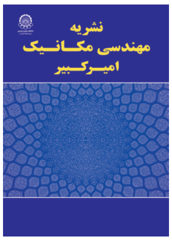


Amirkabir Journal of Mechanical Engineering

Amirkabir Journal of Mechanical Engineering, 49(4) (2018) 283-286
DOI: 10.22060/mej.2016.769

Optimal Control of Electrostatically Actuated Micro-Plate Attached to the End of Microcantilever

H. Tourajizadeh*, M. Kariman , M. Zamanian, B. Firouzi

Mechanical Engineering Department, Faculty of Engineering, Kharazmi University, Tehran, Iran

ABSTRACT: An optimal control is designed for damping the unwanted vibrations of an electrostatically actuated micro-system. The goal is using feasible methods to decrease the settling time and overshoot of the response. This configuration consists of an electro-statically actuated micro-plate attached to the end of a micro-cantilever. The DC voltage is applied between the micro-plate and the opposite electrode micro-plate. This DC voltage causes an electrostatic force. In this model micro-cantilever is considered as a continuous medium for which Euler-Bernoulli beam theory can be implemented. The plate is considered as a rigid body, and the electrostatic force is a nonlinear function of the displacement and the applied voltage underneath the micro-plate. The equation of motion is derived using Newton's second law. In order to extract the corresponding state space and control the system in a closed loop way, exact method is used to reduce related partial differential equation of the systems into a set of two ordinary differential equations and the resultant state space is linearized about the operating point. The linearized state space is then optimized using the linear-quadrant regulator. Efficiency and applicability of the mentioned controller is investigated using comparative analyzing method.

Review History:

Received: 13 December 2015
Revised: 22 August 2016
Accepted: 4 September 2016
Available Online: 6 November 2016

Keywords:

Optimal control
Electrostatic
Exact method
Euler-Bernoulli beam
Micro electromechanical systems

1- Introduction

Sensors are used in many measurement devices and analog and digital control systems. Microsensors waste energy less than conventional ones and are more sensitive to input changes.

Since the mechanical vibrations usually results in destruction and weakening of the microsystems performance, reviewing the control methods to reduce these effects could be a useful study. Because of electrostatic force the actuator dynamic is nonlinear and open loop controllers are not effective. Therefor researchers try to find proper closed loop control methods toward damping the mentioned unwanted vibrations. In order to improve the operator performance, many researchers are trying to design digital systems with dual stability [1,2].

Nayfeh et al. [3,4] presented a comprehensive theoretical model of the clamped-clamped micro-beam under the nonlinear electrostatic actuation that included mid-plain stretching effect. They solved the equation of motion with numerical shooting and Galerkin method. Nayfeh et al [5] investigated natural frequency and static deflection of a gas sensor involving a microplate connected to a cantilever microbeam. Zamanian et al. [6] investigated natural frequency, static deflection and pull in voltage of a clamped-clamped microbeam with a ⊥ shaped part at the midpoint. Maithripala et al. [7] studied control methods for MEMS under electrostatic actuation. Static and vibration control of composite laminates integrated with piezo-electrics microbeam is performed by Liu [8]. Nayfeh et al. [9] delivered a control method for microbeam in. Yagasaki [10] investigated nonlinear dynamics and bifurcations of microcantilevers under external feedback control. Vatankhah [11] used closed loop control to reduce the vibration of non-classical microcantilever beam. He used Galerkin method to solve the problem and also he verified his model performance by the aid of simulation. Pratiher [12] investigated the stability and bifurcation of a highly deformable microcantilever-based resonator which is electrostatically controlled. In this work theoretical and practical methods of controlling and optimization of the system are predicted.

Corresponding author, E-mail: Tourajizadeh@khu.ac.ir

2- Methodology

The model presented in Fig. 1 consists of a micro-cantilever in which the free end is connected to a ⊥ shaped body . The ⊥ shape body consists of two parts. A horizontal part which is a plate parallel to the micro-beam and a vertical part that connects the horizontal plate to the micro-beam end. It is assumed that the ⊥ part shows a rigid behavior. Here the cantilever beam is modeled as an Euler Bernoulli beam.

The mass of the ⊥ shape part is added to the end of the microbeam as a boundary condition and the system response is assumed as a free vibration. The effect of electrostatic force and moments are applied to equations as external disturbance. In order to damp the unwanted vibrations of the mentioned system two closed loop controlling strategies are employed. Pole placement is performed in the first method using state vector feedback strategy while the controller is then optimized in the second strategy using LQR method. Considering the Lyapunov stability condition, it is shown that the closed loop system is completely stable using the designed SVFC controller while the open loop system has some instability zones. On the other hand, the optimality of the system in which the states are controlled using the optimal controller of LQR is verified afterwards by the aid of some comparative simulations.

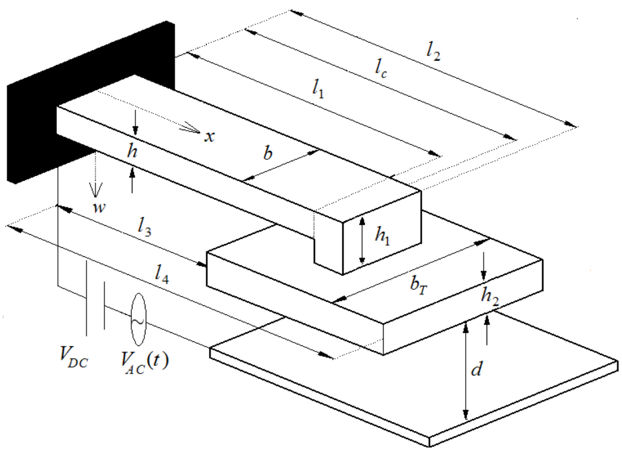


Figure 1. Model of the System

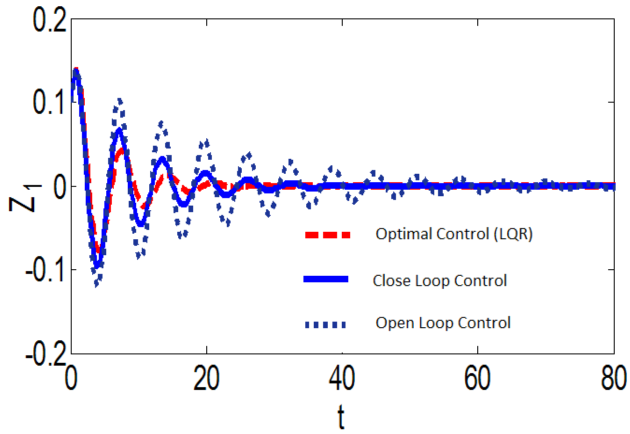


Figure 2. Comparison of the system response between the open loop and closed loop controllers

3- Results and Discussion

Fig. 2 shows a comparison between the open loop response of the system and the response of the systems which are controlled using two mentioned controlling strategies. It is obvious that the close loop controller and especially the optimal one has the best performance to improve the transient characteristics of the unwanted vibrations.

As shown in Fig. 3 optimal control requires lower controlling input in order to damp the system vibration.

Vibration analysis of a micro plate connected to a cantilever micro beam has been investigated in [5]. Fig. 4 shows the comparison of static deflection of the beam between the present work and the mentioned reference. The good compatibility of the profiles verifies the correctness and efficiency of the proposed controller.

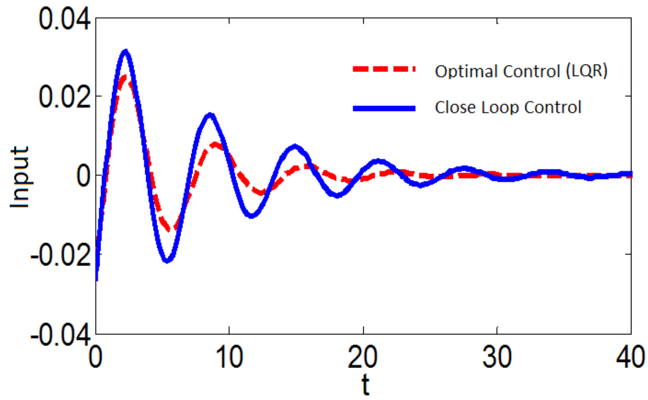


Figure 3. Comparison of the inputs between two studied controllers

4- Conclusions

Flow structure and the wake properties of a surface-mounted finite cylinder have been experimentally investigated by employing a five-hole probe. The flow structure around free end of a 3D cylinder is markedly different from that of a 2D cylinder. The 3D wake structure seems to be induced from an interaction between the ambient fluids entrained from both sides of the cylinder and the separated shear flow descending from the free end. The size of the wake bubble formed above the flat-tip cylinder is largely reduced by shaping of the tip geometry to the elliptical shape. The shear layer separating from the plain tip descends faster as the flow proceeds toward the downstream, compared to the other tips tested. A counter-rotating longitudinal vortex pair is formed in the wake region just behind the cylinder tip. These two longitudinal vortices have almost the same size and are nearly symmetric with respect to the central plane of the wake. Moreover, two weaker counter-rotating vortices are also formed under midheight of the cylinder close to the ground plane.

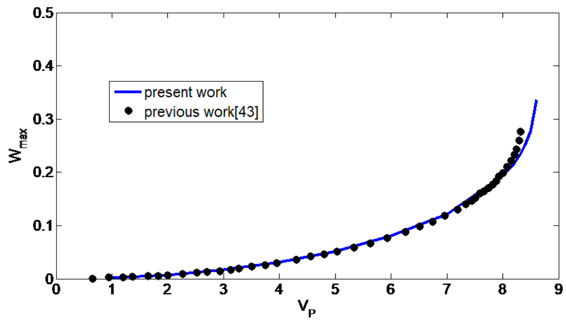
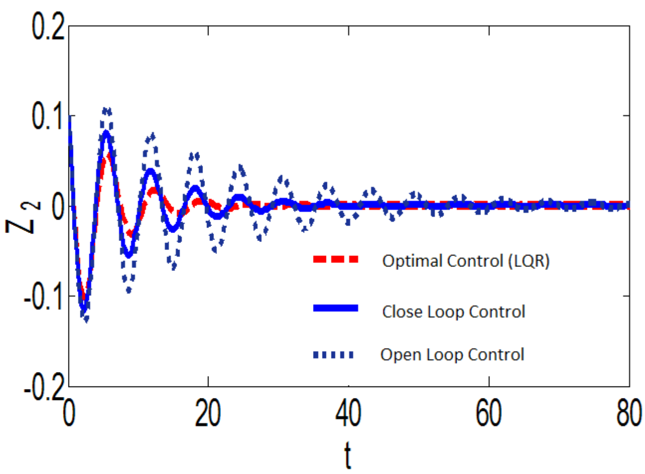


Figure 4. Comparison of the max deflection between the present work and previous study



References

[1] P.B. Chu, S. Pister, Analysis of closed-loop control of parallel-plate electrostatic microgrippers, in: Robotics and Automation, 1994. *Proceedings., 1994 IEEE International Conference on, IEEE*, (1994) 820-825.

[2] L.J. Hornbeck, Current status and future applications for DMD-based projection displays, in: *Proceedings of the Fifth International Display Workshop IDW '98*, Kobe, Japan, (1998).

[3] E.M. Abdel-Rahman, M.I. Younis, A.H. Nayfeh, Characterization of the mechanical behavior of an electrically actuated microbeam, *Journal of Micromechanics and Microengineering*, 12(6) (2002) 759.

[4] A.H. Nayfeh, M.I. Younis, E.M. Abdel-Rahman, Dynamic pull-in phenomenon in MEMS resonators, *Nonlinear dynamics*, 48(1-2) (2007) 153-163.

[5] A. Nayfeh, H. Ouakad, F. Najar, S. Choura, E. Abdel-Rahman, Nonlinear dynamics of a resonant gas sensor, *Nonlinear Dynamics*, 59(4) (2010) 607-618.

[6] M. Zamanian, A. Karimiyan, Analysis of the mechanical behavior of a doubled microbeam configuration under electrostatic actuation, *International Journal of Mechanical Sciences*, 93 (2015) 82-92.

[7] D. Maithripala, J.M. Berg, W. Dayawansa, Control of an electrostatic microelectromechanical system using static and dynamic output feedback, Journal of Dynamic Systems, *Measurement, and Control*, 127(3) (2005) 443-450.

[8] G. Liu, K. Dai, K. Lim, Static and vibration control of composite laminates integrated with piezoelectric sensors and actuators using the radial point interpolation method, *Smart materials and structures*, 13(6) (2004) 1438.

[9] H. Ouakad, A. Nayfeh, S. Choura, E. Abdel-Rahman, F. Najar, B. Hammad, Nonlinear feedback control and dynamics of an electrostatically actuated microbeam filter, in: *ASME 2008 International Mechanical Engineering Congress and Exposition*, American Society of Mechanical Engineers, 2008, pp. 535-542.

[10] K. Yagasaki, Nonlinear dynamics and bifurcations in external feedback control of microcantilevers in atomic force microscopy, *Communications in Nonlinear Science and Numerical Simulation*, 18(10) (2013) 2926-2943.

[11] R. Vatankhah, F. Karami, H. Salarieh, Observer-based vibration control of non-classical microcantilevers using extended Kalman filters, *Applied Mathematical Modelling*, 39(19) (2015) 5986-5996.

[12] B. Pratiher, Stability and bifurcation analysis of an electrostatically controlled highly deformable microcantilever-based resonator, *Nonlinear Dynamics*, 78(3) (2014) 1781-1800.

Please cite this article using:

H. Tourajizadeh, M. Kariman, M. Zamanian, B. Firouzi, Optimal Control of Electrostatically Actuated Micro-Plate Attached to the End of Microcantilever, *Amirkabir J. Mech. Eng.*, 49(4) (2018) 805-818.

DOI: 10.22060/mej.2016.769