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Estimation of oscillation period/switching time for electrostatically actuated microbeam type switches

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ABSTRACT

The undamped dynamic response of step-voltage driven parallel-plates, cantilever, and fixed–fixed type electromechanical switches is numerically investigated. In each case, application of energy technique yields the threshold values of the amplitude and the applied voltage beyond which the oscillatory motion of the movable electrode ceases to exist. These critical values are identified as the dynamic pull-in parameters of the corresponding microactuator model. For all three microactuator configurations, empirical expressions for the switching time and oscillation period are developed. These empirical relations are applicable over a wide range of applied voltage, and the estimates obtained using the proposed empirical relations correlate very well with the previously published results. Furthermore, the phase portraits of these actuators have been thoroughly investigated in order to examine the role of static pull-in point in a dynamic setting and also to propose the design rules to build faster microswitches.

1. Introduction

Microelectromechanical actuators are prevalent in a variety of applications related to automobile, biomedical and aerospace industries. Electrostatic actuation is the most preferred mode of actuation in such microsystems owing to its compatibility with microfabrication processes and favorable scaling properties at the microscale. Electrostatically actuated microstructures (typical examples include microbeams) have been used in a wide range of applications such as accelerometers, microrelays and microswitches [1,2]. These devices experience a well-known instability termed as pull-in that restricts the travel range of a typical electrostatic microactuator [3–8].

The focus of the present investigation is on the dynamic pull-in response of electrostatic actuators, commonly deployed as microresonators and microswitches [9,10]. A typical microelectromechanical switch consists of a movable electrode and a fixed electrode separated by a gap. In such applications, the movable electrodes are driven by a voltage signal, which can be closely approximated by the Heaviside step function. Under such actuation, the response of the movable electrode is periodic up to the dynamic pull-in voltage and becomes nonperiodic for voltages higher than the dynamic pull-in voltage. The periodic response is utilized in resonators, while the nonperiodic response is utilized in digital operations such as switches.

A parallel-plates model is the one-dimensional idealization of an electrostatic microactuator that is used to develop insight into its pull-in behavior [3,11]. However, a practical microactuator device is closely approximated by a continuous mechanical system such as a microbeam, micromembrane or microplate [12–14]. Microbeams with fixed–fixed and fixed–free (cantilever) end conditions are widely used in microelectromechanical systems (MEMS) and have been thoroughly investigated for their pull-in characteristics. Several researchers have described rigorous approaches towards the dynamic analysis of electrostatically actuated microbeams. Some of the representative approaches include: two degrees of freedom model described by Elata and Bamberger [15], Galerkin method leading to the multimode analysis [16–18], finite element analysis [19], reduced order modeling [20,21], nonlinear modal analysis [22], and the application of perturbation method [23]. Comprehensive reviews of the modeling and simulation techniques pertinent to the structural dynamics of microsystems have been presented by Lin and Wang [24] and Rhoads et al. [25].

In contrast to the aforementioned computationally expensive approaches, Ijntema and Tilmans [26] inferred that the lumped 1-dof models of microbeams can closely predict their dynamic response under the action of the applied electrostatic load. Kacem et al. [27] have recently demonstrated the dominance of the first vibrational mode over higher modes in the dynamic analysis of electrostatically actuated Euler–Bernoulli type nanobeams. In the recent past, Batra et al. [28] used a similar approach of 1-dof model to analyze the dynamic behavior of narrow microbeams. Their results compare well with three-dimensional finite element simulations, which reinforces the utility of using the simplified 1-dof

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