Journal of Applied and Computational Sciences in Mechanics, Vol. 27, No. 2, 2016.

Beyond Pull-in Stabilization of a Torsional Micro-Actuator

A.R. Khorshidi[1], H. Moeenfard[2]

1- Introduction

Electrostatic MEMS-based torsional micro-mirrors, with the role of actuators, have several optical network usages such as optical switches and cross-connects, etc. In optical switching applications, the torsional micro-actuators are required to have the least possible overshoot and settling time and reducing the time between two effective switching actions. Besides, the tilting limited area of a micro actuator that is restricted by the “pull-in” phenomenon, must be increased.

In the literature, some control algorithms are available for electrostatic torsional micro actuators. Chu and Pister stabilized a micro-gripper theoretically. Juneau et al. marked out tilt angle control of a dual-axis optical mirror from the perspective of a fully integrated solution. Zhao et al. applied a feedback control method called Integral Sliding Mode Control (ISMC) to stabilize the dual-axis micro-mirror beyond the pull-in point. Moeenfard et al. designed a fuzzy controller to stabilize the tilting angle of a dual-axis torsion micro-mirror beyond its pull-in range. Using a 1-DOF model, Malmir and Salarieh proposed a robust adaptive critic-based neuro-fuzzy controller for electrostatic torsional micro-mirrors. In this paper, an attempt is made to present a 2-DOF model considering both DOF’s of the actuator to design a more powerful fuzzy controller.

2- Two DOF micro-mirrors

The micro-actuator shown in Fig. 1 is considered.

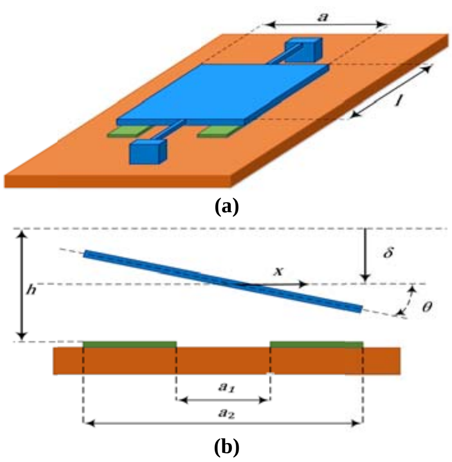


Fig. 1. Schematic (a) perspective and (b) front view of a torsional micro actuator

1- M. Sc. student, School of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.
2- Corresponding Author: Assistant professor, School of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.

When voltage is applied between the actuator plate and the underneath substrate, the actuator is rotated by an angle θ. Since the actuating electrostatic force is applied in the vertical direction, the center line of the actuator plate will also be deflected by an amount δ.

3- Dynamic study of the system

By solving the system of differential equations, one can show the effect of the applied voltage to the normalized tilt angle of the actuator.

Fig. 2, the greater the input voltage, the higher the amplitude of the vibrating tilting angle. It is also observed that increasing the voltage more than a certain amount causes a kind of dynamic inconsistency of the actuator in which the normalized tilt angle goes through its maximum physically possible amount. So in physical perspective, the actuator has failed.

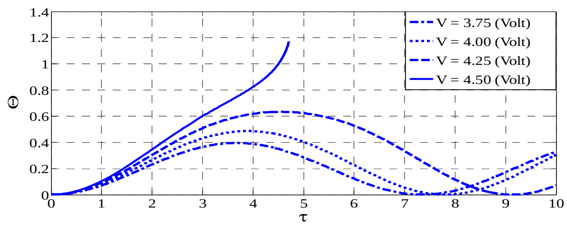


Fig. 2. Effect of voltage on the dimensionless tilting angle and the stability range of the system

4- Development of the fuzzy controller

Fuzzy systems are knowledge-based or rule-based systems. The main part of a fuzzy system is a knowledge base consisting of the so-called fuzzy IF-THEN rules.

As far as the value of the tilt angle is the control objective, θ and $\dot{\theta}$ could be considered as the inputs. Based on these definitions, the fuzzy IF-THEN rules are presented. Using these rules and the famous combination of singleton fuzzifier, product inference engine and center average de-fuzzifier, the control signal of the controller is derived.

5- Result and discussion

A micro-actuator with certain physical and geometrical properties is considered. As it was obtained, the normalized static pull-in angle of this actuator is 0.49. So, in order to show the effectiveness of the performance of the designed fuzzy controller, two different step commands are used. Firstly, it is desired that the micro-actuator is settled down at some tilt angle smaller than the static pull-in one which is called “*within pull-in*”. After that the micro-actuator is commanded to be set at some tilt angle larger than the static pull-in angle which is usually called “*beyond pull-in*” control.

In Fig.3, Fig. the dynamic behavior of the microactuator under the step commands $\Theta = 0.4$ is shown. It is discovered that the actuator perfectly follows the commands with acceptable overshoot and small settling time.

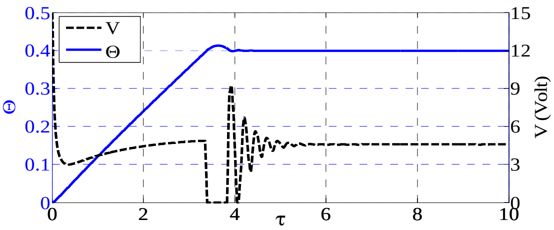


Fig. 3. Within the pull-in control of the system, and the corresponded control signal V, versus normalized time

Because of the inherent instability of the actuator at angles greater than the pull-in angle, controlling the system in this area is extremely difficult. However, because of the smartness of the fuzzy controllers and also the suitable design of the fuzzy rule-base, the same control scheme utilized for within pull-in control, may be used for beyond pull-in control of the system. In Fig. 4Fig. , the simulation outcomes for the step commands greater than static pull-in angle are presented. Like the case of within pull-in stabilization, the system can acceptably follow the command and reach the desired angle value. The only difference between these two simulations is that in the beyond pull-in control, the control voltage does not converge to a certain amount. The cause is that in beyond the pull-in region, the actuator has a kind of inherent instability and the controller shall continue its effort to keep it at the set point angle value.

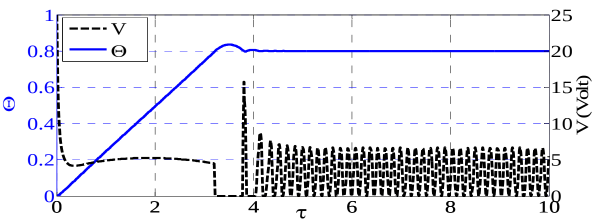


Fig. 4. Beyond pull-in control of the system and the corresponded control signal V, versus the normalized time

6-Comparing the fuzzy controller with a classic PID

In order to check the effectiveness and performance of the fuzzy controller, a classic PID controller is proposed. The schematic of PID block diagram is as follows:

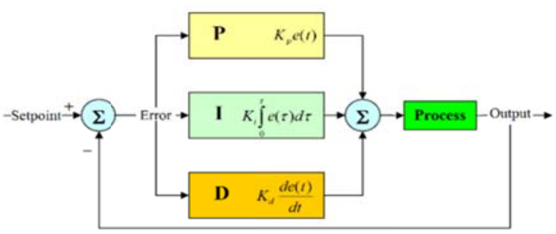
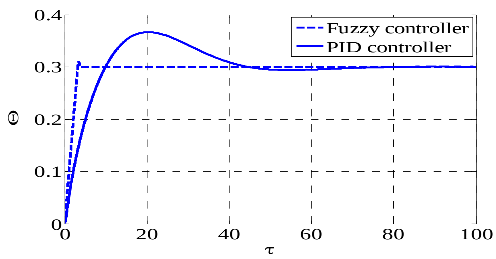
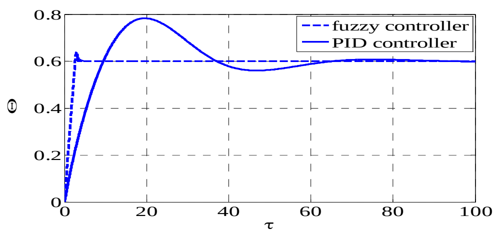


Fig. 5. Schematic of PID controller

The comparison is shown for both within and beyond pull-in situation in Fig. 6. As it is expected, the fuzzy controller has improved all control specifications such as settling time and overshoot.



(a)



(b)

Fig. 6. Comparing the fuzzy controller with PID (a) within pull-in (b) beyond pull-in

7- Conclusion

The significance of studying the dynamics and control of torsional micro actuators to better address their design and optimization is well-recognized. However, the existence of the effects, such as pull-in instability and coupled translational-rotational dynamics, can make this investigation complicated and nontrivial. From the designer's viewpoint , the tilting range of such actuators remarkably suffers from the pull-in instability. Also, the translational dynamics of the mirror which is commonly ignored, can efficaciously change the stability range of the actuator. In this paper, by considering both translational and rotational DOFs, a new fuzzy controller is designed to control the tilting angle of a micro actuator within and beyond its pull-in limits. The efficiency of the designed controller is studied by simulating a sample actuator. It was demonstrated that the controlled system was able to follow the step command effectively immediately. Also in order to examine the superior features of the fuzzy controller, a classic PID controller is proposed. It was indicated that fuzzy controller is better in all control specifications. The 2-DOF model as well as the fuzzy controller reported in this paper can be utilized for efficacious and precise modeling, stabilizing and designing optimization of torsional micro actuators.