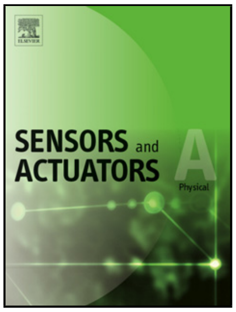

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A Parametric Electrostatic Resonator Using Repulsive Force

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Abstract

In this paper, parametric excitation of a repulsive force electrostatic resonator is studied. A theoretical model is developed and validated by experimental data. A correspondence of the model to Mathieu's Equation is made to prove the existence and location of parametric resonance. The repulsive force creates a combined response that shows parametric and subharmonic resonance when driven at twice its natural frequency. Experimental data show quasiperiodic behavior and a strong interaction with the surrounding air. The model, which includes the air spring effect, can accurately predict the response frequency components resulting from the electrostatic force. The resonator can achieve large amplitudes of almost 30 μm and can remain dynamically stable while tapping on the electrode. Because the pull-in instability is eliminated, the beam bounces off after impact instead of sticking to the electrode. This creates larger, stable trajectories that would not be possible with traditional electrostatic actuation. A large dynamic range is attractive for MEMS resonators that require a large signal-to-noise ratio.

Keywords: MEMS, Parametric Resonance, Repulsive-Force, Quasiperiodic, Electrostatic

1. Introduction

Vibrating micro-structures have played an important role in the development of micro-sensors because of their fast response time, low power consumption, and low bulk fabrication costs. MEMS (Microelectromechanical Systems) resonators are a class of MEMS devices that use the vibration of these structures for microphones [1, 2], energy harvesters [3–7], accelerometers [8], signal filters [9–12], and many more applications [13]. Micro-sensors that require actuation, as opposed to those that rely on ambient vibration sources, typically use electrostatic forces for the ease of fabrication and power efficiency [13]. This usually comes at the cost of highly nonlinear behavior and the pull-in instability, which occurs when the attractive force between electrodes causes them to collapse. Nearly all electrostatic MEMS resonators have been designed around this usually undesirable phenomenon. Pull-in significantly limits the travel ranges of electrostatic MEMS sensors, which hinders performance. Because the sensitivity of capacitive sensors depend on the electrode voltage and travel range of the device, which are limited by pull-in, an electrostatic device that is not susceptible to pull-in would be very valuable [13].

In 2001, Lee and Cho [14] reported that two grounded electrodes would push away from each other if they were placed near a charged electrode on one side. This is not a pure repulsive force, but an attractive force that pulls the grounded electrodes apart. He and Ben Mrad used the same principle as Lee and Cho to create out-of-plane actuation [15–18] by flipping the design on its side. In this configuration the actuator is suspended above three electrodes (shown in Figure 1). The actuator and center electrode are grounded while the side electrodes are charged. The resulting electrostatic field (visualized in Figure 1b) pulls on the top of the beam more than the bottom because of the presence of the center electrode, which results in a net force away from the substrate. This is technically an attractive force; however it acts in the opposite direction of the electrodes and is referred to as repulsive to differentiate it from traditional electrostatic actuation. This design achieved large out-of-plane actuation; however it requires a high voltage potential because of the weak forcing associated with fringe electrostatic fields. The primary focus of their study was for static actuation; however a large range of motion is very attractive for sensors.

The authors have recently extended the work by He and Ben Mrad to include dynamic applications [19–21]. It was shown that if the beam moves far enough from the electrodes, the force becomes attractive again. While the beam-electrode gap distance at which this occurs highly depends on the geometry, it can be as large as 60 μm, which provides a large repulsive regime. A large DC bias is required to push the static position of the beam far enough from the substrate to allow the beam to move without hitting the electrode. Because the beam and middle electrode are grounded, even if the beam strikes the electrode, it will not stick, but bounces off. This allows the device

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