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Deflection Modelling of MEMS Cantilever Beam Through Collocation Method Taking B-Splinesas Approximating Functions

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ABSTRACT

The mathematical modeling and analysis of cantilever beam adhesion problem under the action of electrostatic attraction force is carried out. The model uses Euler-Bernoulli beam theory for one end fixed and other end free type beams for small deflection. A MATLAB code has prepared to predict and plot the deflection profile of MEMS cantilever beam during the action of stiction force on application of applied voltage as snap down occurs. The model predicts the cantilever behavior on occurrence of snap downvoltage. To envisage the deflection profile, a collocation method employing B-Spline as approximating functions and Gaussian quadrature point as collocation points has been utilized for solving the governing equation by keeping the four end boundary conditions of cantilever beam in mind. The numerical results reveal the deflection profile of the MEMS cantilever beam, which are validated with the previous data and deflection profile available by numerous published research papers.

KEYWORDS

Adhesion, B-Spline, Cox De Boore Recursion Formula, Euler Bernoulli Cantilever Beams, Fringing Field, MEMS, Point Collocation, Stiction

1. INTRODUCTION

Today because of the advantages of electrostatic actuators, such as, favorable scaling property, lower driving power, large deflection capacity, relative ease of fabrication, and others, have led their being more widely applied the electrostatic-actuator applications in micro-electromechanical systems (MEMS). Thundat et al. (1997) described about MEMS based micro-cantilever which has been proven as an outstanding platform for extremely sensitive sensors. In the past decade micro-cantilevers has become so popular due to its high sensitivity, selectivity, ease of fabrication and flexibility of on chip circuits. Also it has become interesting due to convenience to calibrate, readily deployable into integrated electromechanical system and does not require external detection devices (Thaysen et al.

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2000; Gotszalk et al. 2000; Pinnaduwage et al. 2003; Grabiec et al. 2002). Many previous researches reported attempts made to improve the cantilever sensitivity using micro-cantilevers comprise of a poly-silicon piezo-resistor integrated with silicon / silicon-nitride cantilever (Rasmussen et al. 2003; Thaysen et al. 2000).

The electrostatic principle is common in the sensing and actuating devices of MEMS. There are two basic components of MEMS, sensors and actuators. A sensor gathers the information from the environment by utilizing mechanical, thermal, biological, chemical, optical, and magnetic properties. The actuator contains the mechanical members, which are acted upon by various mechanisms like electromagnetic, thermo actuation, use of shape memory alloys, piezo actuation, magneto static actuation and electrostatic actuation. Out of all these, electrostatic actuation is widely used. The popularity of electrostatic actuation is due to ease of fabrication, low power consumption and higher energy density is explained by Kaneria et al. (2013). There are many examples of MEMS structures depending on electrostatic deformation and/or pull-in of a beam or diaphragm. For examples, the sensing devices such as the widely used capacitive accelerometer and the capacitive pressure sensor for measuring blood pressure gradients inside the coronary artery of the heart; the actuating devices such as the comb driver, the electro-statically driven micro elastic joints, the rotary electrostatic actuator, and the electro-statically actuated MEMS power switch. The most successful commercialized examples are the static electrically actuated inkjet head applied in inkjet printers and the digital micro mirror array applied in optical scanner and digital light projector. Hu et al. (2004) explained that in addition to the sensing and actuating devices, the material parameters of microstructures, such as Young's modulus and intrinsic stresses can also be given by the relationship between the electrostatic loads and structural deformations.

These MEMS devices are relatively simple to design and fabricate as well as to integrate on a chip with CMOS circuits. However, voltage driving may exhibit an inherent instability situation, known as the pull-in phenomenon. This effect may be either derogatory or useful, depending on the application. On the other hand, with the growth of micromachining process technologies for Microelectromechanical systems (MEMS), there has developed a need for simple, accurate, and standardized process monitoring and material property extraction capability (e.g., Young's modulus, residual stress, and fracture strength) at the wafer level, one end fixed and other end free beams under the voltage driving are commonly used for test structures. It is therefore necessary to study the pull-in phenomenon of the voltage driving one end fixed and other end free beams and develop advanced models of pull-in voltage. Previously, static analyses have been performed to determine the beam equilibrium position for a given voltage using both lumped parameter and finite difference methods (Majumder et al. 1997; Zavracky et al. 1997), but these models cannot capture exact model, such as fringing field, residual stress and varying section effects. An analytical expression of the pull-in parameters is given about the MEMS switches in Osterberg P.M. (1995).

Two deformation shapes for a stuck beam are found: the arc-shape and S-shape (de Boer and Michalske, 1999; de Boer et al., 1999; Jones et al., 2003; Rogers et al., 2002). Rogers et al. (2002) presented a summary on the formation of the arc-shape and S-shape: shorter beam forms the arc-shape and its un-stuck length is approximately equal to the beam length; longer beam forms the S-shape and its unstuck length is appreciably shorter than the beam length.

A lumped two degrees of freedom pull-in model is presented in Bochobza-Degani O. and Nemirovsky Y. (2002) for a direct calculation of the electrostatic actuators. The effect of fringing field has great influence on the behaviour of MEMS switches, and even causes the failure of devices Zhang et al. (2002). The pull-in phenomenon widely exists in many micro-machined devices that require bi-stability for their operation, such as MEMS switches Zhang et al. (2003). The present paper aims to study the behaviour of MEMS switches considering the fringing field effect.

Stiction is a major failure mechanism for MEMS structures (Legtenberg et al. 1994; Mastrangelo et al. 1993). Stiction occurs in a two-step process Legtenberg et al. (1994): Firstly, an external load such as capillary force Legtenberg et al. (1994), electrostatic force De Boer and Michalske (1999),

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