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Internal resonance induced in the impacting dynamics in a MEMS device

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Abstract: This work investigates the dynamics of a microbeam-based MEMS in the neighbourhood of the first natural frequency. The device is intentionally designed to have the capacitor gap larger than the air gap. When the oscillation reaches elevated amplitudes, the microbeam impacts with the substrate. This event causes the lengthening of the resonant branch and the concurrent activation along this range of an internal resonance between the first and the third mode.

Keywords: MEMS, impacting dynamics, internal resonance

1. Introduction

Nonlinear features of MEMS/NEMS are increasingly applied for novel devices to achieve superior performances [1, 2]. Special attention is devoted to the nonlinear interactions among different vibration modes and the related energy transfer [3, 4]. The present work is focused on a MEMS device electrically actuated and investigates the internal resonance induced in the impacting dynamics.

2. Results and Discussion

The MEMS device under investigation is constituted by a clamped-clamped rectangular microbeam electrically actuated by an electrode placed directly underneath it on a substrate. An optical image is reported in Fig. 1(*a*). For bottom to top, the microbeam is composed of 1.5 μm Silicon Nitride, 50 nm Chrome, and 200 nm Gold. The lower electrode is composed of 50 nm Chrome, and 200 nm Gold. The microbeam has length 400 μm and width 50 μm. The lower electrode spans half of the length of the microbeam. The equivalent capacitor gap is composed of both the air gap plus the contribution due to the Silicon Nitride layer, i.e. is larger than the air gap.

An extensive experimental investigation is conducted, where both forward and backward sweeps are acquired. Both resonant and non-resonant branches are detected, which exhibit hardening bending behaviour. When reaching elevated oscillation amplitudes, the resonant branch impacts with the substrate, after which oscillations continue for a non-negligible range of the driving frequency. Along a part of this interval, the system experiences the activation of the internal resonance with the third mode (second symmetric). An example of the corresponding FFT spectrum extracted from the data experimentally acquired at the internal resonance dynamics is reported in Fig. 1(*b*), showing the occurrence of both the main first mode peak and the third mode one.

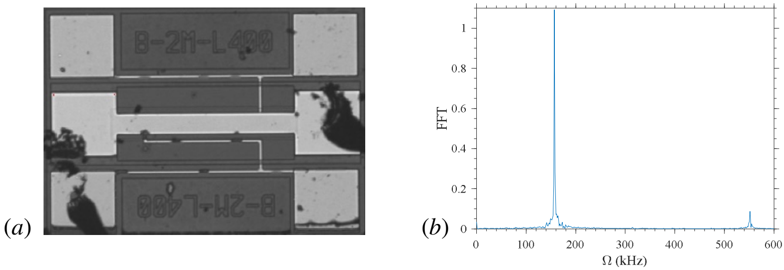

Fig. 1. (*a*) Optical image of the fabricated MEMS device. (*b*) FFT spectrum of the device experimental response at the internal resonance in the impacting dynamics.

Constantly referring to the experimental data, numerical simulations are developed. The impact with the substrate is modelled as a nonlinear foundation of springs and dampers. A two degrees of freedom Galerkin reduced-order model is derived accounting for both the first and the third mode dynamics, where the electric force term is integrated numerically. The main aspects induced by the impacts are analysed. The internal resonance activated along this range visibly alters the device response, which occurs for a wide operational range. Close is the correspondence of the theoretical simulations with the experimental data.

3. Concluding Remarks

The impacting dynamics occurring in the experimental data of a MEMS device are analysed. Not only the lengthening of the range of existence of the resonant branch is observed, but also the activation along this interval of an internal resonance is detected. We emphasize the relevance of these results for the design stage.

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