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Control Instability Applied to a Micro Electro Mechanical Actuator System (MEMS)

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Abstract. MicroElectroMechanical Systems (MEMS) are devices what have been considered the technology of the future, being used in too many areas. MEMS are a combination of microstructures, micro sensors and micro actuators. The purpose of this work is to reduce the chaotic movement of the micro-actuator electrostatic to a small periodic orbit using the linear optimal control technique. The simulation results show that this technical is very effective.

Introduction

Micro Electro Mechanical Systems (MEMS) promise to revolutionize any product category, through the union of electronic technology (silicon-based) and micromachining technology, making possible the production of a "Full System on a Chip". MEMS are a technology that enables the development of smart products, increasing the computational ability of microelectronics with the perception and control of micro sensors and micro actuators expanding the space of possible designs and applications. Its application has grown in recent years and today you can see in pressure sensors, accelerometers, micro motors, gas sensors, among others. The growth of MEMS technology has indicated that these systems have great importance in future technology, so that their study and analysis are increasingly relevant and even necessary [1].

In the work [3], is investigated, through numerical simulations, the behavior of a MEMS device proposed by Takamatsu and Sugiura [2]. The non-linear behavior is simulated numerically demonstrating the stable, unstable and chaotic behavior, depending on its physical properties. The aim of this paper is to propose the application of the Linear Optimal Control [4] to control the chaotic movement of a Micro Electro Mechanical System [2].

Microelectromechanical Model

The beam-type micro electrostatic actuator which is object of our study consists on a mass-spring system for constant k ($1,31.10^{-8}$ kg/s) and mass m ($1,31.10^{-10}$ kg) of a degree of freedom that is a beam and also the capacitor C ($1,07.10^{-13}$ F). Between the plates (electrodes) there is an applied voltage $V(0)$ and the distance between them is denoted by D ($2,02.10^{-6}$ m). As we've said, one of the plates is movable and is connected to the spring of constant k while the other is the stationary electrode, as shown in Fig. 1. The damping coefficient, characteristic of the geometry of the object and of the environment properties is denoted by c ($1,0.10^{-15}$ kg/s). [2]

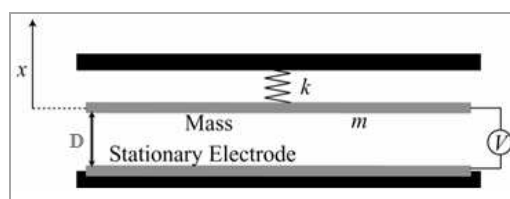


Fig. 1 Modeling of a beam by a spring-mass system [2]

As we can see at the Fig. 1, the x -axis is taken along the vertical direction with positive direction upwards. Its origin is defined as the position of the mass for $V=0$. We denote the charge on the electrode for q . Equating detail can be seen in [3].

The system's dimensionless equation of motion is given by:

$$\ddot{x} + 2\gamma\dot{x} + x + \frac{4\beta^2(1 + \alpha \sin \delta t)^2}{27(1+x)^2} = 0 \quad (1)$$

γ is the damping coefficient, β is the DC voltage (the ratio to V_b that the equilibrium point disappears according to the bifurcation), α is the amplitude of AC voltage (the ratio to DC voltage), and δ is the frequency of AC voltage.

Fig. 2 shows our simulations for the parameters $a=0.33$, $\beta=0.78$, $\delta=0.86$ and $\gamma=5.5$, the same used by [2]. Aiming to leave the system with a chaotic behavior, we include a parametric resonance caused by the term including $\alpha \cos 2\delta t$ to the excitation voltage, and its behavior is illustrated in this Fig. 2.

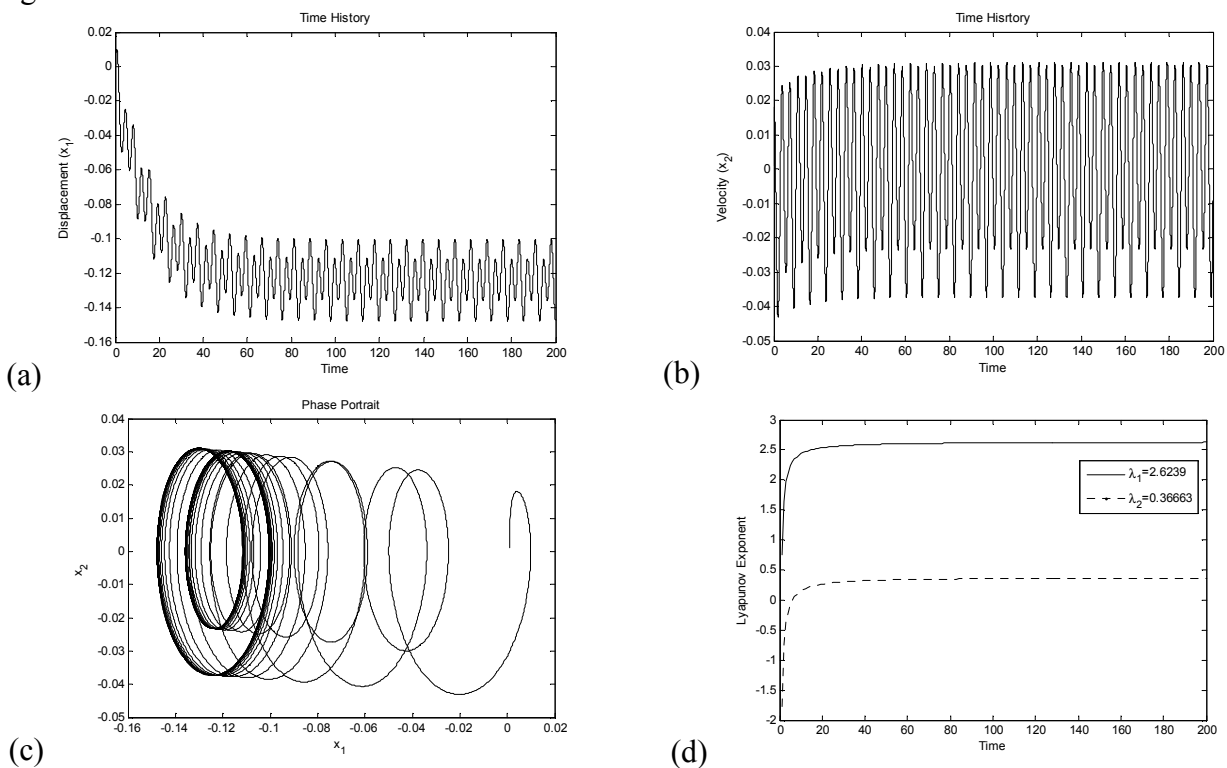


Fig. 2 MEMS system. (a) Time History (x_1, t), (b) History (x_2, t), (c) Phase Portrait (x_1, x_2) and, (d) Lyapunov exponents.

Fig. 2(d) shows the dynamics of unstable chaotic behavior of Lyapunov exponents ($\lambda_1=+2.6239$; $\lambda_2=+0.3666$), caused by parametric resonance as shown in [3].

Control Design

We consider the nonlinear system

$$\dot{x} = Ax + g(x) \quad (2)$$

If one considers a vector function $\tilde{x}$, that characterizes the desired trajectory, and taken the control U vector consisting of two parts: $\tilde{u}$ being the feed forward and if is a linear feedback, in such way that

$$u_t = Bu \quad (3)$$

where B is a constant matrix. Next, taking the deviation of the trajectory of system (2) to the desired one $y = x - \tilde{x}$, may written as being

$$\dot{y} = Ay + g(x) - g(\tilde{x}) + Bu \quad (4)$$

where $G(y, \tilde{x})$ is limited matrix we proved the important result [4].

If there is exit matrices $Q(t)$ and $R(t)$, positive definite, being Q symmetric, such as the matrix $\tilde{Q} = Q - G^T(y, \tilde{x})P(t) - P(t)G(y, \tilde{x})$ is positive definite for the limited matrix G , then the linear feedback control is

$$u = -R^{-1}B^T P y \quad (5)$$

It is optimal, in order to transfer the non-linear system from any initial to final state $y(t_f) = 0$ [4], minimizing the functional $J = \int_0^\infty (y^T \tilde{Q} y + u^T R u) dt$, where the symmetric matrix $P(t)$ is evaluated through the solution of the matrix Ricatti differential equation

$$PA + A^T P - PBR^{-1}B^T P + Q = 0 \quad (6)$$

satisfying the final condition $P(t_f) = 0$.

In addition, with the feedback control (6), there exists a neighborhood $\Gamma_0 \subset \Gamma$, $\Gamma \subset \mathbb{R}^n$, of the origin such that if $x_0 \in \Gamma_0$, the solution $x(t) = 0$, $t \geq 0$, of the controlled system (4) is locally asymptotically stable, and $J_{\min} = x_0^T P(0) x_0$. Finally, if $\Gamma = \mathbb{R}^n$, then the solution $y(t) = 0$, $t > 0$, of the controlled system (4) is globally asymptotically stable. Then we will use the theorem done by [4] and used in [5-8]. The equation (1) describing the uncontrolled MEMs can be rewritten in the following form

$$\ddot{x} + 2\gamma\dot{x} + x + \frac{4\beta^2(1 + \alpha \sin \delta t)^2}{27(1+x)^2} = U \quad (7)$$

Where the function of control U is determinate by (7). The matrix A is $A = \begin{bmatrix} 0 & 1 \\ -0.8363 & -11 \end{bmatrix}$, $B = \begin{bmatrix} 0 \\ 0.5 \end{bmatrix}$,

$Q = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $R = [0.001]$. Where $y = \begin{bmatrix} x_1 - \tilde{x}_1 \\ x_2 - \tilde{x}_2 \end{bmatrix}$, $\tilde{x} = \begin{bmatrix} 0 \\ 0.003 \end{bmatrix}$ and the matrix is a definitive positive

matrix. Obtaining $P = \begin{bmatrix} 1.2314 & 0.0599 \\ 0.0599 & 0.0360 \end{bmatrix}$, solving the algebraic equation of Riccati, the function of optimal control u has the following form $u = -29.9942x_1 - 18.0496x_2$.

The Fig. 3 shows the trajectories of the system without and with control.

Conclusion

In this work, we proposed the use of a Linear Optimal Control strategy applied to the micro electrostatic actuator proposed by [2] and shown in Fig. 1. Fig. 2 shows chaotic behavior of the proposed system, which motivated us to propose a method of stabilization control to cancel this chaotic behavior. We propose the application of the Linear Optimal Control to control the chaotic movement of a Micro Electro Mechanical System. In comparing of numerical results of controlled system with the non controlled system (Fig. 3) we can verify that control orbit generated by Linear Optimal Control (Fig. 3) has small diameter.

The technique control reduces the chaotic movement of the MEM systems to a small orbit periodic. The Fig. 3 illustrates the effectiveness of the control strategy taken to these problems.

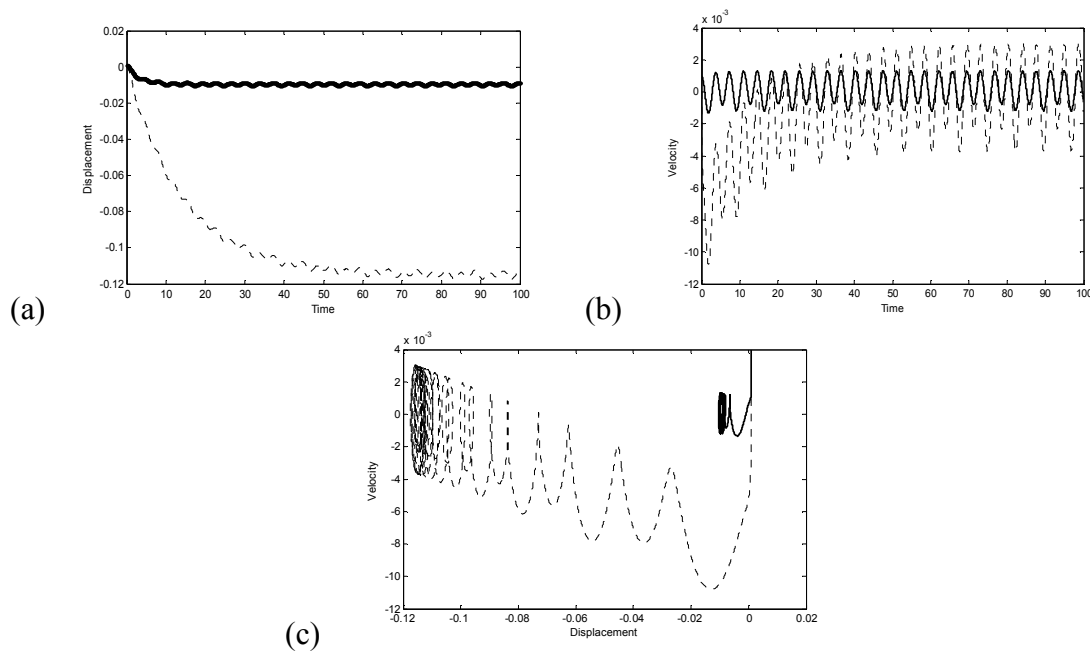


Fig. 3 The Control MEMS. Black line represents the controlled system and dashed gray line represents the unstable system. (a) Time History (x_1, t); (b) Time History (x_2, t) and (c) Phase Portrait (x_1, x_2)

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