Nonlinear analysis and control of the uncertain micro-electro-mechanical system by using a fuzzy sliding mode control design

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ABSTRACT

This study analyzes the chaotic behavior of a micromechanical resonator with electrostatic forces on both sides and investigates the control of chaos. A phase portrait, maximum Lyapunov exponent and bifurcation diagram are used to find the chaotic dynamics of this micro-electro-mechanical system (MEMS). To suppress chaotic motion, a robust fuzzy sliding mode controller (FSMC) is designed to turn the chaotic motion into a periodic motion even when the MEMS has system uncertainties.

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1. Introduction

Nonlinearities exist ubiquitously in micro-electro-mechanical systems (MEMS). Examples include nonlinear springs and damping mechanisms [1], nonlinear resistive, inductive and capacitive circuit elements [2] and nonlinear surface, fluid, electric and magnetic forces [3]. Many researches have been conducted on various nonlinear dynamic phenomena, including bending of the frequency response curve and the jump phenomenon in MEMS resonators [4]. Nonlinearities may also cause chaotic behavior [5]. Modeling [6] has been used to predict the existence of chaotic motion in electrostatic MEMS. In one study [7], the chaotic motion of MEMS resonant systems close to the specific resonant separatrix was investigated under the corresponding resonant condition. An optimal linear feedback control strategy has been adopted [8] to reduce the chaotic motion of the system proposed in the former study [7] to a stable orbit. In a later investigation [9], the chaotic behavior of a micro-electro-mechanical oscillator was modeled by a version of the Mathieu equation and was studied both numerically and experimentally. Chaotic motion of a micro-electro-mechanical cantilever beam under both open and close loop control has also been reported [10].

This study develops a fuzzy sliding mode control (FSMC) scheme [11–13] that is designed to control chaos in a MEMS with system uncertainties. Firstly, the switching surface that is required to achieve chaos control is specified, and then a switching control law based on fuzzy linguistic rules is developed to generate a suitable chatter-free control signal for driving the error dynamic system such that the error state trajectories converge asymptotically to zero.

2. System description

Fig. 1 presents the electrostatically actuated micro-beam, where d is the initial width of the gap and z is the vertical displacement of the beam. An external driving force is applied as an electrical driving voltage on the resonator that causes