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Suppression of pull-in in a microstructure actuated by mechanical shocks and electrostatic forces

Faouzi Lakrad, Mohamed Belhaq *

University Hassan II-Casablanca, Laboratory of Mechanics, Casablanca, Morocco

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This work investigates the effect of a high-frequency voltage (HFV) on the pull-in instability in a microstructure actuated by mechanical shocks and electrostatic forces. The microstructure is modelled as a single-degree-of-freedom mass-spring-damper system. The method of direct partition of motion is used to split the fast and slow dynamics. Analysis of steady-state solutions of the slow dynamic allows the investigation of the influence of the HFV on the pull-in. The results show that adding HFV rigidifies the system, creates new stable equilibria and suppresses the pull-in instability for adequate high-frequency voltages. To illustrate the applicability of the result, a specific capacitive microelectromechanical system consisting of a clamped–clamped microbeam is considered.

1. Introduction

Analysis of vibrational behavior of Microelectromechanical systems (MEMS) is an active topic of research with applications in many engineering fields such as communications, automotive, robotics and others. One of the most critical issues in the design of MEMS is their reliability and survivability under mechanical shocks and electrical loads. In the case of capacitive MEMS devices the pull-in [1–3] constitutes one of the main roots to the device failure. Pull-in is a structural instability phenomenon resulting from the interaction between elastic and electrostatic forces in MEMS devices. This instability results from the unbalance between the electric actuation and the mechanical restoring force leading a movable electrode to hit a stationary electrode causing stiction and short circuit problems and hence the failure in the device's function [4]. Several works [5,6] investigated the static pull-in phenomenon and performed techniques to predict its occurrence by determining the largest DC voltage for which the system operates in a stable behavior. The dynamic pull-in was studied under various loads, such that step voltage [7], AC harmonic voltage [8,9] and mechanical shock load [10,11]. It was shown that the dynamic actuation reduces drastically the static pull-in threshold. Nayfeh and co-workers [8,9] studied the dynamic pull-in of MEMS resonators actuated by a resonant AC voltage. They found three distinct mechanisms leading to the dynamic pull-in instability. The first mechanism is the cyclic-fold or symmetry instabilities, the second mechanism depends on the system transient dynamics and the number of coexisting attractors and the third one is characterized by the sensibility to initial conditions due to the existence of homoclinic tangles. Moreover, Younis and co-workers [10,11] showed that the combination of a shock load and an electrostatic actuation makes the instability threshold much lower than the threshold predicted considering the effect of the shock alone or the electrostatic actuation alone. They also studied the effects of the shape of the shock pulse and its duration on the pull-in threshold. Recently, Ibrahim and Younis [12] presented a theoretical and experimental investigation of the response of electrostatically actuated parallel-plate resonators subjected to mechanical shocks. They concluded that a resonator may experience early dynamic pull-in instability depending on the shock duration.

Keeping a MEMS device operating in a stable attracting regime away from the pull-in instability limit presents a major interest from design, fabrication process and commercialization point of view. This challenge has motivated researchers developing strategies to avoid the pull-in, and hence, increase the range of movable electrode. For example, Castañer et al. [13] used an interesting technique based on charge control, instead of voltage control. This method allows extending the travel range, but it is limited by the charge pull-in [14]. Lenci and Rega [15] used a control method based on adding superharmonics to a reference harmonic excitation and showed the possibility of shifting the dynamic pull-in towards high excitation amplitudes. Lakrad and Belhaq [16] showed that applying an appropriate high-frequency harmonic voltage can delay the static pull-in.

In the present paper, a HFV is used to suppress the pull-in instability induced by the combined effect of electrostatic and shock forces. The proposed method is applied to a simplified mass-spring-damper

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* Corresponding author.
E-mail address: mbelhaq@yahoo.fr (M. Belhaq).

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