounded by electrodes that rotates about its symmetry axis at a rate Ω much smaller than its vibration frequencies ω_n, as is the case in applications. The focus is on the pair of degenerate elliptical modes, one of which is taken as the drive mode and the other as the sense mode for the sensor. These modes are coupled through both inertial (Coriolis) and geometric nonlinear effects, as described by general forms of the kinetic and potential energies that account for finite deformation kinematics, as well as electrostatic effects. We investigate the specific effects of this coupling on the system performance and its sensitivity when used as a sensor for the spin rate. Specifically, we show that drive mode vibrations with sufficiently high amplitude affect the sense mode dynamic behavior in the form of parametric pumping, which leads to a considerable amplification of the sense mode response. As this response amplitude is proportional to Ω, it results in a substantial increase of the gyroscope sensitivity with respect to the external angular rate. We also illustrate that the effects of the sense mode vibrations on the drive mode dynamics can be neglected in the model when $\Omega/\omega_n \ll 1$. Finally, we illustrate the applicability of our results by considering the dynamic response of a representative MEMS gyroscope model and quantifying the predicted benefits of these nonlinear effects.

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