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Mass detection through symmetry breaking in a MEMS array

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Abstract In this contribution, an original mass sensing technique exploiting the nonlinearities of a symmetric array of coupled MEMS (micro electro-mechanical systems) resonators is proposed. It is shown that the nonlinear normal modes (NNMs) of the system are modified after a symmetry-breaking event, with the creation of isolated branches of NNMs. This modification is used to produce easy-to-detect jumps in amplitude when an additional mass is dropped on the resonator.

Due to their small size and high sensitivity, MEMS resonators are very good candidates for mass sensing devices. Classical MEMS-based sensing techniques rely on detecting a shift in frequency induced by an external perturbation (acceleration, addition of mass, ...) in a single MEMS resonator. The need for parallel mass sensing and highly sensitive devices led to the development of MEMS arrays [1] and alternative mass sensing techniques based on nonlinear phenomena [2–4].

In this paper, an array of two coupled electrostatically-actuated MEMS resonators is considered, as sketched in Figure 1a). The two beams 1 and 2 are identical with the following design and material properties: h=300nm, b=160nm, l=10μm, E=1.69 10^{11}N/m^2, ρ=2330kg/m^3, a quality factor Q=5000 and identical gaps g=200nm between two adjacent beams. Each beam i is subjected to lateral vibrations w_i due to nonlinear harmonic electrostatic forces generated by the adjacent beam and electrode. The model is similar to the two-beam model detailled in [4]. The spatial dependence is removed with a Galerkin method using the linear undamped eigenmodes. The continuation and stability analysis of the underlying NNMs is performed with the harmonic balance method using 5 harmonics [5].

In the case of a perfectly symmetric configuration (symmetric voltages, no additional mass), the system exhibits two main (pure) NNM branches corresponding to the out-of-phase and in-phase motions of the beams respectively, see Figure 1b). A branch point (BP) bifurcation is found on the in-phase NNM. After this BP, the in-phase NNM becomes unstable and a stable mixed NNM appears, whose modal shape is an asymmetric mix of the two pure modal shapes.

When a small mass δm=$10^{-4}m$, with m the mass of one microbeam, is added on beam 1, the system becomes asymmetric and the symmetry breaking turns the BP of Figure 1b) into an imperfect bifurcation, see Figure 2. As a result, the in-phase and mixed NNMs are transformed into an asymmetric (different on each beam) in-phase pure NNM and an isolated NNM (INNM) which is detached from the pure NNMs. A starting point for the continuation of the INNM is obtained by performing a bifurcation tracking with respect to δm from the BP of Figure 1 (δm=0) until δm=$10^{-4}m$ corresponding to the limit points (LP) of Figure 2. It is worth noting that the two plots of Figure 2 are switched if δm is added on beam 2 instead of beam 1.

The nonlinear forced response curves (NFRCs) of this asymmetric array are composed of a main NFRC supported by the pure NNMs and of isolated solutions (ISs) detached from the main NFRC and supported by the INNMs and possibly by the pure NNMs. Therefore, in the

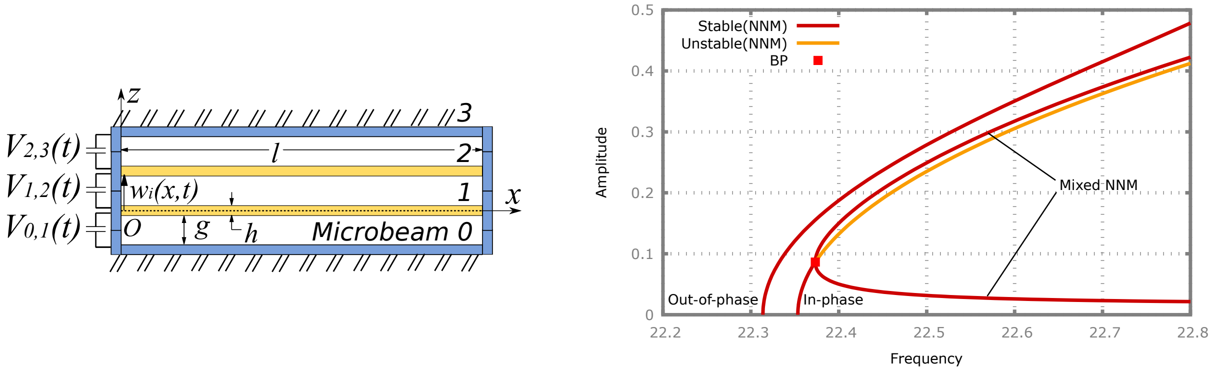

Figure 1: Left: Two-beam MEMS array. Right: NNMs of the symmetric array.

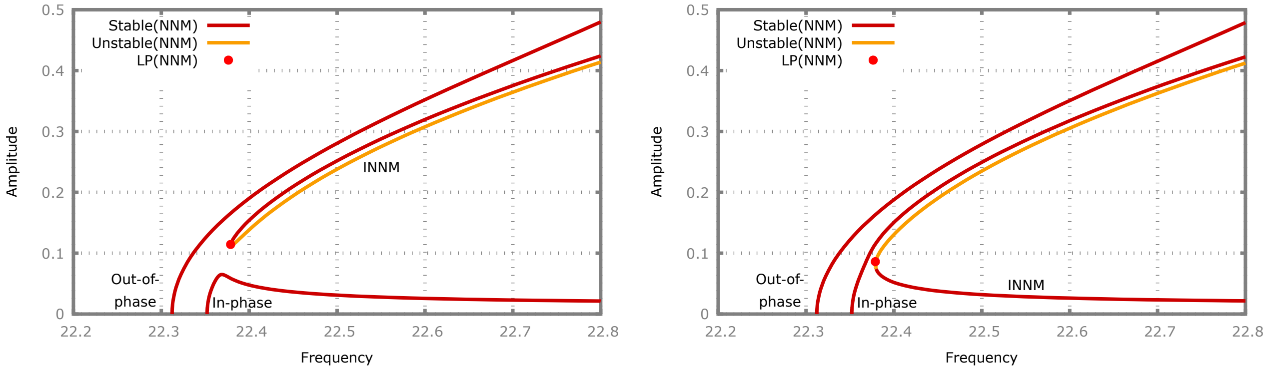

Figure 2: NNMs of the asymmetric array. Left: Beam 1. Right: Beam 2.

case of in-phase response, the main NFRC of beam 1 has a much lower amplitude than beam 2. This localization of motion resulting from symmetry breaking can be exploited for mass detection. Real devices are likely to be inherently asymmetric due to manufacturing defects for instance. In this case, the mass detection is based on the reversal of localization of motion that occurs when the added mass exceeds the level of asymmetry.

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